PROCESS CONSTRAINTS IN LIVING SYSTEMS

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During the past ten years major advances have been made in understanding living systems. Of particular importance is the unfolding of the chemical nature of these systems. It is instructive, therefore, to examine living systems as ordinary chemical processes. Constraints known to be applicable to such processes should then be applicable to living systems. It is the purpose of this presentation to suggest a few such constraints.

Recently, the Office of Student Life sponsored a Religion and Life Seminar on campus. One of the topics was "Finding Our Roots: Created or Evolved." The subject is of timely interest, and much debate in regard to "roots" is current. Some of this debate centers on the age-old argument of creation vs. evolution. The issue will not be settled in this discussion, or in any other for that matter, since origins cannot be subjected to scientific scrutiny. Some will argue that evolution has been proved and, therefore, any other view is either not scientific or not worthy of serious consideration. Such an attitude is naive since *any* construction of origins must remain speculative. Neither creation or evolution can be proved, except possibly by inductive reasoning, as no life existed at the "beginning," and no extra-Biblical record is available of the event or the occurrence. We can examine only a small spectrum of the system and that only over a small segment of time.

Some Terms Defined

Since the subject of origins is highly controversial and often misunderstood, a few definitions are necessary. The words "creation" and "evolution" have different meaning for different people. In this presentation the words are intended to mean the following:

> Evolution—the belief that the world in which we live, including the complexities of life, came about by natural causes.[1]
>
> Creation—the belief that natural causes or processes are impotent in themselves to effect either the origin or development of the complexities of life.

These definitions have been elaborated in a position paper on the teaching of creation/evolution in public schools by the Iowa Department of Public Instruction as:

Evolution

> "The theory of evolution . . . states that modern biologic organisms descended,with modification, from pre-existing forms which in turn had ancestors. Those organisms best adapted, through anatomical and physiological modifications to their environment, left more offspring than did non-adapted organisms. The increased diversity of organisms enhanced their ability to survive in various environments and enabled them to leave more progeny . . . ."[2]

Creation

> ". . . all permanent, basic life forms originated thousands of years ago through directive acts of a Creator independent of the natural universe. Plants and animals were created separately with their full genetic potentiality provided by the Creator. Any variation, or speciation, which has occurred since creation has been within the original prescribed boundaries. Since each species contains its full potentiality, nature is viewed as static, reliable and predictable . . . "[3]

It needs to be emphasized that these fundamental postulates are not "religious" in themselves. They do not involve worship. They are legitimate areas of investigation and constitute appropriate classroom inquiry. The fact that people who hold either belief may also be "religious" is only a testimony that people have a religious nature. Fortunate is the man or woman whose religious perspectives do not conflict with his or her scientific perspectives. Indeed, they need not conflict. The tendency to discredit creation views as only religious perspectives is obviously an attempt to minimize a growing mistrust in the evolutionary explanation of origins.

Development

Observations of the world about us show the development of increasing order in matter and cases of the apparent operation of abiogenesis, ontogenesis, and phylogenesis. These processes are sometimes referred to as the "facts of evolution". They are, in the same manner, the "facts of creation". Being observations of the present, they offer little to an understanding of origins, except by inductive reasoning. And it is just such reasoning that form the bases of any theory of origins. By examination of the processes of life on the basis of equilibrium, free energy and entropy, rather significant inference can be made however, in regard to the competing theories.

Application of Thermodynamics

To do this requires information gained from the application of thermodynamics to the life systems. That thermodynamics is applicable is asserted by Stull.

> "The laws of thermodynamics and thermochemistry are linked and govern the behavior of all the matter in the Universe."[4]
>
> "Combination of the energy and entropy with the absolute temperature yields quantitative information on the thermodynamic behavior and stability of chemical substances."[5]

Dr. Melvin Calvin has proposed a sequence of chemical reactions from hydrogen to present life in an article on chemical evolution. He states that

> "Life is a logical consequence of known chemical principles operating on the atomic composition of matter."[6]

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A particularly important thermodynamic principle applicable to life systems seems to be the Second Law. Dr. L. Brillouin introduces his interesting and informative article on Life, Thermodynamics and Cybernetics by:

> "How is it possible to understand life, when the whole world is ruled by such a law as the second principle of thermodynamics, which points toward death and annihilation?"[7]

Later in the same article he states:

> "Let us simply state at this point that there is a problem about "Life and the second principle" . . . "Nobody can doubt the validity of the second principle, no more than he can the validity of the fundamental laws of mechanics . . . We do not know of any experiment telling against the second principle . . . ."

Such a universal acceptance of thermodynamic principles is testimony to the soundness of those principles. Thermodynamic laws have been shown to apply to open as well as closed systems, unstable as well as stable systems, and irreversible as well as reversible systems. It is not always possible quantitatively to evaluate the various states of thermodynamic systems, but is possible to predict the probable state of a system from thermodynamic principles.

Therefore, let us consider life systems as processes. A typical process can be represented as

$$aA + bB \rightarrow cC + dD \tag{1}$$

This general expression relates reactants A and B to products C and D. The small letters represent amounts. (Any number of reactants or products could be considered). The energies associated with the reactants and products are: internal energy, U, potential energy, X, kinetic energy, $v^2/2g_c$ and pressure-volume energy, PV. The "system" can absorb heat, Q_i, from the surroundings and do work, W_s, on the surroundings. In addition, the system may be subject to other work efforts, such as electrical, W_e, gravitational, W_g, magnetic, W_m, etc. If other than random work effects are present, appropriate additional terms must be included. Examples of non-random work are the separation of products, stacking a deck of cards, and the increase in system order in complex processes of life. Such processes require a work term, $-W_o$, to account for the work done on the system in directing the process outcome.

All of these energy terms can be included in a First Law expression for the process represented by Eq. 1. In general

$$dQ_i - dW_s = dE \tag{2}$$

where: Q_i = heat added to the system, W, = work done by the system in expansion or shaft work, and E = total energy of the system. For open systems, the integral expression is

$$Q_i - W_s = E_2 - E_1 + \Delta U + \Delta PV + \Delta v^2/2g_c + \Delta X\, g/g_c \tag{3}$$

For steady flow $E_2 = E_1$ and only expansion or shaft work considered,

$$Q_i - W_s = \Delta U + \Delta PV + \Delta v^2/2g_c + \Delta X\, g/g_c \tag{4}$$

Where the other work effects are important, Equation 4 must be written as

$$Q_i - W_s = \Delta U + \Delta PV + \Delta v^2/2g_c + \Delta X\, g/g_c + W_e + W_g + W_m - W_o \tag{5}$$

since $U + PV = H$ (the enthalpy of the system)

$$Q_i - W_s = \Delta H + \Delta v^2/2g_c + \Delta X\, g/g_c + W_e + W_g + W_m - W_o \tag{6}$$

For systems where potential, kinetic, electromagnetic and gravity effects are negligible:

$$Q_i - W_s = \Delta H - W_o \tag{7}$$

$$\text{and} \quad Q_i = \Delta H + W_s - W_o \tag{8}$$

If the system or process is not doing expansion or shaft work on the surroundings, the term W, is zero, and

$$Q_i = \Delta H - W_o \tag{9}$$

For such a system the Second Law expression for the entropy (S) change is

$$\Delta S_{TOT} = \int \frac{dQ_i}{T} = \int \frac{d(\Delta H - W_o)}{T} = \int \frac{dH}{T} - \int \frac{W_o}{T} = \Delta S_R - \Delta S_o \tag{10}$$

where: ΔS_{TOT} = total entropy change, ΔS_R = entropy change due to random effects, and ΔS_o = entropy change due to increasing order. The expression for the change in entropy is, therefore, the sum of the change in entropy due to the chemical reaction, i.e., the integral of dH/T, and the entropy change due to the increase in order or information in the system, ΔS_o.

Equation 10 in its later forms is useful in explaining complex processes having both random and non-random character. As an example, crystallization takes place partially by well defined change of state heat effects which are reversible and purely random. The crystal formation, however, is not random, and the atoms deposit themselves in a specific order. This order is so precise that many very sophisticated analytical techniques depend on crystalline structures being exactly ordered. The entropy of the random cooling process is quantitatively measured by the term $\int dH/T$. The non-random part of the process, or the ordering of the crystal, is represented by the term $\int -W_o/T$. It cannot be quantitatively measured for it represents the information contained in the atomic structure of the atom species. The second term effect is, however, clearly evident in the regularity of the crystal!

The final form is helpful in analyzing processes in which chemical effects are negligible and probability effects prominent. As an example, the process of "stacking" a deck of cards as opposed to a random "shuffle" involves -W, only and

$$\Delta S_{TOT} = O - \Delta S_o \tag{11}$$

In this case the $-\Delta S_o$ can be calculated from probability theory since $S = k \ln p$ where p = the probability of the "stacked" order, and k = Boltzman constant. It should be emphasized that the two entropy terms in the different forms of Equation 10 result from different "types" of energy transfer, and the interchange of

energy between the system and its surroundings in terms of entropy exchange must be of the same "kind". The argument that an "open" system will provide the necessary entropy sink for life systems is erroneous. The decrease in entropy due to increasing order cannot be financed by an increase in entropy in the sun or in any other random process in the surroundings. It can only be financed by energy from an equivalent "quality" source.

This can be illustrated by considering a process of putting a watch together. If the parts of a watch were arrayed on a table, "opening" the system to the sun, or to the universe for that matter, would not be effective in making a watch. Only the application of a certain "kind" of energy—intelligence or ordered energy—could do it. And, of course, we know that is just what happens. The watchmaker provides the $-W_o$ energy work on the system in accord with Equation 9.

The introduction of the $-W_o$ term into Equation 5 does not *a priori* imply a Creator. It does imply a certain kind of operation that must take place. The term, having been introduced, could be omitted once the proper understanding of energy interchange is achieved. Evolutionary theory claims that the term $-W_o$ is a result of natural selection, random chance, and long time spans. Creation theory claims that $-W_o$ comes from supernatural causes.

Development of Matter and Abiogenesis

Let us now examine the process of abiogenesis. The proposal (or allegation) is:

non-living matter → living matter (12)

Dr. Calvin proposes possible processes (for abiogenesis) from what we know about present-day chemistry. (Figure 1).

> "In the beginning most of the elements of the universe were in the form of hydrogen, which eventually had to undergo fusion reactions, giving rise to higher elements in the periodic table, particulary those important to living things: carbon, nitrogen, oxygen, sulfur, phosphorous, halides and certain metals, particularly iron, which are important catalytic functions in living organisms.
>
> Then, the primitive (prebiotic, primeval) molecules were formed from the organogenic elements with which the earth was initially coated: methane, ammonia, carbon monoxide, water, carbon dioxide, hydrogen sulfide, and of course, hydrogen. These first three stages present no chemical problem, since the first two are nuclear and the third is simply the result of presence of carbon, hydrogen, nitrogen and oxygen at a low enough temperature to produce the small, primitive molecules.
>
> The next stage of chemical evolution—from the organogenic molecules to the biomonomers—does present a chemical problem, and it has been an area of major progress in the last twenty years . . . The conversion of organogenic molecules into amino acids, sugars, nucleic acid bases, and other carboxylic acids (acetic acid and citric acid) has been achieved in the laboratory under the influence of a

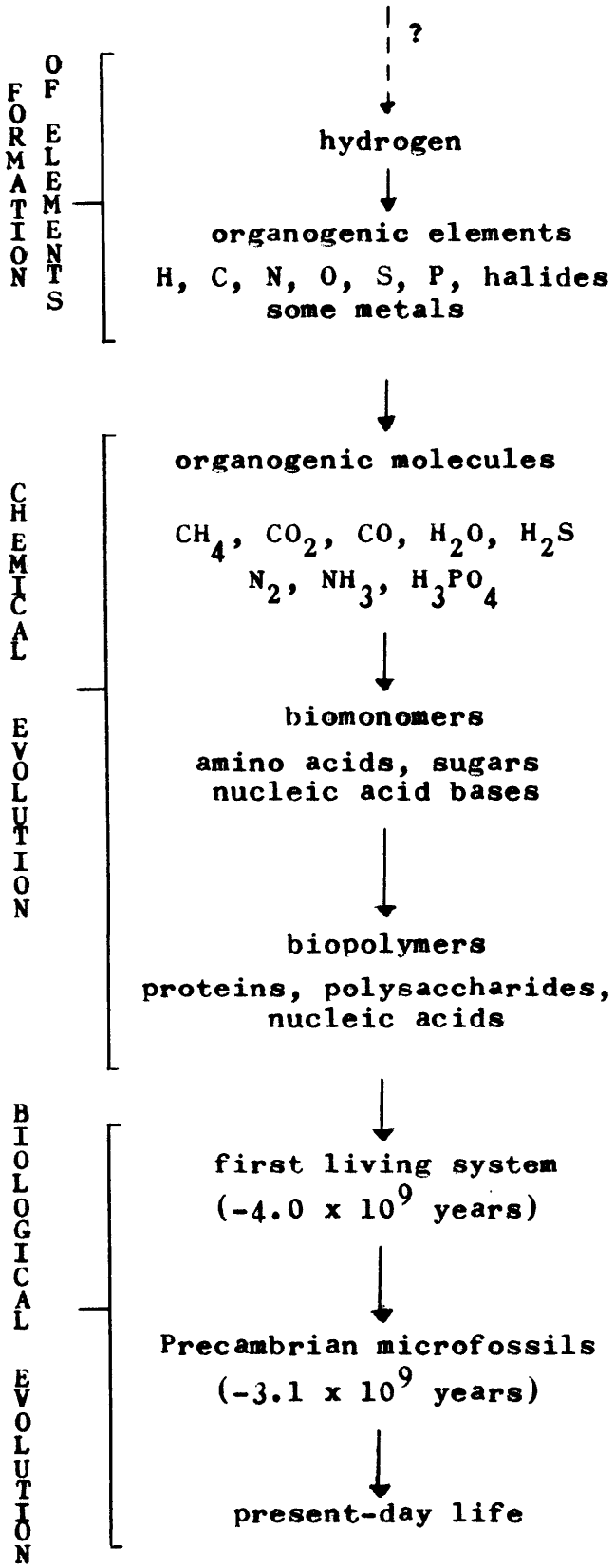

Figure 1. The time sequence of evolution (as commonly claimed), from the formation of the elements up to the present. After Calvin, reference 6, page 171.

wide variety of energy sources, ranging from the ultraviolet light of the sun to radioactive energy (in the form of ionizing radiation) to mechanical energy (in the form of meteoritic shock waves). All these energy sources give rise to the transformation of the organogenic molecule to biomonomers.

The next stage-the transition from biomonomers to biopolymers-is more difficult to achieve in terms of chemical evolution . . . which eventually gave rise to the first living organisms about four billion years ago."[8]

Calvin ***assumes*** existing hydrogen and the necessary conditions for a "fusion" reaction. Now, in the state in which there were no suns or stars for such reactions and certainly no fusion furnaces, could this fusion take place? Modern fusion work is testimony to the difficulty in "arranging" such reactions, even with sophisticated laboratories. The proposition that . . . "hydrogen had to undergo fusion reactions, giving rise to the higher elements in the periodic table . . ." is contrary to the Second Law. And, of course, the hydrogen had to come from somewhere. It was "created". The formation of higher elements in the periodic table from hydrogen is not a "natural" process. As Stull points out, the free energy difference is prohibitive.

The equilibrium for any reaction or process is derivable from heat quantities alone. These heat quantities are related as follows:

The Gibbs free energy, G, is defined as

$$G = U + P V - T S \qquad (13)$$

where: U = is internal energy, P = pressure, T = temperature, and S = entropy.

Since H = U + PV and G = H - TS, at constant temperature and standard states

$$\Delta G^o = \Delta H^o - T\Delta S^o \qquad (14)$$

This free energy change is related to equilibrium by

$$\Delta G = -RT \ln K \qquad (15)$$

where K is the equilibrium constant, given in terms of the things in Equation 1 by $K = C^cD^d / A^aB^b$. Combining Equations 14 and 15

$$-RT \ln K = \Delta H^o - T\Delta S^o \qquad (16)$$

which can be written

$$\ln K = \frac{\Delta H^o}{RT} + \frac{\Delta S^o}{R} \qquad (17)$$

According to Stull, these

". . . relationships clearly indicate that the atoms present in a reaction will prefer the molecular configurations in which the entropy is maximized and in which the energy is minimized (algebraically). The maximum entropy is associated generally with the molecular configurations having the largest number of states available to the system, thus providing more "freedom" for the system. The minimum energy is associated generally with the molecular structure in which its atoms are most strongly bound to each other (or the structures in which the atom will have the maximum stability)" . . . "At low temperatures the equilibrium is determined largely by the value of ΔH^o, the "stability" term, while at high temperatures the equilibrium is determined largely by the value of the ΔS^o, the 'freedom' term."[9]

Calvin suggests that, higher elements in the periodic table eventually "evolve" into organogenic molecules by stages . . ."the first". . . nuclear and the third simply the result of carbon, hydrogen, nitrogen, and oxygen at a low enough temperature. This process demands that simpler molecules evolve into more complex molecules. It is a classic case of increasing order. The The Second Law expression, Equation 10, tells how this takes place, viz.:

$$\Delta S = \int \frac{dH}{T} - \Delta S_o = \Delta S_e - \Delta S_o \qquad (18)$$

Since increasing order is the goal of the reaction, the process must have, in addition to the chemical heat effects, an energy source which can establish order. The molecules themselves must either be credited with intelligence (molecular predestination) or some other intelligent or order direction tapped. The limited success achieved in laboratory experiments is directly attributable to the order-directing force-the scientist. Calvin admits to this . . . "I designed an experiment . . ." This is just what the Second Law demands-a "creative" force. It is not evolution that Calvin describes. It is creation (in the limited sense).

Ontogenesis

The development of the embryo is many times taken as evidence of evolution. Here, the Second Law clearly requires a $-\Delta S_o$ term apart from the chemical process. A "direction" of energy is clearly evident. Brillouin recognizes this.

"There are many strange features in the behavior of living organisms, as compared with dead structures. The evolution of species, as well as the evolution of individuals, is an irreversible process. The fact that evolution has been progressing from the simplest to the most complex structures is very difficult to understand, and appears almost as a contradiction to the law of degradation represented by the second principle. The answer is, of course, that degradation applies only to the whole of an isolated system, and not to one isolated constituent of the system. Nevertheless, it is hard to reconcile these two opposite directions of evolution. Many other facts remain very mysterious: reproduction, maintenance of the living individual and of the species, free will, etc."[10]

". . . we must be prepared to accept a 'life principle' that would allow for some exceptions to the second principle" . . . "What about life and the second principle? Is there not, in living organisms, some power that prevents the action of the second principle?"[11]

". . . a living organism is a chemical system in unstable equilibrium maintained by some strange "power of life" which manifests itself as a sort of ***negative*** catalyst."[12]

This "negative catalyst" is the $-\Delta S_o$ term of Equation 10 and which is the needed "power of life."

Phylogenesis

The development of species is generally considered to have occurred through random chance and long time spans. Random chance is supposed to provide the negative entropy necessary for the "upward mobility" in speciation. However, the only energy identified is random energy from the sun. As stated before, such energy cannot provide the energy of order ($-\Delta S_0$, of the last form of Equation 10). There must be an energy which can direct the speciation process. Much of this "direction" is found in the DNA coding. The coding in these molecules has been shown not to be randomly derived. Dr. L. Quinn[13] has demonstrated by molecular modeling that the codon structure of proteins is not redundant and represents unique molecular instructions.

Prigogine proposes that "fluctions" or "instabilities" in what he calls "dissipative" structures" can generate higher order in an open system. He acknowledges, however, that there is no evidence that life originated by any such means.

> "The probability that at ordinary temperatures a macroscopic number of molecules is assembled to give rise to the highly ordered structures and to the coordinated functions characterizing living organisms is vanishingly small . . . ."[14]

That random chance cannot be effective in DNA coding can be seen in an example of chance formation of a simple protein. Assume a hypothetical molecule consisting of 100 amino acids using 20 distinct amino groups. The number of possible arrangements of these amino acids is $20^{100} = 10^{130}$, and the probability that one essential arrangement would occur by random chance is 10^{-130}, which is a fantastically small number. It is fantasticaly small because 10^{130} is fantastically large. For comparison, consider that the total number of electrons in the universe (5 billion light-years radius) has been estimated to be 10^{80}. And the total number of seconds elapsed since the beginning of time (according to the evolutionary theories) is 10^{18}.

Thus, the number of possible arrangements which could occur by chance is so very great in relation to any number with meaning that the probability of any such molecule occurring by chance is for all practical purposes zero.

With such small probabilities it is necessary to propose long time spans for the "improbable to become probable." George Wald[15] says:

> ". . . the important point is that since the origin of life belongs in the category of at-least-once phenomena, time is on our side. However improbable we regard this event . . . given enough time it will almost certainly happen at least once . . . Time is in fact the hero of the plot . . . given so much time, the impossible becomes possible, the possible probable, and the probable virtually certain. One has only to wait; time itself performs miracles."

This statement is repeated frequently in defense of evolution. The idea of time being a "hero" was recently repeated by Dr. K. E. Boulding.

> "That which has probability of one percent in a year, such as a 100-year flood, has a 66 percent chance of occurring in 100 years and 99.9 percent chance of occurring in 1000 years."[16]

Such statements have some basis in fact for repeated and independent trials of an experiment with two outcomes-success and failure.

If p = probability of success and q = probability of failure, $q = 1 - \boldsymbol{p}$. The probability of a number of successes, k, in a number of repeated trials, $\boldsymbol{n}$, is[1] $b = \boldsymbol{p}^k \boldsymbol{q}^{n-k}$. So, the probability of no successes, or $k = 0$, is $\boldsymbol{b} = q^n$ and therefore the probability of at least one success is $1 - q^n$.

Now, with numbers of the order of magnitude used by Dr. Boulding, the quoted statement is valid. For example, if the probability of an event is 1% (p = .0l) and there are 100 trials ($\boldsymbol{n}$ = 100), the following probability of at least one success ($1 - q^n$) or occurrence in 100 years is $1 - q^n = 1 - (0.99)^{100} = 0.634$ or 63.4%. For 1000 trials (or 1000 years in Dr. Boulding's example) $1 - q^n = 1 - (0.99)^{1000} = 0.99996$ or 99.99%. But, for very small probabilities such as for random chance of protein formation, the inference of "time as a hero" is simply erroneous. Even at relatively large probabilities, as l/10 %, the statement is erroneous. If $\boldsymbol{p} = .001$ and $q = 0.999$ for 100 trials $1 - q^n = 1 - (0.999)^{100} = 0.0952$ or 9.52 %.

For n = 1000, $1 - q^n = 1 - (0.999)^{1000} = 0.6323$ or 63.23%.

With this ten-fold decrease in probability, repeated trials do not produce the certainty which Dr. Boulding's statement might lead one to believe. However, as for protein production by random chance, for even a very simple molecule of only 100 amino acids, the probability is not only small, it is ***infinitesimally*** small. As developed above, it is of the order of magnitude of $1/10^{130}$. For this case, then, $\boldsymbol{p} = 1/10^{130}$, and $q = 1 - p = 1 - 10^{-130}$, which would be written: $q = 0.9999\ldots 999$, there being 130 nines altogether.

The probability equation for at least one success would be $1 - q^n = 1 - (1 - 10^{-130})^n$.

An expansion according to the binomial theorem, in which only two terms are retained, is legitimate here; and that gives for the result $n/10^{130}$.

Even if $q = 1 - 10^{-9}$ and $\boldsymbol{n}$ = 1000, $1 - q^n$ comes to only 0.0001%. And if $q = 1 - 10^{-130}$, as discussed above, the resulting $1 - q^n$ is small beyond all imagining.

Thus, the evolutionary theory demands long spans of time, which is another way of saying that many more repetitions than 100 or 1000 would be necessary. But even if repetitions occurred a billion times a second since the beginning of evolutionary time (30 billion years) the probability is still infinitesimally small.

In this case, $\boldsymbol{n} = 10^{27}$, so if $q = 1 - 10^{-130}$, then $1 - q^n = 1 - [(1 - 10^{-130})$ raised to the power $10^{27}]$. Even a large computer could not readily work this out as a direct problem in arithmetic. However, the binomial theorem may be used again, to give for the result $10^{27}/10^{130} = 10^{-103}$. This number is still inconceivably small. So time is not a hero; it is simply impotent to make an impossible event (evolution) possible.

In conclusion, living systems seem to be negative entropy processes. It is evident that abiogenesis, ontogene-

sis and phylogenesis proceed from lower order to higher order. Application of the First Law to such systems shows that the entropy change must include a random and a non-random contribution. The random contribution explains the general demise of the system through aging. The non-random contribution explains growth and development. The non-random contribution, or the $-\Delta S_o$ term in Equation 10, is necessary to account for the increasing order of living systems.

Equation 12: *non-living matter → living matter* is therefore not correct. It has a missing term. This missing term is the $-W_o$ contribution to Equation 10. It is the required intelligence (coding, design, direction, etc.) that the scientist (or creator) provides to the process. Intellectual activity is the highest form of energy. By this people do things. They build. They make. They CREATE. Intelligence is seen in the DNA coding, in the assembly of a watch, in the design of a pump to get water to go uphill, and in any higher order energy requirement to finance the processes of life. Equation 12 therefore needs to be modified. The equation is then[17]

$$\text{matter} + \text{intelligence} \rightarrow \text{life} \qquad (19)$$

This equation fits the universe in which we live. The key component in the transformation of non-living matter into living matter is intelligence. This intelligence must come from a source outside of "matter" itself. It must reside in the scientist, the designer or, in the case of life, in the Creator.

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TRUE CREATIONISTS

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The doctrine of social Darwinism is not popular nowadays. But it and Darwinism in nature should stand or fall together; those who reject the former and hold the latter are being inconsistent.

Indeed, even nowadays an occasional voice is heard in support of social Darwinism. Here, one such recent attempt serves to initiate a critical investigation of Darwinism generally.

Darwinism is still with us in the life sciences, I am sorry to say. As for the doctrine of social Darwinism, about which so much used to be heard, I had hoped that it had passed into a richly deserved oblivion. Evidently it has not, at least not entirely so; for a recent article[1] has expounded a doctrine which hardly differs from the social Darwinism of the last century, when it was in its heyday.

Charles Darwin believed in the inheritance of acquired characters; and to show how it worked he professed a belief called pangenesis. Heredity was supposed to be accomplished by gemmules which are brought from all parts of the body in the blood. Francis Dalton disproved the groundless belief by injecting blood from black rabbits into white rabbits with no change in the color of the offspring. Social Darwinism, too, like the claims of Darwin himself, is lacking in scientific foundation.

The author of the article cited (he does not sign his name) claims that sociobiology is a new science. Really it is but slightly younger than the original Darwinism, which is 120 years old. It advocates individual selfishness, claiming that progress comes by self-effort, overcoming other individuals, working to rise by their fall. Even a little deceit is helpful; but too much may cause repulsion, it is claimed. The yardstick by which progress is measured is selfish gain. Thus this doctrine recognizes, indeed glorifies, one's lower impulses and condones yielding to them, just as Darwin said that struggle is the natural means by which the weak are eliminated, the strong become stronger and thus the average is raised. It may be true that natural selection eliminates crippled and diseased animals; but no genetic mechanism has been discovered by means of which fit animals become fitter at each reproduction. Darwin visualized what would now be called the genes chang-

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