

## Chapter 3

### THE ORIGIN OF LIFE

#### Introduction

The difficulties of accounting for Evolution in terms of neoDarwinism are, as we have seen, daunting indeed. But they are nothing as compared to those of coming to terms with how life ever got started.

".....We may surely say of the advent of enzymes, like that of then origin of life, which is essentially the same thing, bristles with difficulties, as Hopkins said of the advent of life, that it was 'the most improbable and the most significant event in the history of the universe.'  
Dixon & Webb (1964, p.668)

".....The origin of life appears to be almost a miracle, so many are the conditions which would have to be met to get it going."  
Crick (quoted by Horgan 1991, p.125)

First of all, we have no equivalent of fossil records telling us *what* happened, hence confronting us with an extra challenge; it's no longer *merely* a matter of *how*, of accounting for what we already know. In passing, it is of interest to note that there are embarrassing gaps *within* the fossil records which are proving extraordinarily difficult to bridge. For example we just cannot imagine just how flight feathers evolved, or how parts of the jaw metamorphosed into the bones of the middle ear. All we know for certain is that most of these transitions were extremely rapid. If we can't fill a gap given a firm grasp of the beginning and end points, it's hardly surprising that we are having trouble with the *open-ended* origin problem.

Central to the whole business is a succession of problems of chemical transformation and synthesis. *All* of these need to have been successfully negotiated if life was to bootstrap itself into existence. First of all, was the atmospheric ambience sufficiently hospitable, and were appropriate 'starter' mesomolecules present in sufficient and maintainable concentrations (and in sufficient purity) from which things could get started? In addition, it need be demonstrated that credible transformation pathways exist whereby the postulated pre-protoplasmic building blocks (in particular, suitable monomers for polymerization) could be brought into existence from whatever the primordial 'soup' was kind enough to provide. And because macromolecular synthesis is largely an endergonic matter, sufficient free energy, in suitable form, must needs have been available.

Although the nature and stringency of these requirements varies somewhat from scenario to scenario the outlook is, in general, not encouraging. What has proved to be a great disappointment is the conclusion that the atmosphere was insufficiently reducing to allow the formation or survival of the kind of mesomolecules that are mostly called for -e.g. those related to the bases of nucleic acids or the amino acid monomers of proteins.

Secondly, life must somehow arise from such a mesomolecular 'soup' in the absence of both enzymes and of a suitably organized and packaged influx of energy. The chemistry of life is both *vector* and *chiral*, yet this must somehow take origin from a more primitive form which was *scalar* and *racemic*. In vivo chemistry is vector in the sense that almost all chemical reactions are mediated by enzymes which studiously position and orientate molecules which are to interact; metabolic transformations are organized into a reticulum of pathways. 'Soup' chemistry, on the other hand, is scalar in that reactions must proceed under the happenstance of quasi-random collisions of the reactants. Again, the chemistry of life is chiral, normally operating with only one

of two available enantiomorphs, and it is difficult to imagine how life could proceed in its absence -one need only consider DNA. But its not easy to see how 'soup' chemistry could bring such discrimination into existence; one would have thought it was in the same boat as our own in vitro chemistry. When the organic chemist synthesizes tartaric acid he gets a 50:50 racemic mixture of laevo- and dextro-molecules.

The noted chemist Cairns-Smith makes no bones about this:

".....I cannot be dogmatic but I can no more imagine an effective racemic molecular biology than I can imagine an effective racemic typewriter. Suppose you had a typewriter factory in which the operatives were provided with racemic boxes of nuts and bolts, racemic heaps of little bent levers and so on, with which to make a machine."  
Cairns-Smith (1982, p.40)

He goes on to point out that about the *best* you could hope for would be a racemic mixture of typewriters which would certainly take a great deal longer to assemble. Such considerations are among those which led him to explore the possibility of a mineral origin of life (which is to go much further than to fall back upon minerals as primitive catalysts).

We have been made painfully aware of the distinction between in vivo and in vitro chemistry in our attempts to duplicate many of the intricate chemical syntheses which the microorganism *Pseudomonas* can perform without batting an eye. Primitive bacteria found within the rumen and intestine of herbivorous animals have no difficulty in making as much cobalamin (vitamin B<sub>12</sub>) as they need on-the-run while it took Woodward, supported by two teams of organic chemists some years to duplicate this feat. Such was the crowning triumph of a career involving the synthesis of some of the most intractable mesometabolism in nature -for all of which he was awarded the Nobel prize<sup>1</sup>.

We now come to the matter of *staging*. Organic syntheses undertaken in the laboratory usually call for a careful control of the reagents and their products in following through the series of steps demanded by the synthetic pathway being followed. One needs such equipment as reaction vessels perhaps connected by tubing with stop-cocks, distillation columns: some control of ambient conditions, such as temperature and pH, and the addition of catalysts as appropriate. Intermediate products may need to be isolated by physical or reversible chemical means, or freed from the presence of contaminants. Under the primitive origin-of-life conditions, however, all that we had at our disposal was one vast cauldron. At best we had a primitive soup of appropriate ingredients, while what we needed was a soup kitchen staffed by competent chefs supported by appropriate culinary apparatus. To quote Cairns-Smith once more:

".....We should be cautious with reactions that presuppose starting materials that have to be themselves the products of other reactions. Could cyanoacetylene and cyanate [possible cytosine intermediates] have been made under the same overall conditions, and if not, could they themselves necessarily come together?"  
Cairns-Smith (1982, p.26)

".....Too many scene changes in this theater, argues Shapiro, with no stage manager."  
Kauffman (1995, p.36)

[Shapiro (1986) enlarges upon this p.178]

Perhaps, in those primitive days, what we had was something a bit more tractable, e.g. a series of pools or lagoons or marshes which drained into each other, but such can hardly be stretched into the equivalent of a kitchen or of a chemical laboratory. Or perhaps the environment shifted over a period of time, in a way which precisely favoured the required biochemical staging.

This is asking a lot, but something of the kind had *better* occur, if the origin of life is to be sustained under physicalist presuppositions; can you imagine what Stanley Miller's original recycling spark chamber experiment, written large into a world of thunder and lightning, would do to any useful polymers lucky enough to have brought themselves into existence?

Anabolic processes are mostly endergonic, hence calling for a supply of free energy. But it is very far from being sufficient to establish the presence of a credible *source*; it is also necessary to demonstrate that adequate *means of delivery* are at hand so that it may be conveyed to the point at which it is needed, and in a way which can be used for the purpose at hand. This brings us back once more to the contrast between *in vitro* and *in vivo* chemistry; the delivery of energy needs to be of vector rather than of scalar character. Of course, where advanced life forms have been firmly established, anabolism is handled by two ongoing sets of processes appropriately intercoupled; an endergonic one through which the synthesis of protoplasm actually proceeds, and an exergonic one which furnishes the needed energy in conveniently packaged form through the degradation of 'energy' foods. It is this latter process which provides the 'negentropy' needed to maintain life in a state remote from thermodynamic equilibrium. We do not need to have such apparatus in existence at the beginning, and it is most unlikely that any atmospheric oxygen to speak of was present at that time. What must be demanded is that *some* means must have been at hand of delivering energy from its source to its destination.

Something which must not be lost sight of is that the required upwards march towards a self-sustaining organization had somehow to occur in the face of the depredations of thermodynamics. Just to *maintain* any increment of progress which was lucky enough to have been made is challenging enough. As Bertalanffy observed:

".... What is at present quite inexplicable is why and how organic substances, nucleoproteins, or coacervates would have formed against the second principle [of thermodynamics] -systems tending toward thermodynamic equilibrium but 'open systems' maintaining themselves at a distance from equilibrium in a most improbable state. This would be possible only in the presence of 'organizing forces' leading to the formation of such systems. Before such systems had emerged, selection could not even start to act." Bertalanffy (1972, p.73)

In other words the second law of thermodynamics must be contended with throughout. As Eddington long ago insisted:

".....The law that entropy always increases -the Second Law of Thermodynamics' holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations -then so much the worse for Maxwell's equations.....But if your theory is found to be against the Second Law of Thermodynamics I can give you no hope; there is nothing for it but to collapse in deep humiliation." Eddington (1955, p.81)

This law is the great dissolver of coherence, and the simplicity of the starting conditions put us beyond reach of any question of Prigoginean rescue.

## Thermodynamics -A Brief Digression

Bradley [1996] and Thaxton [1984] present a crystal clear, truly perspicuous account of the thermodynamics underlying the synthesis of polymers from a supposed primordial 'soup' containing (among other molecules) the required monomer building blocks. They deal principally with the formation of protein polymers, but precisely the same principles apply to all such syntheses. The paragraphs which follow draw freely upon these sources.

Two kinds of entropy may be distinguished, the one thermal and the other informational. They are alike in that both are dependent upon the number of possible arrangements. The one orders energy and the other mass. Thermal entropy is given by the number of translational, vibrational and rotational energy states and that of configuration by the number of arrangements of molecules.

The two entropies are given, respectively, by:

$$S_{\text{thermal}} = k \cdot \ln \cdot \Omega_{\text{thermal}}$$

$$S_{\text{config}} = k \cdot \ln \cdot \Omega_{\text{config}}$$

-where:

$$k = \text{Boltzmann's constant} = 1.38 \times 10^{-16} \text{ erg/deg K}$$

$$\Omega_{\text{thermal}} = \# \text{ of thermal arrangements}$$

$$\Omega_{\text{config}} = \# \text{ of arrangements of monomers within the polymer.}$$

The number of configurational arrangements is given by:

$$\Omega_{\text{config}} = N! / [(N/n)!]^n$$

-where N is the number of monomers in the polymer chain, and n the number of different kinds of monomers (20, in the case of amino acids, and 4 of nucleic acid bases). Actually, the above computational procedure (Thaxton 1984) is based upon Fermi-Dirac statistics, that is, assumes there is a single set of amino acids or bases present needed to put together a single polymer; as such it understates the gravity of the problem because each monomer, correctly selected, reduces by one the remaining pool from which selection may be made, so that the final monomer is correctly selected automatically. More reasonable is the assumption that a great many sets of such monomers are present, and that therefore Bose-Einstein statistics are more appropriate. This gives us:

$$\Omega_{\text{config}} = n^N$$

-again, where N is the number of monomers in the polymer chain, and n the number of different kinds of monomers.

The total Gibbsian free energy required to perform the synthesis is given by:

$$\Delta G = \Delta H - T\Delta S = \Delta E + P\Delta V - T\Delta S = \Delta E - T\Delta S$$

-where:

$\Delta H$  is the change of heat energy or Enthalpy

T the temperature, in degrees Kelvin

T $\Delta S$  the total change in entropy

$\Delta E$  the change in bonding energy.

The product of the pressure and volume change may be disregarded in the present context.

The term T $\Delta S$  for the overall entropy change contains a number of components, as shown in the following expansion of the overall Gibbsian free energy which is called for:

$$\begin{aligned}\Delta G &= \Delta E - T\Delta S_{\text{thermal}} - T\Delta S_{\text{config}} \\ &= [\Delta E - T\Delta S_{\text{thermal}}] - [T\Delta S_{\text{seq}} + T\Delta S_{\text{l/d}} + T\Delta S_{\text{bond}} + T\Delta S_{\text{misc}}]\end{aligned}$$

This way of writing the expression groups the needed components of free energy into two groups; the first gives the energy of polymerization required to give a random polymer, i.e. one totally free of selection or significant 'information'.  $\Delta E$  gives the bonding energy, and  $T\Delta S_{\text{thermal}}$  the reduction in thermal entropy. This entropy goes down, i.e. the thermal energy becomes more ordered, because the gain in vibrational and rotational degrees of freedom is more than compensated by the reduction in translational energy states. What might be called the 'chemical' work of polymerization is divided between these two terms (in the polymerization of amine acids), the second term makes somewhat the greater contribution of the two, in the case of amino acid polymerization.

To go from a random to a specific, ordered polymer (e.g. protein or nucleic acid molecule) calls for four kinds of ordering, corresponding to the four terms in the above equation:

- $T\Delta S_{\text{seq}}$  The entropy decrease in passing from a random to a unique sequence of monomers within the polymer.
- $T\Delta S_{\text{l/d}}$  The decrease if only laevo amino acids (out of a racemic mix) are to be included.
- $T\Delta S_{\text{bond}}$  The decrease if only peptide bondings (one of two possibilities) are to be formed.
- $T\Delta S_{\text{misc}}$  The decrease if only authentic monomers enter the polymerization, i.e. the various contaminants within the primordial 'soup' were somehow avoided.

The second and third terms clearly apply only to protein synthesis.

In approaching this problem, the authors suggest that:

".....For computational purposes [the synthesis] may be thought of as requiring two steps: (1) polymerization to form a chain molecule with an aperiodic but near-random sequence, and (2) rearrangement to an aperiodic specified information-bearing sequence." Thaxton (1984, p.134).

That is to say, one can think of the necessary substitutions being made at no cost in free energy. In fact, of course, no such substitutions are called for because only a single stage embracing both aspects of the synthesis would actually be involved.

The term  $-T\Delta S_{seq}$  giving the component of free energy required in creating a *specified* sequence of monomers from a *random* sequence is given by:

$$\begin{aligned} -T\Delta S &= -T.(S_{random} - S_{required}) \\ &= T.(k.\ln \Omega_{required} - k.\ln \Omega_{random}) \\ &= T.(k.\ln 1 - k.\ln n^N) \\ &= T.k.\ln 20^N \text{ for proteins} \end{aligned}$$

The first term is zero, simply because a precisely specified sequence has only a single arrangement, and  $\ln 1 = 0$ .

Should it be the case that some of the links along the polymer chain are insensitive to the monomer identity, so that the polymer would do its job about equally effectively, then this may be taken into account in the above calculation by subtracting the number of such insensitive residues from the total number of links N.

In the case of protein polymer synthesis, two further substitutions need to be made to produce the required functional entity; first, the 50% non-peptide bonds must be substituted for peptide ones, and the 50% dextro-rotary amino acids swapped for biologically functional laevo-rotary forms. In each case the required component of free energy is given by: necessary .

$$-T\Delta S_{l/d} = -T\Delta S_{bond} = -T.k.[(\ln 2^{N/2}) - \ln 1]$$

(The value will be slightly less for the bond correction because there will be only N-1 peptide bonds within a polymer of length N.)

The authors (Bradley 1996) compute the following values for the various components of Gibbsian free energy demanded to put together a viable polymer from an impure primordial 'soup' which contains all of the needed monomers.

First, the free energy required to create a peptide bond between two amino acids is taken to be 300,000 cal/mole, or 30 cal/gm, assuming an average molecular weight of 100 for amino acids. For a chain of 101 amino acid residues,  $-T.k.(\ln.20^{101} - \ln.1) = 18.2$  cal/gm. Each of the corrections for the dextro-rotary amino acids and non-peptide bonds is given approximately by  $-T.k.(\ln.2^{50} - \ln.1) = 2.1$  cal/gm. The free energy required to move out garbage monomers masquerading as amino acid residues is unknown, depending as it does upon the degree of purity of the 'soup', but can hardly be anything less than considerable. We end up with this grand total:

$$30.0 + 18.2 + 2.1 + 2.1 + ? = 52.4 + ? \text{ cal/gm.}$$

The corresponding expected concentration of protein to its constituent amino acid molecules, under equilibrium conditions, is given by:

$$K = \text{the equilibrium constant} = e^{(-\Delta G/RT)}$$

-where R is the gas constant = 1.9872 cal/deg-mole.

For a required free energy of  $52.4 \text{ cal/gm} = 524 \text{ kcal/mole}$ , this gives us an expected protein concentration of  $10^{-382}$ , at a temperature of  $300^0\text{K}$ . Clearly, such a concentration absolutely excludes -and by a huge margin- any possibility of a single protein molecule making its appearance.

"....Morowitz has estimated the increase in the chemical bonding energy as one forms the bacterium *Escherichia coli* from simple precursors to be 0.0095 erg, or an average of 0.27 eV/atom for the  $2 \times 10^{10}$  atoms in a single bacterial cell. This would be thermodynamically equivalent to having the water in your bathtub spontaneously heat to  $360^0\text{C}$ ....He goes on to estimate the probability of the spontaneous formation of one such bacterium in the entire universe in five billion years under equilibrium conditions to be  $10^{-10^{**11}}$ . Morowitz summarizes the significance of this result by saying that 'if equilibrium processes alone were at work, the largest possible fluctuation in the history of the universe is likely to have been no longer than a small peptide'." (Ibid. p.102)

Of particular interest in the partitioning of the components of Gibbsian free energy demanded by protein synthesis is that the configurational entropy decrease demanded isn't far short of that of the bonding energy, especially when any kind of realistic allowance is made for the presence of soup impurities. And there is no way that any surfeit of free energy can compensate for this. But such is not at all to say that free energy is sufficient in itself to perform the bonding. There has to be some means of bringing the energy to bear to precisely where it is needed, and to protect the growing peptide chain from thermodynamic degradation until the job be complete:

".....There does not seem to be any physical basis for the widespread assumption implicit in the idea that an open system [one in which free energy is continually available] is a sufficient explanation for the complexity of life." Thaxton (1984, p. 183)

".... If one wishes to restore a messy room to its original neat (low entropy) condition, one must do work on the system. Although throwing a stick of dynamite into the room will provide a sufficient flow of energy through the system, it is doubtful that the configurational entropy of the room will be lowered or that the room will be restored to its original low entropy state. The flow of energy through the room needs to be directed if the configurational entropy of the room is to be reduced.; i.e someone needs to do very specific kinds of work to restore the room to neat condition." Bradley (1996, p.3)

### The Further Challenge of Self-Replication

Even assuming that all of the above difficulties could be met, and a polymer of requisite length could somehow have emerged, what are the chances that it would have the sought-after property of self-replication? Producing *any* such polymer of what might be taken to be requisite length is quite challenging enough. Up to the present time, leaning upon all of the resources which the organic chemistry laboratory is able to supply, no one has been able to put together *any* polymer which is truly self-replicating, i.e. able to separate itself from its copy, thus enabling an endless repetition. Jules Rebek Jr. has probably gone as far along this road as any. He has succeeded in crafting a molecule which could reproduce itself, but only under the most inhospitable of conditions (Horgan 1991, p.120). He succeeded in producing another molecule which could reproduce itself within a more normal aqueous environment, but unfortunately, the duplicated molecule was unwilling to forsake its template -necessary if the process is to continue indefinitely (Rebek 1990). Yet we are asked to believe that what we cannot do by *trying* was

somehow successfully *blundered into* in those far-distant days. Why should naked causality succeed where dedicated teleology fails?

In the Ribozyme-first scenario a two-stage process is called for; in the first a complementary polymer must be formed, followed by a second, in which the original template is synthesized. The first step can occur spontaneously (as when an all-cytosine polymer was shown to be able to produce an all-guanine complement in the presence of the appropriate nucleotides) but no one has been able to demonstrate the second in the absence of assistance of enzyme catalysts.

Actually, there is yet one further condition which the first self-replicating molecule to emerge must meet. And that is, it must be a *robust* replicator from the first moment. Almost any polymer which had blundered upon self replication would be much more likely to fall apart very soon thereafter than to found an expanding colony:

".....There is a further irony. Even should the miracle occur and the replicator find itself awash in the seas of the prebiotic Earth, its fate would be unkind. It would perish without further issue. For in the random sea, it would encounter only hosts of unrelated chemicals and not the subunits it needs to reproduce itself. A second miracle would be needed to surround it with exactly the ingredients it needs for further progress."  
Bertalanffy (1969, p.170)

Last of all, supposing the miracle of a self-replicating molecule be happened upon, how is this to give rise to the first cell? The leap from the most primitive self-replicating system -whether of a single self-replicating molecule or a small set of macros which are mutually self-reproductive is a daunting one, but it is something which, by hook or by crook, had to occur, and as early as possible:

"...Almost at their inception, living things had to become able to process materials absorbed or ingested, using them to carry out vital processes, to grow and reproduce. Such an exchange is the essence of animation. A minimum set of about 300 biochemical processes are necessary; in the simplest known self-sustaining organisms, there are about 550."  
Wesson (1991, p.54)<sup>2</sup>

Simpler systems can be conceived:

".....The minimum requirements for a simple living system must include the capacity to: 1) process energy (to make use of energy from the surroundings), 2) store information, and 3) replicate. The simplest organic system proposed to date that is capable of these functions is the hypercycle of Eigen. This system, consisting of a deoxyribnucleic acid molecule (DNA) and a minimum of 40 proteins, is much simpler than the simplest known living systems, namely the bacteria."  
Bradley (1996, p.1)

If ribozymes of some sort were indeed the progenitors of life, then the immediate next step would hopefully be the putting together of primitive catalysts of enzyme type which, of course, would demand the presence of a number of different amino acids or related molecular species in sufficient concentration and state of purity. A membrane will be needed to contain the nucleic acid and protein catalysts and, as Wesson (1991, p.55) cautions, should have been semi-permeable from the start.

Although not a part of the origin of life problem, it is worth pointing out that the means by which the next step was managed -that of the passage from prokaryotes to eukaryotes- has been proved hard to envisage (de Duve 1996). Judging by the time it took to achieve, it must have

been very tricky. In all, it occupied over two billion years -several times the interval needed for prokaryotes to evolve from scratch; however the accomplishments of bacteria are quite astonishing enough; they are the master metabolizers.

Leaving the problems of chemistry aside, we must now confront these final embarrassments. Neither of the two 'shaping' and 'self-organizing' mechanisms by means of which evolution is claimed to be driven were present at the beginning. Life must get started without benefit of natural selection, because until self-replication gets under way, there is nothing to select *from*.

"....The most important gap in the entire proceedings concerns the steps prior to the appearance of the first replicator. Natural Selection does not apply, and we are left with only chance itself. Spontaneous creation crawls out of the woodwork once again."  
Shapiro (1986, p.166)

Speaking more generally, Bertalanffy has noted:

".....selection *presupposes* self-maintenance, adaptability, reproduction, etc of a living system. These, therefore, cannot be the *effect* of selection. This is the oft-discussed circularity of the selectionist argument. Proto-organisms would arise, and organisms further evolve, by chance mutations and subsequent selection. But in order to do so, they must already *have* the essential attributes of life."  
Bertalanffy (1972, p.26)

As discussed in the previous chapter, attempts have been made to bolster the conservative discipline of natural selection with the benefits of spontaneous self-organization said to inhere within systems as complex as organisms have become. But no such organized complexity was there in the beginning, hence anything which 'complexology' may hope to offer wasn't available where it was most desperately needed. Life would need to have proceeded long beyond its initialization before there could be any question of complexology delivering whatever tricks it may have up its sleeve. (Stuart Kauffman has proposed a 'complexity first' origin of life scenario - which we shall briefly examine further below).

The relative weighting of many of the embarrassments presented in the depressing litany intoned above will vary somewhat with the scenario which is being addressed. The odds-on favourite at present is that which envisages the creation of a self-replicating macromolecule of RNA type as being the key event which, it is claimed, once achieved, would launch evolution onto a secure upwards path. Most of the discussion which follows is grounded upon this scenario. At its conclusion a number of alternatives will be examined which seek to circumvent one or another of the difficulties to which the 'RNA first' mode of origin is subject. None seems to fare any better; very often one problem is ameliorated at the expense of exacerbating others elsewhere.

The analysis which occupies the body of this chapter makes it clear that it is absolutely inconceivable that life could have gotten started by any of the means which have yet been considered; the *combination* of seemingly unsolvable problems which besets them all leaves scant hope that current lines of thought are going to solve the riddle. We need to confront the bad news head-on, that the thesis that life could bring itself into existence under the regimen of Natural Law limited to its currently accepted scope is just about as disconfirmed as it is possible for a hypothesis to be. Notwithstanding, obviously, Life *did*, willy-nilly, succeed in pulling itself out of a primitive physico-chemical environment. In consequence, if such is to be accounted for by natural process, extensions to natural law must be postulated whose presence only become manifest when matter is suitably arranged or organized. This must obviously be the case with protoplasm and must also have been true for the nominally inorganic context from which life somehow got started. But here, as with respect to life in general, to contemplate the taking such

a step is anathema to the intellectual who fears that to do so would be to fall -automatically- into the heresy of vitalism. Of this, much more later.

As is discussed elsewhere within this volume, the organic realm abounds with problems which defy explanation in classical, reductionist terms. Arguably, however, the enigma of life's origin is the most intractable.

### Did Life Start as a Self-replicating RNA Polymer?

Modern speculation has found itself confronted by a classical chicken-or-egg dilemma. The essence of life resides within nucleic acids (in the form of the engrams of base-sequencing) while its expression and implementation depends primarily upon proteins -above all those which serve as enzyme catalysts. The process of reproduction at the nuclear level depends upon enzyme-directed reactions. If *both* nucleic acids and enzymes must be co-present, then how did life ever get started? It is difficult to see how either could have come first in complete isolation from the other. Proteins are too unstable to be long-term repositories of 'information' while nucleic acids are remarkably inept at 'doing' anything. But a discovery made by Thomas R. Cech and Sidney Altman in the early 1980s was to cast the whole matter in a new light. What they found out was that some RNAs could act as catalysts, in particular, acting upon themselves. This was dramatic news indeed -enough so, for the pair responsible to be awarded a Nobel prize; it raised the possibility that life might have started with the spontaneous emergence of a self-reproducing 'ribozyme' -an RNA polymer with self-catalytic properties.

In other words, it is suggested that life took origin neither from the chicken nor the egg but rather from a hybrid entity upstream of both. This hybrid must be considered as closer to the egg, in view of the ineptness of nucleic acids as catalysts. The exploration of this scenario (and others related to it) is particularly associated with the name of the much-respected chemist Leslie Orgel -See Orgel (1973) or more recently his excellent summary article in Scientific American (Orgel 1994).

### Speculations on the Availability of Bases

However, for this hopeful promise to be redeemed a number of initial conditions must be satisfied and a succession of synthesis hurdles surmounted. At the beginning, we need to have at hand both pyrimidine and purine bases, a pentose sugar (ribose) and phosphate molecules suitably energized. The nucleotide monomers must then be derived by a two-stage process; first, the sugar must be attached to the bases to form nucleosides, followed by the addition of the phosphate moiety. All of these syntheses must be accomplished without benefit of enzymes; any catalysts present must necessarily have been inorganic.

Since the above words were first written, the noted nucleic acid expert Dr Robert Shapiro (1996) [page # ?], in reviewing this chapter, commented:

".....The situation is even worse than you describe. For example, the adenine synthesis that you site on page 8 is of no value at all in the origin of life.....Further, it is very unlikely that the base cytosine was present at the start of life because of its instability. In addition, purine nucleosides have not been produced without enzymes (the products obtained by Orgel in the 1970's had ribose on the wrong nitrogen of adenine)"

Assuming such mesometabolism to have been successfully set in motion, the next step would be the polymerization of monomers to form an RNA polymer capable of creating its complementary macromolecule. Such an accomplishment would still be one step away from true

self-replication -which additionally calls for a means of duplicating the original template. Such a feat is taken, by many of the supporters of this scenario to be seminal; such is to accept self-replication as being as good a definition of the presence of life as any, provided that the replication process be sufficiently imperfect to furnish the variety of progeny upon which natural selection may operate.

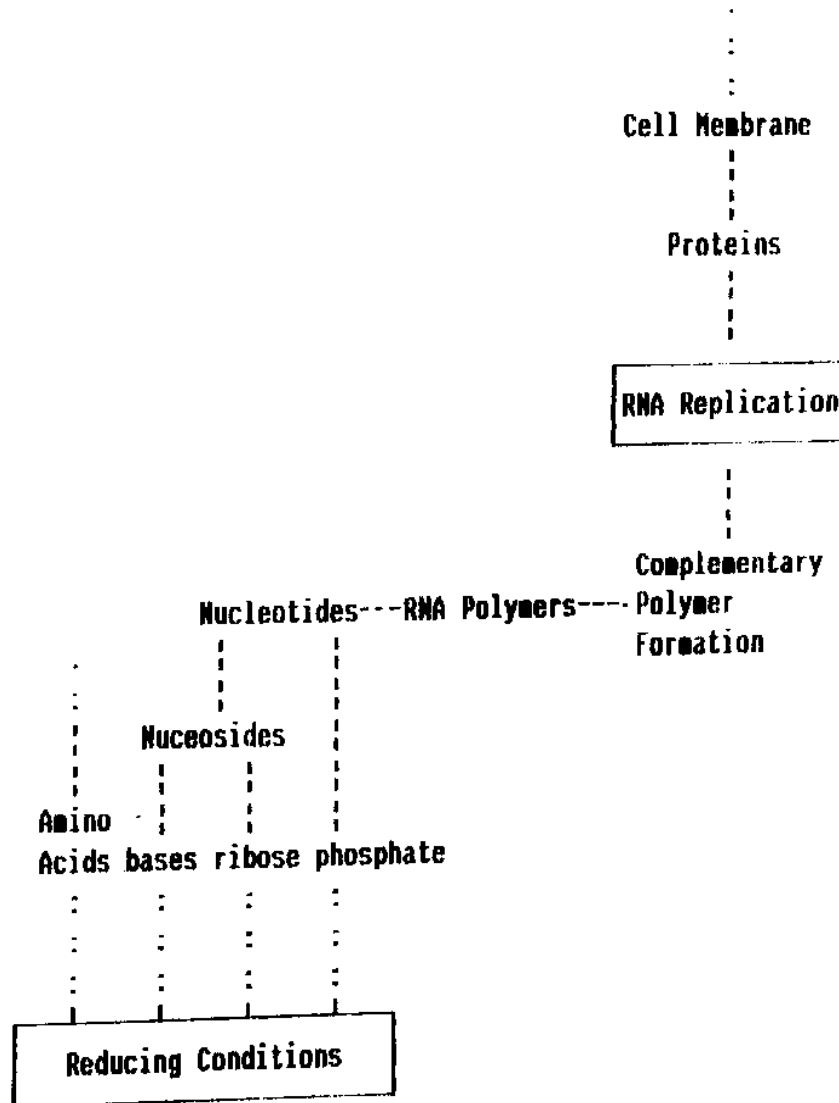


Figure 3.1

From this point all of the rest of the apparatus needed to bring the first cell into existence must somehow be co-evolved. Highest on the list must surely be proteins, followed by some kind of membrane which could create the necessary enclosure demanded if metabolic processes are to operate under close control.

How credible is this scenario? First, if appropriate source molecules are to be present from the start, it is essential that the atmosphere be sufficiently reducing. In his epoch-making experiment made in 1953, Stanley Miller recirculated a mixture of hydrogen, methane and ammonia through a spark chamber. An analysis of the reddish sludge which developed disclosed the presence of 'organic' molecules including some amine acids in non-trivial concentration. As

much as 2% of the products were actual amino acids, with another 8% of identifiable organic compounds (Orgel 1994, p.80) This was, indeed good news -and not just for the scenario under consideration; the ensuing euphoria was understandable:

".....The chemist William Day states in his description of the Miller-Urey results: 'no longer was there the dilemma of how organisms could have produced organic compounds before they themselves existed -the building blocks had already been there on the primordial Earth'." Shapiro (1986, p.107)

" These compounds (in Haldane's words) must have accumulated until the primitive oceans reached the consistency of a hot dilute soup." Shapiro (Ibid. p.110)

However, geologists have come to revise their opinions about the composition of the primitive atmosphere -rather drastically. It is now believed that CO<sub>2</sub> was dominant, followed by N<sub>2</sub>, and some water vapour, plus a trace of H<sub>2</sub>. More significant, there was no CH<sub>4</sub>, or NH<sub>3</sub>; It is also unlikely that there was any O<sub>2</sub>. Any CH<sub>4</sub> or NH<sub>3</sub> which might have made an appearance would have been destroyed in a few thousand years by chemical reactions primed by sunlight (Shapiro 1986). Some still hold out the hope that more reducing conditions than these latest findings suggest might have existed -among them Stanley Miller himself- but things don't look too good.

Stanley Miller repeated his experiments utilizing revised estimates of the composition of the primitive atmosphere. The relation of H<sub>2</sub> to CO<sub>2</sub> was found to be critical. Of the 20 amino acids currently drawn upon in protein synthesis, only glycine emerged. Miller notes:

"If it is assumed that amino acids more complex than glycine are required for the origin of life then these results indicate a need for CH<sub>4</sub> in the atmosphere." Shapiro (Ibid. p.112)

Gunnar Sillen (Ibid. p.113) has figured that even with CH<sub>4</sub>, any build-up of amino acids would decay back to the status quo unless maintained by a high energy input -which organic chemicals are less adept at using than living systems.

Other sources of the needed organic 'primitives' have been proposed -for example from meteors and meteorites with which the earth was heavily bombarded during the early period following its formation. Many of these must have been quite large, however, and the force of their impact would have generated sufficient heat to destroy most of the molecules of interest - indeed, if not even to boil the oceans.

This lack of reducing conditions was an important factor driving Cairn-Smith (1982) to propose a mineral origin of life, with a later transfer to the organic form familiar today; of this more later.

If it should subsequently be proved that initial conditions were in fact sufficiently reducing, it would seem that pathways leading to the creation of all of the pyrimidine and purine bases might be credibly postulated. For example, in one experiment, the most abundant complex molecule to emerge from a mixture of HCN and NH<sub>3</sub> was adenine -a key reagent indeed in present day metabolism (Orgel 1994). Not all four bases need have been there at the start, but at the least a matching pair would have had to have been present.

However, there would still be formidable hurdles to be cleared if fully-fledged nucleotide monomers were to come into existence. Thus although ribose could have been produced through a series of reactions starting from formaldehyde, it is always admixed with other sugars whose

presence would certainly interfere with nucleoside synthesis. Although purine nucleosides have been produced without the aid of enzymes, no one has yet duplicated this feat for the corresponding pyrimidine molecules. Again, it's one thing to add the phosphate moiety to the nucleoside to arrive at the corresponding nucleotide, but quite another to ensure that it is attached to the right place. Possibly adsorption onto appropriate mineral catalysts might help, but none such have yet been found. Hence somehow or other, a means had to have been found of producing only correct nucleotides, or of somehow proceeding to the next step in the presence of contaminants. A further problem is appropriate polymer formation would demand the presence of a single enantiomorph rather than the racemic mixture which is about the best one could hope for in the absence of enzymes.

Pursuing our concatenation of 'ifs' to its final link, what is the probability that a self-replicating RNA polymer could come into existence, given adequate and maintainable concentrations of the four ribonucleotides in a state of reasonable purity? Of course, there would have been no enzymes present to lend a helping hand, but at least the monomers are self-energized thus making the process of polymerization exergonic, that is to say, the path is made easier by being downhill. In consequence, it is, perhaps, not too surprising that oligonucleotide strands can form spontaneously in the presence of suitable inorganic catalysts (the common clay montmorillonite was found to serve this purpose). And thanks to the phenomenon of Watson-Crick base-pairing, a complementary polymer might have been formed, though slowly in the absence of enzymatic direction. For example, it was found that an all-cytosine polymer was able to form its all-guanine complement -in the presence of zinc ions (as are found in all present day enzymes which can polymerize nucleic acid). However, as Crick reminds the reader:

".....Molecules as long as 40Gs in a row can be detected in the incubation mixture, and longer ones are likely to be present in amounts below the present levels of detection.....[the system] is unnaturally pure. It is difficult to imagine how a little pond with just these components, and no others, could have formed on the primitive earth."  
Crick (1981, p.84)

But such an achievement still falls short of the goal of true self-reproduction. For this process to be set in motion, the two polymer strands must be separated, and the complement polymer used to recreate the original template. For this to occur, the original polymer must be possessive of catalytic properties which will bring about the separation of arbitrarily constituted polymers and put together a copy of itself from the complement strand. As Orgel frankly concedes, this has so far proved to be a pons asinorum:

"....After years of trying, however, we have been unable to achieve the second step of replication -copying of a complementary strand to yield a duplicate of the first template- without help from protein enzymes. Equally disappointing, we can induce copying of the original template only when we run our experiments with nucleotides having a right-handed configuration. All nucleotides synthesized biologically today are right-handed. Yet on the primitive earth, equal numbers of right- and left-handed would have been present. When we put equal numbers of both kinds of nucleotides in our reaction mixtures, copying was inhibited."  
Orgel (1994) [page # ?]

It is therefore evident that the two critical links in the above succession of demands are: first, obtaining a sufficiently high concentration of all right-handed ribonucleotides, and second, given such a renewable resource, of being lucky enough to synthesize a polymer possessive of the catalytic power needed to create a new copy of itself. No-one has yet demonstrated that such a polymer could indeed exist *at all* under anything remotely suggestive of the ambient conditions, and given the ineptness of ribozymes as catalysts, the prospects are not encouraging. Rather than RNA, might the first self-reproducing polymer have been something more tractable which is

related to it? A number of avenues of approach are currently being pursued. For example, pyranosyl RNA (which substitutes a six-atom ring for regular ribose) would be more separable from its complement, because the polymer-pair do not twist around each other, as is true of nucleic acids. This, and other proposed polymers depend upon a Watson-Crick templating mechanism as the nucleus of the self-reproductive process. So far, no one has been able to produce, or to propose a macromolecule capable of self-reproduction which does not depend upon such hand-in-glove copying process. It is very difficult to establish any kind of number which states the improbability that any polymer which might be formed would be self-replicating. The improbability of forming any *particular* polymer from a sufficiency of monomer molecules through chance selection has already been examined in the previous chapter. It was demonstrated that if  $n$  kinds of monomers are called for in equal proportions, then the improbability of forming any particular polymer which one has in mind would be given by the reciprocal of  $N!/[(N/n)!]^n$ . Let us assume that we knew, or suspected that a particular sequence of 400 nucleotides (in which the bases were present in roughly equal proportions) had the desired magical attribute. Then the probability that a polymer could be formed through the random addition of nucleotides would be given approximately by the reciprocal of  $400!/(100!)^4$ , or approximately  $10^{-237}$ . Small though this number be, it does not really answer the question because of the way it takes for granted that at least *one* such polymer would display the required characteristics if brought into physical existence. This is a dubious assumption indeed, implying as it does that nature has managed to blunder to a success which we have been unable to match -even on paper. Hence the true improbability, in the above example would be somewhere between  $10^{-238}$  and a value of literally zero; that is to say, we simply do not know if any such molecule with the size-range under discussion could exist at all. The converse could, of course be the case, that is to say many possible polymers might meet the requirements; in this eventuality, the corresponding probability value will be improved -but time enough to speak of this when a single such has been devised. It is a complete non sequitur to claim that the brute fact of life's actual start proves that such a polymer *must* have brought itself into existence. It is a non sequitur because it begs the very question under discussion -whether or not the origin of life is to be accounted for within a reductionistic framework of physical law.

Once more, apart from everything else, is it really credible that the trial-and-error of nature, exercised in ignorance of the principles of organic chemistry, could outwit the teleological exertions of some very knowledgeable experts?. I will return to this matter in a wrap-up at the end of the chapter.

### Some other Proposed 'Origin' Scenarios

Some other alternatives have been made which seek to mitigate one or more of the difficulties inherent in the Ribozyme approach or which recommend themselves for some other reason. Each brings its own particular problems with it, but more importantly, all share a number of the same fatal weaknesses as the 'default' scenario, hence would appear equally to be dead-ends. Needless to say, this is not at all how mainstream intellectual thought views the matter:

".....None of these approaches has gained enough support to qualify as a new paradigm. On the other hand, none has been ruled out. That bothers Miller who is known both as a rigorous experimentalist and a bit of curmudgeon. He calls the organic-matter-from-space concept 'a loser', the vent hypothesis 'garbage' and the pyrites theory 'paper chemistry'. Such work, he grumbles, perpetuates the reputation of the origin-of-life as being on the fringe of science and not worthy of serious pursuit."  
Horgan (1991) [page #  
?]

Only a sampling of what is being offered will be presented here:

- (1) Holistic Approaches of Oparin, Fox & Matthews.
- (2) Cairns-Smith's 'Mineral Life First' Proposal.
- (3) Thermal Vents as Sites of Life's Origin.
- (4) Stuart Kauffman's 'Complexity First' Scenario.

### Holistic Theories of Oparin, Fox & Matthews

Oparin (together with J.B.S. Haldane) suggested, back in the 1930s that life might have started under very much the same conditions under which Stanley Miller ran his famous experiment. Very little was known about nucleic acids in those days. Regardless, Oparin also envisaged the emergence of reproduction as being at the top of the list of priorities. What he attempted to show was that appropriately constituted colloids could be persuaded to precipitate second-order colloidal globules which in turn might grow and reproduce by pinching themselves into two. But such has only the most superficial of resemblances to the binary fission of such organisms as amoeba -in which the terminal event is preceded by a great deal of organized replication and organization of internal components. Oparin's schema can hardly be called *simulation*; it is no more than *mimesis*. Fox was able to produce spheres of oligopeptide strands through heating solutions of amino acids -but where does one go from there?

".....What, then, is the missing fragment in the case of the origin of life, that which distinguishes a system capable of life from shadow-play? It is the ability to grow, reproduce and evolve. The system must convert simple materials in the environment into more of itself, not simply in the way that a rolling snowball gathers more snow, but in a manner which copies the internal organization of the system."  
Shapiro (1986, p.204)

As described in Bradley (1996, p.7), Fox's procedure is to synthesize proteins in two stages. The first, starting with energy rich gases such as ammonia, methane and hydrogen runs downhill to produce the needed amino acids. In the second, polymerization is achieved through a heat-driven condensation reaction, driving off molecules of H<sub>2</sub>O in the process. The only problem is that only 2% of the monomers formed are amino acids -which must first be separated from the rest before proceeding to the polymerization.

Matthews [Bradley 1996 p7] in contrast, performs everything in a single operation. Starting with energy rich compounds such as cyanide, the path to monomer and polymer formation is downhill all the way.

Unfortunately, both procedures produce d- as well as l-amino acids, and both produce other than peptide linkages. Only 50% of Fox's bonds are of peptide character; Matthews is in worse shape, because polymerization proceeds in the presence of compounds other than amino acids.

### Cairns-Smith's Mineral Startup of Life

Cairns-Smith (1982) proposed a completely different scenario -that life and reproduction were initially mineral, only later making the transition to organic substrates. This approach was attractive because it no longer calls upon a reducing environment -now considered to be very unlikely (Schopf 1983). In addition it seemed that irregularities and imperfections on the surfaces of suitable minerals might do more than merely catalyze but in addition introduce the much-needed chirality into primitive chemistry. Silicon, like carbon, forms chains -unfortunately mostly with oxygen.

Kaolite crystals, for example, like salt crystals, grow by accretion; in one form of growth, sheets are produced; he calls such minerals 'living clay'. Information, he feels might be stored in the form of imperfections. To mimic life, the stacks would be required to divide into several derivative stacks as well as merely extend themselves; he feels that a rainy spell followed by a dry period might achieve this. Such replication might occur with 'mutational' imperfections. At this point, natural selection could take over. Energy is taken to be of tectonic origin. Chemical reactions could come to be mediated by systems of tubes, pipes, pores, membranes and even pumps. Mineral life would be succeeded first by organic hybrids, then by purely organic forms. Shapiro (1986, p.218).

Central to his scenario is the way in which information is stored in terms of a stack of kaolite or similar plates bearing one of a number of different kinds of imperfection, thus presenting us with a two-dimensional analogue of the linear sequence of DNA bases.

In the absence of sufficient research, it would be premature to pass judgment upon the effectiveness of the inorganic mechanisms which Cairns-Smith proposes. However, one hardly needs to agonize about such matters since this is not where the basic weakness lies. Once again, as Bradley (1996) insists, the central problem is a configurational one; how can a sufficiently complex and meaningful stack of plates come into existence, and how -when the time comes for a transfer to the familiar organic life form- is the necessary equivalence to be established between the pattern of imperfections amongst the clay plates and the genetic code upon which organic life has come to be based.

"....some random sequence of imperfections in clay can hardly be expected to encode a biopolymer of any kind." Bradley (1996, p.16)

and finally, *some* version of the 'primordial soup' must finally be postulated from which the 'organic takeover' can draw its substance.

#### Proposed Thermal Vents Theories

The theories of Christian De Duve and Günter Wächtershäuser among others, dodge the atmosphere problem of 'surface' scenarios entirely by siting the origin of life in the neighbourhood of deep-sea hydrothermal vents. There would have been no lack of energy, and the chemical compounds issuing from them might, the proponents suggest, have been supportive of an initially sulphur-based chemistry, a transition to more conventional chemical substrates taking place later. But once again, how are the information-dense aperiodic polymers to be brought into existence? Indeed, despite the copious free energy offered by such vents, putting together *any* polymer of requisite length would be challenging enough.

#### Thermodynamics -a Second Digression

Thermodynamics was to have its origin over a century ago, its principle architects being Boltzmann and Willard Gibbs. Here are its basic laws:

- O First Law -The Principle of the Conservation of Energy. This states that within a closed system, the totality of its contained energy remains constant, and is completely unaffected by any transformations of its character which may be taking place. As Thaxton (1984, p.113-4) puts it "...A major part of the science of thermodynamics is accounting -giving an account of the energy of a system which has undergone some sort of transformation."

- Second Law -That in Nature, the energy flow, in the large, is irreversible, and is such as to tend towards a more even distribution. Local reverses of this process may be possible, but they are always bought at the expense of greater losses elsewhere. The concept of entropy gives quantitative expression to the process in question; it is given by  $S = Q/T$ , where Q is the quantity of energy, and T the absolute temperature.
- Third Law -That entropy tends towards a maximum, having as a corollary that the entropy of a system at absolute zero is zero.

Oddly enough, the theory in its classical form was soon to experience a most bizarre augmentation:

".....The French mathematician physicist Henri Poincaré ..... rigorously proved that a finite collection of particles confined in a box and subject to Newton's laws of motion must always return to its initial state (or at least very close thereto) after a suitably long period of time. The state of the gas therefore undergoes 'recurrences'. Poincaré's theorem carries the obvious implication that if the entropy of the gas goes up at some stage, then it eventually has to come down again so the gas can return to its initial state. Whatever set of molecular motions may increase the entropy, or chaos, of the gas, there must be another set which decreases it. In other words, the behaviour of the gas over a long time scale is cyclic. This cyclicity in the state of the gas can be traced to the underlying symmetry of Nature's laws, which do not distinguish past from future."  
Davies (1995, p.38)

In other words, taking the longer view, the entropy of a system tends, not towards a maximum but to a *distribution* of states which is, however, very heavily weighted in favour of higher values. Poincaré's insight, while philosophically fascinating, makes no practical difference, and offers little consolation for those who would wish to enlist the machinations of probability in the creation of arbitrarily high states of order:

"....The length of Poincaré's cycles are truly enormous....in the case of a macroscopic system, the length of the Poincaré cycles dwarfs all other known time scales.....The foregoing argument was siezed upon by...Friedrich Nietzsche, who concluded that cosmic recurrences robbed human life of any ultimate purpose."  
(Ibid. p.38)

Much more recently, a new player has entered upon stage of thermodynamics in the character of the Russian-born Belgian Ilya Prigogine -who was to receive a Nobel Prize in recognition of the importance of his work. What he has sought to demonstrate is that thermodynamics is not wholly destructive, and that with respect to certain classes of systems thermodynamics manifests a bright upper face whereby it can maintain, and create order out of chaos. Further -and it is at this point that things become contraversial- he or his followers have seemingly claimed that *all* of the order which has come to arise in the cosmos -including you and I- is not only consistant with, but stems from the 'new thermodynamics' or the mathematical principles upon which it is grounded.

I take Prigogine to be the founding father and leading inspirator of most of the current endeavours which seek to account for the full gamut of organic and mental order without stepping beyond the bounds of what current physical law, and the mathematics with which it is associated. Kauffman's 'Boolean nets' -to which we shall shortly be turning our attention- is one such development which is currently enjoying a great deal of attention and notoriety.

Prigogine is indeed a formidable adversary, as anyone attempting to penetrate his recondite mathematics will quickly discover; this makes it no easy matter for the non-mathematician to bring what has been accomplished into focus, or question some of the extravagant claims which have been made in the name of non-equilibrium thermodynamics, and of the various 'isms' which have sprung into existence in its wake. There can hardly be any question that his recondite mathematical erudition has cast a spell upon many; surely, they might ask mathematics this obscure must be proving *something* -to say nothing of the coup-de-grace of a Nobel prize. But shorn of their formal trappings, most of the underlying principles are not difficult to grasp.

Prigogine's studies are centered upon the behaviour of open systems which are far removed from equilibrium. No one doubts that living organisms maintain themselves in this state, and that no violence is thereby done to the Second Law of Thermodynamics, since this continues to hold when organism and environment are taken in conjunction. Organisms continually import free energy, feed on 'negentropy' and maintain their status quo indefinitely.

".....The second principle of thermodynamics, in its classical form, applies by definition only to closed systems. In open systems, an expansion of thermodynamics is necessary.....In the generalized entropy function, according to Prigogine, we find therefore, not only a term expressing the production of entropy, due to irreversible processes, but also one for entropy transport, which can be due to the importation of material rich in free entropy into the system. Because the second term may over-compensate the first, the entropy balance in an open system may be negative. As an open system the organism may retain a constant level of negentropy, i.e. of high order and organization, or may even advance towards states of decreasing entropy and increasing order.....In a steady state, the system remains constant over time, although irreversible processes are going on, and remains at a distance from maximum entropy."  
Bertalanffy  
([1972?], p.71)

An open system, let us remind ourselves, is one open not only to a flux of energy, but also to matter, in particular that containing abundant free energy which once imported can be put to productive use. [Green plants and other so-called autotrophic organisms can use radiant energy from the sun as a source of internal energy, requiring the importation of matter solely to provide the raw materials for the creation of living protoplasm]. But all of the more complex forms of living organisms are obligate heterotrophs who must feed constantly upon 'negentropic' matter.

Such complex, open, homeostatic systems remote from equilibrium, then, may be thought of as harbouring three thermodynamic modules. The primary one, the praxial engine, disposes of free energy in the process of fulfilling the 'wishes' of the organism, that is, of doing for it whatever it is that its life is all about. But the machinery of protoplasm, at every level, is both delicate and complex, and the components which are its principle operating agents -the proteins- are endothermic, hence forever at risk of decomposing back into their constituents. And adding to the peril here are the ever-present protolytic enzymes which are only held at bay by a delicate system of checks and balances.

This attrition must be made good, and it is the second engine -the anabolic one- which must busy itself with the never-ending house-keeping chores of repair and maintenance. This engine is unique for the way in which it runs *informationally* uphill. It is able to draw upon structurally simple components and weave them into the ingenious configurations with which protoplasm abounds. The knowledge it needs to do so is not conjured out of thin air, but stolen from plans studiously archived within the magic helices of DNA.

However, as figure 3.2 indicates, we are in need of yet a third thermodynamic module. The negentropy within the ingested food stuffs is tightly locked away, so must be extracted and rendered into usable form: ".....Food would do little for a man whose stomach, intestines, liver or pancreas were removed".[Thaxton 1984 p124] But such digestion and assimilation is the easy part, in comparison with the complicated energy transduction needed to package this energy into the ATP quanta with which to maintain the cool flame of metabolism and the praxes it supports. The Krebs cycle, and the oxidation chain within mitochondria are indeed wonderful to behold. The contrast here, once more, is that between scalar and vector operations. As Thaxton also notes [ibid], even in an automobile, the equivalent problem calls for a lot of mechanism for its solution; pistons, crankshaft, transmission and drive train are needed to couple the explosive source of energy within the cylinder to the drive wheels where it is needed.

Hence, in summary:

".....If anything is clear by now, however, it is that living systems are virtual paradigms of systems that are constrained away from equilibrium and that they pay what they owe to the second law by building internal kinetic pathways that send things in the environment, instead of themselves to thermodynamic equilibrium."

Depew (1995, p.464)

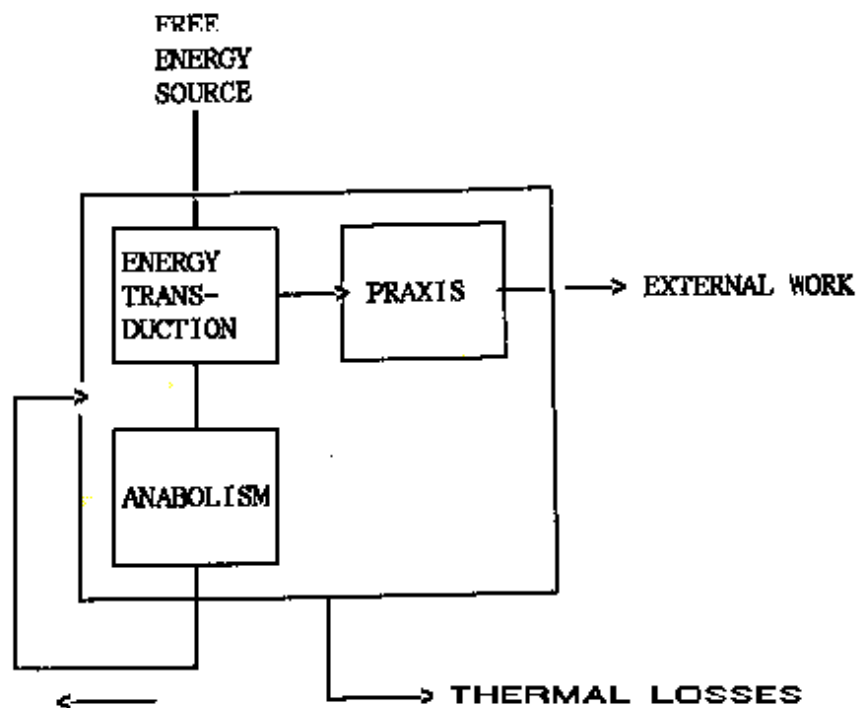


Figure 3.2

Yet,

".....While the maintenance of living systems is easily rationalized in terms of thermodynamics, the origin of such systems is quite another matter."

Thaxton (1984, p.125)

For, there is a overwhelming and seemingly qualitative distinction between *homeostasis* - no matter how subtle and elaborate- and a *progressive self-organization* which ascends to higher

and higher levels of significant order and coherence. The question is: where is the needed information to come from?

For sufficiently simple systems there is no problem. One does not have to search far for instances in which both free energy and shaping principles are copresent, leading to the emergence of significant form. We have only to consider cosmology. Starting from a seeming maximum of entropy at the 'big bang' we see, as the expanding universe cools, the progressive appearance of the fundamental particles of physics, followed by atoms and molecules, galaxies and stars. Most of the 'free energy' comes ultimately from gravitational attraction, and the order which emerges from an interplay of the four forces of nature. Closer to home, we may instance the formation of snow crystals under appropriate meteorological conditions, or the emergence of Henri Bénard's patterns of vortices within water contained within a saucepan heated from below; the needed 'information' comes from the electronic shaping of the water molecule, in the first case, and the equations of non-linear hydrodynamics in the second. Finally, figure 3.3 below illustrates the spontaneous patterns emerging from the dynamic interactions within suitable mixes of inorganic chemicals -e.g., citric acid, sulphuric acid, potassium bromate and an iron salt. Figure 3.3 does no more than hint at the enchantment.

The big question which remains is how the gulf is to be crossed between such simple instances, where the shaping forces can be clearly identified, and the far more challenging problems of the progressive self-organization of life and mind. That the New Thermodynamics is up to the task has never been in doubt to Prigogine and his followers, given that the systems in question be sufficiently complex and distanced from thermodynamic equilibrium.

".....Although the molecular nature of living organisms has been indisputably established for several decades the physico-chemical laws that could 'animate' molecules of inert matter into thriving life were not available till recently."

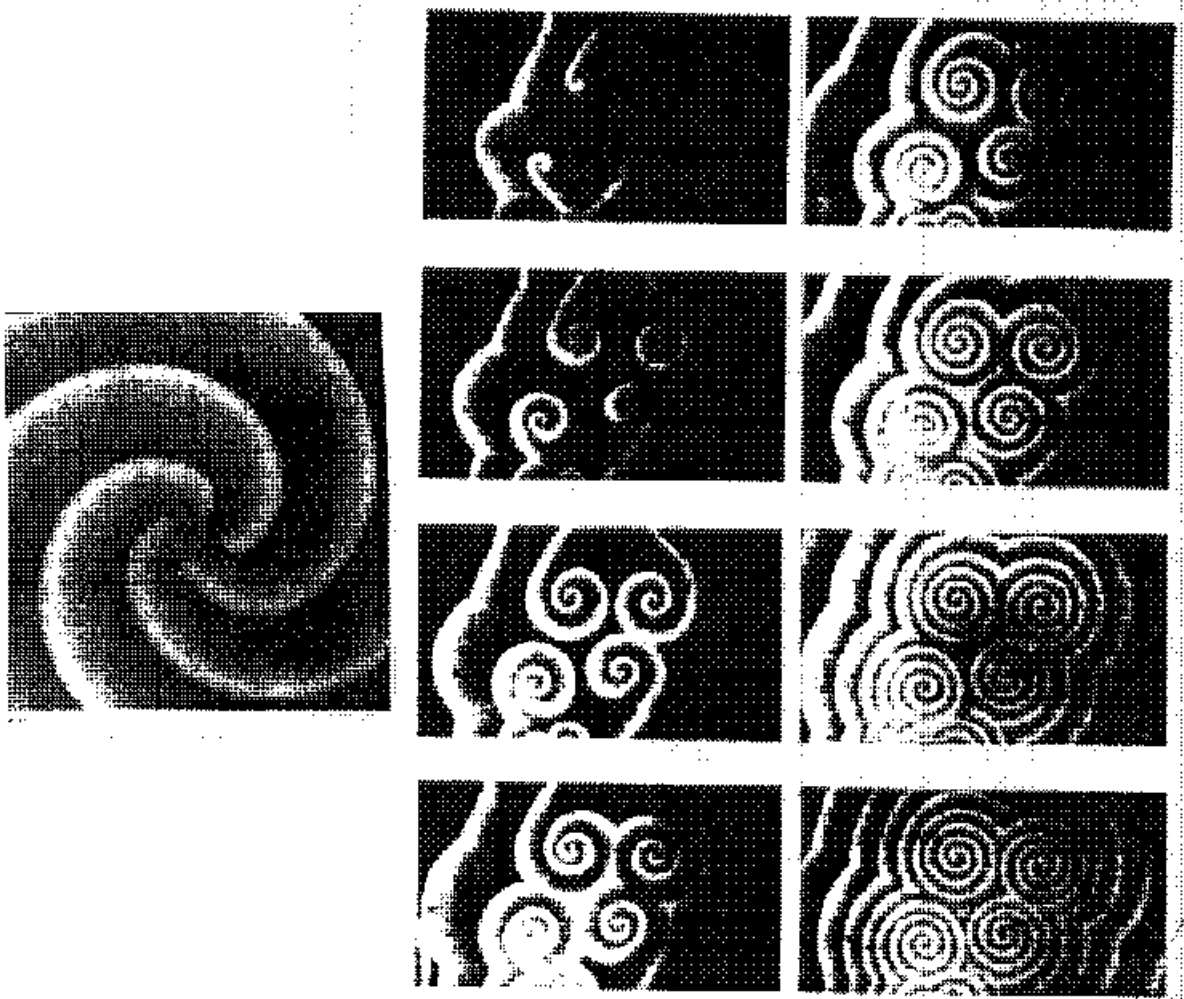
Babloyantz (1986, p.1)

The kind of system architecture which they claim will furnish the needed 'upward mobility' in manifest behaviour may be described in the following formal terms. Their building blocks are nonlinear differential equations which are intercoupled by positive and negative feedbacks (Babloyantz, *ibid.* p.329) . Stuart Kauffman -whom we will get to shortly- grounds his hopes upon Boolean networks which desport the same kind of recursive architecture. Such systems are best described in terms of their phase spaces within which a number of regions of attraction -each with its characteristic drainage basin- may be depicted. Such systems are subject to chance fluctuations, which, in those which are sufficiently unstable, may lead to a switch from one dynamic regime to a totally different one.

"...The words *fluctuation* or *disturbance* have been used throughout this book, meaning a slight change in the conditions of a system. If such processes are endogenous, random and spontaneous, we are dealing with fluctuations. The role of fluctuations is of crucial importance for the onset of self-organization in a homogeneous but unstable system. The analysis of fluctuations in nonlinear systems is an important and fast-growing field. Self organization may arise in some stable systems only if they are perturbed by external fluctuations."

Babloyantz (*Ibid.*)

".....In Prigoginian terms, all systems contain subsystems, which are continually 'fluctuating'. At times, a single fluctuation or a combination of them may become so powerful, as a result of positive feedback, that it shatters the pre-existing organization. At this revolutionary moment, -the authors call it a 'singular moment' or 'bifurcation point'- it is inherently impossible to determine in advance which direction change will take: whether the system will disintegrate into more



fh

Figure 3.3

[Some legend necessary]

'chaos' or leap to a new, more differentiated, higher level of 'order' or organization, which they call a 'dissipative structure' (Such physical or chemical structures are called dissipative because, compared with the simpler structures they replace, they require more energy to sustain them.....*Under certain conditions*, entropy itself becomes the progenitor of order." From Forward by Alvin Toffler (in Prigogine 1984, p.xv).

Summarising up to this point, what is being claimed is that thermodynamics is not wholly destructive, but may, on occasion, lend a helping hand:

".....When a system is constrained far from equilibrium, macroscopic order arises not as a violation of the second law of thermodynamics, but as a consequence of it."  
Depew (1995, p.464)

A very simple example of chaotic instability is given by the 'three body' problem -a system of three planets whose orbits are held together by a sufficiently strong gravitational attraction. It has been known for some time that no closed-form mathematical solution for such a system (as is the case when only two planetary bodies are involved) is possible. The reason is the lack of any means of predicting what may occur sufficiently far in the future -since, for example, energy may get progressively transferred to one of the orbits from the other two, with the ultimate result that its planet is ejected from the system to escape into outer space. Such systems are, nevertheless deterministic; their long term behaviour cannot be obtained numerically by brute-force arithmetic from the initial conditions because there is an upper limit to how precisely these be specified. The greater the resolution of the initial conditions, the longer predictions hold their ground before becoming washed out. Only unobtainable -and unusable- initial conditions of infinite resolution would furnish the needed information. This example demonstrates the emergence of chaotic behaviour without benefit of internal 'fluctuations' which the system is too simple to harbour,

Some of the more interesting systems which have been explored within the New Thermodynamics are those whose patterns of instability may be steered by disturbances arising from the inner or intruding from the outer environment. By such means it was felt, for example, that chaotic behaviour might provide Darwinian natural selection with something more positive to work with than the noise of merely random mutations which is all that has been classically offered:

".....The decisive point is that self-organizing systems continually generate their own internal fluctuations, and test their stability and that it is these internal fluctuations when they become internally reinforced (through autocatalytic and other highly non-linear mechanisms), that drive the system over an instability threshold to a new structure. There is no stability, period; only metastability or delayed evolution. ....Evolution is *self-transcendent* that is to say, always ready to reach out beyond the system's own boundaries, *without any need*, just for the joy of it. Only then can evolution be understood as *creative* and not adaptive".  
Erich Jantsch (Quoted by Hitching [year?], p.163)

Likewise, it has been speculated that the circulating currents within the 'enchanted loom' of the cerebral cortex, behaving as a chaotic system, might provide just the needed dynamic substratum to account for the 'upward mobility' of learning and progressive mental self-organization.

".....The dynamics is chaotic, not merely noisy, so that each act of perception involves a new construction by the cortex and not mere information processing. From these findings we infer that chaotic dynamics plays a crucial role in the formation of associational contexts of the memories of experimental subjects, so that intentionality is characteristic of early stages of cortical function including primary sensory cortexes in lower mammals."  
Freeman (1993, p.507)

".....Where do the neural patterns come from? How are they generated? Our answer is straightforward. A key to understanding brain function lies in the use of nonlinear dynamics to model the perceptual function of the olfactory system. In brief, we believe that the olfactory system maintains a global chaotic attractor.....with multiple wings and side lobes, one for each odor that a subject has

learned to discriminate. Each lobe is formed by a bifurcation during learning, which changes the entire structure of the attractor, including the pre-existing lobes and their modes of access through basins of attraction. During an act of perception the act of sampling a stimulus destabilizes the olfactory bulbar mechanism, drives it from the core of its basal chaotic attractor by a state transition, and constrains it into a lobe that is selected by the stimulus for as long as the stimulus lasts..."  
Freeman (Ibid. p.513)

But shorn of the poetry with which Prigoginians are wont to embroider their speculations, and looked at in the cold light of day, such hopes cannot be sustained for a moment, for the following unforgiving reason. No formal system, in the process of its exercise, can transcend or escape from its formal basis. That they may behave in some very surprising ways is simply beside the point; such are simply manifestations of what might be called Gödelian mathematics; the behaviour which is observed, though not *deducible* (e.g. by mathematical induction) from the formal basis of the system, is nonetheless *consistent* within that system. Indeed, classical dynamics itself is a most striking example of such a discipline, and continues to intrigue us for the odd way in which it seems to float free of the underlying equations of motion of the constituent particles upon which it must ultimately rest.

What one gets out of any such system is totally constrained by what might be called its degrees of freedom, and the way in which they are intercoupled. There is, in fact, a systematic correspondance between what one puts into the system, by way of its constitution, and what one gets out from it.

".....The order produced in prigogine systems *is of the same magnitude as the information implicit in the boundary conditions.*" [my emphasis]

Bradley (1996, p.8)

".....Balanovsky, who has followed Prigogine's work for a number of years, thought that [it failed to meet Popper's test of falsifiability]; (a) the papers were based upon a set of assumptions that were by no means proved, and (b) so many variables had to be built into the mathematics that he didn't see any way they *could* be proved."  
Hitching (1982, [p.?.])

Such assertions are not contradicted by the characteristic divergence between a dynamic system's formal basis and the envelope of behaviour flowing from it; indeed, *much* may be accounted for by *little*. Yet such an envelope is no cornucopia, but is constrained to remain within its formal basis, and there is no way, by its own resources, it can escape from, or break out of this prison.

The fact that evolution or cortical behaviour is *accountable for* or can, in a very general way be *described by* the mathematics of chaos is no proof that the New Thermodynamics is actually *responsible*. To claim that it is so, is to beg the whole question of physicalist reducibility. To seek, therefore, to cloak such systems with the mathematics of chaos is simply to indulge in an elaborate piece of curve-fitting which points to nothing beyond itself. This remains true despite claims made that 'lifelike' manifestations have been forthcoming. The simple candle flame has seemed to embody the very essence of life as testified by its votive presence within Catholic and other churches. It is however, but a metaphor which points nowhere beyond itself. Exactly the same applies to Dawkins (1986) Computer-Generated "Biomorphs", or the objects which emerge from cellular automata or the kinds of simulations being put together at the Santa Fe Institute and elsewhere. One may see a man in the moon, faces in clouds, and almost anything within Rorschach's ink blots.

"....The concept of dissipative structures went in the opposite direction by showing that, under appropriate conditions, inert bulk matter is no longer simple and may show a great variety of complex behaviours reminiscent of living states".

Babloyantz (1986, p.220)

-Indeed, but reminiscent to whom? To draw such inferences is to confuse true similitude with a surface mimesis.

In summary, the issue isn't about the modus operandi of self-sustaining systems remote from equilibrium, whether one is talking about the enchantment of the BZ chemical dynamics or living organisms. The issue at stake is whether complex systems can be brought into existence, based on Prigoginian Principles, which will crackle into life -to exhibit the characteristic of open-ended formal upward mobility. Gödel's discoveries rule out any such possibility. The distinction is finessed away by shameless word-smithing:

".....Prigogine and Stengers also undermine conventional views of thermodynamics by showing that, under non-equilibrium conditions, at least, entropy may produce, rather than degrade, order, organization *-and therefore life.*"

(Introduction in Prigogine 1984, p.xxi)

What Prigogine has actually done is to add a fascinating coda to classical thermodynamics. As such, his work is to be seen as complementing that of Boltzmann and Gibbs. But something much more startling is being claimed, namely that Prigogine has done for Boltzmann what Marx did for Hegel -turned him through 180<sup>o</sup>- thus transforming thermodynamics from an adversary into a resourceful ally. By such means, it is seemingly hoped that bricks may be made without straw.

One is left asking...why? The answer has to do with the unspoken zeitgeist casting a pall over all of our thought. *That* life and mind exhibit trans-Gödelian self-organization and an open-ended upward march in formal coherence can hardly be doubted. But equally *taken to be beyond doubt* is that physicalism and the mathematics with which it is associated *must* be able to do the job; anything else is unthinkable. This being the case, Prigogine offers the only real hope, so *must* be able to cut the mustard, if we but stay with it.

Hardly encouraging is the way in which this movement has become something of a cult. Here's how Hitching viewed the matter many years ago:

".....To an outsider like myself, the symposium had a curiously surreal air, more akin in some ways to missionary fervour.....Moreover the speakers seemed unanimous in believing that Prigogine offered the only alternative to the aridity of orthodox evolutionary thinking.... a strikingly similar attitude to that struck by Creationists".

Hitching (1982, p.163)

But things seem to be much the same today, as judged by John Horgan's [The End of Science Addison-Wesley Publishing Company 1996 ? 5?] recent encounter with Prigogine:

"....At the faculty lounge, Prigogine and I were joined by a dozen or so other researchers employed at his center.....We assembled at a long rectangular table. Prigogine sat at the middle of one side, like Jesus at the last supper, and I sat beside him, like Judas, listening along with everyone else, as he held forth.

"Sporadically, Prigogine called on one of his disciples to say a word or two -enough to draw attention to the vast gap between his rhetorical powers and theirs.

At one point, he asked a tall cadaverish man sitting across from me- to explain his non-linear, probabilistic view of cosmology. The man dutifully unburdened himself, in a lugubrious eastern European accent of an impenetrable monologue about bubbles and instabilities and quantum fluctuations. Prigogine quickly stepped in. The meaning of his colleague's work, he explained, was that there was no stable ground state, no equilibrium condition of space-time; thus there was no beginning to the cosmos, and there could be no end." (Ibid. p.219)

### Stuart Kauffman's 'Complexity First' Scenario.

We come finally to the researches of Stuart Kauffman which seem to have caused quite a stir within the intellectual community. In Kauffman's judgment, life is intrinsically and necessarily complicated. Arriving at a self-replicating molecule is unlikely enough, but if you were lucky enough to succeed, how could you ever walk yourself up from there to the simplest cell, with all of its irreducible histological and biochemical complexity? For that matter, could things ever really get started at all?

".....Grant that such a fine molecule arose. Could it maintain itself against mutational degradation? And could it evolve? The answer to both questions seems to be no. The self-replicating ribozyme would necessarily produce mutant variants. But those mutant variant ribozymes themselves are likely to be less efficient than the normal, or wild type, and hence are likely to make errors more frequently.....over cycles the system could produce a runaway system of mutant variants. If so, the original ribozyme with its ability to faithfully reproduce itself and others, would be lost in a flurry of sloppy catalysis heading to a system of RNA sequences that are catalytically inert. Life would have vanished in a runaway error catastrophe."  
Kauffman (1995, p.41)

Kauffman has long been engaged in the exploration of the fascinating and quite unexpected properties exhibited by large-scale systems organized in accordance with certain rules. His 'Origin of Life' speculations may be taken as a spin-off from his extended 'complexology' studies; in company with an increasing number among the intellectual community, he believes that many of the elusive and baffling problems of life, mind and society are rooted in such formalisms.

In the context of the present problem, what he has proposed is essentially a graphical model -in the 'graph-theoretic' sense of a topological structure consisting of nodes interconnected by arcs. The nodes correspond to chemical compounds and the arcs to possible transformations between them. The chemicals may be merely substrates but at least some of these are required to be catalytically-active with respect to one or more of the transformational processes within the network. Typically they will be enzyme -or enzyme-like polymers -although a few may owe their activity to templating processes.

Central to his scheme of things is the way in which the success of such an ensemble is highly levered upon the *size* of the network, that is, upon the total number of polymers (or other putative catalysts and substrates) which are present. For example, as this number  $n$  goes up, the number of possible synthetic and transformational pathways between them goes up by the square (if we include the possibility of autocatalysis). Again, as the size of the polymers (in terms of the number of monomers they contain) goes up, so does the number of synthesis routes by which they may be put together; the size dependency here is even more highly levered. Perhaps the easiest visualization here would be the synthesis of proteins from a small set of amino acid monomers.

The argument then proceeds as follows. Let's assume that a given polymer has a probability of only  $10^{-6}$  of catalyzing any one such reaction or transformation. Then, in a system large enough to offer a million potential transformational pathways, the system as-a-whole-, Kauffman argues, should become self-sustaining:

".....At that diversity, on average such polymer will catalyze one reaction. A million to one multiplied by a million equals one. When the ratio of catalyzed reactions to chemicals is 1.0, then with extremely high probability.....a web of catalyzed reactions will form -a collectively autocatalytic set of molecules."

Kauffman (Ibid. p.63/4)

Or, more generally,

".....When the number of catalyzed reactions is about equal to the number of chemical dots [compounds located at the nodes of the graph], a giant catalyzed reaction web forms, and a collectively autocatalytic system snaps into existence. A living metabolism crystallizes. Life emerges as a phase transition." (Ibid. p.62)

Clearly, size and complexity is of the essence, so that we need to have this present from the start; scaled-down systems aren't going to do much for you:

".....In this view of the origin of life, a critical diversity of molecules must be reached for the system to catch fire, for catalytic closure to be attained. A simple system with 10 polymers in it and a chance of catalysis of one in a million is just a set of dead molecules. Nothing happens in the inert soup save for very slow spontaneous chemical reactions." (Ibid. p.64)

So, how large must the system actually be, if life is to issue forth? After dismissing viruses as not being truly alive because incapable of independent existence, Kauffman notes that in Pleuronoma, the simplest organism known to be capable of independent existence, having the 'full complement of standard gear' -including nucleic acid, protein-synthesizing machinery, a cell membrane and so on- calls upon a number of genes variously estimated to lie between a few hundred to a thousand.

Under the heading of 'An Unrepentant Holism' Kauffman concludes in a way calculated to reassure the reader that no ghost-in-the-machine or vitalism is being proposed:

".....This theory of life's origins is rooted in an unrepentant holism, born not of mysticism, but of mathematical necessity.....Life emerged whole, not piecemeal, and has remained so."

".....Autocatalytic sets exhibit the emergent property of holism. If life began with collectively autocatalytic sets, they deserve awed respect, for the flowering of the biosphere rests on the creative power they unleashed on the globe -awed respect and wonder, but not mysticism." (Ibid.p.69)

".....What I aim to show is simple but radical. I hold that life, at its root does not depend upon the miracle of Watson-Crick base-pairing or any other specific template-replicating machinery. Life at its root lies in the property of catalytic closure among a collection of molecular species. Alone, each molecular species is dead. Jointly, once catalytic closure among them is achieved, the collective system of molecules is alive." Kauffman (1995, p.50)

".....How different is humanity's stance, if it proves that true that life crystallizes out almost inevitably in sufficiently complex mixtures of molecules, that life may be an expectant emergent property of matter and energy.....But we have only begun to tell the story of emergent order. For spontaneous order, I hope to show you, has been as potent as natural selection in creating the world."

Kauffman (1995, p.71)

So, finally, "If I am right, the motto for life is not We the improbable, but We the expected." (Ibid.p.43)

Kauffman has sought to flesh-out his computer simulations by an appeal to some possible 'wet' concomitants in the real world of chemistry, partly no doubt to parry suspicions that what he is doing is closer to computer hacking than to honest-to-God science. To this end he has proposed that confining the 'reaction chamber' to a surface would speed things up by increasing encounter rates between reagents, that dehydration, if it can be brought to bare could coax reversible reactions into following the synthetic path rather than that of decomposition, and, finally, that energetic polyphosphate molecules could take a leading hand in the game. Energy could indeed ultimately come from the sun, and chemical pathways would need to be established to serve this up to the process of synthesis in a suitable chemical form. Then, "All [sic!] that is required, after all, is that the autocatalytic set include catalysts that link exergonic to endergonic ones, so that one powers the other". (Ibid.p.68)

But things don't quite end there. Kauffman has made an emprico-mathematical study of networks in which the elements (molecules, genes, or whatever) interact through boolean functions<sup>4</sup>, in particular noting how small adjustments in the nature of this function may bring the system to the "edge of chaos":

".....The reason complex systems exist in the ordered regime near the edge of chaos is because evolution takes them there." (Ibid. p.90)

As has been the case with Prigogine, Kauffman seeks to conjure upward mobility out of a combination of the quirky, unpredictable behaviour of complex recursive systems and the pruning discipline of natural selection

What are we to make of Kauffman's scenario? For a start, his proposal displays most of the fatal weakness shared by all the rest -I will not weary the reader with their repetition. But setting aside all of these difficulties, *is* his scenario less demanding than the standard 'self-replicating-RNA-Polymer-first' one? It may well be true that once you have a certain degree of complexity in existence, the path to further evolution would be smoothed. But any such advantage is massively counter-balanced, by the much greater difficulty of bringing this 'minimum' into existence in the first place -in comparison with that of producing a single self-replicating polymer. Recall for a moment how huge that minimum is. He's talking about at least hundreds of compounds. All of these need to have been brought into existence within an environment which continues to supply all of the starting ingredients in adequate concentrations. I leave the reader to make his own judgments.

But more serious than any of this is the scalar logistics under which his proposed scheme must labour, whereas in fact nothing less than a highly organized vector architecture would have any hope of delivering the goods; individual reactants would need to be linked together by something more substantial than words. What Kauffman is offering is a soggy bag of chemicals, whereas what the system cries out for is a highly organized network of channels between components to bring scalar chaos into vectorial life. This applies both to the basic reactions themselves and to the sources of packaged energy needed to drive endergonic polymerizations up

the energy gradient. We are not told how this mammoth logistics demand is to somehow be met by the meagre resources which he has to offer.

Kauffman has made some fascinating discoveries in what might be called Gödelian mathematics -the interested reader should consult note 5 for one such example- but I fail to see that they have anything to tell us about most of the perplexing problems we have been discussing.

### Wrap-up

Let me start by summarizing my justification that the odds-on favourite -the 'self-replicating RNA (or similar) polymer first' theory- is just about as disconfirmed as it is possible

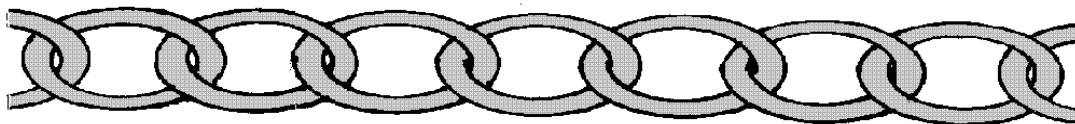


Figure 3.4  
Balanced Chain

for a hypothesis to be. A chain is only as strong as its weakest link. To account for the putative miracle of life's origin, seven links each of sufficient strength must be firmly in place -as indicated in figure 3.4.

Be there a single weak link anywhere, and the chain will not hold. In particular, a weakness in any one link is not to be compensated for by any excess of strength in links elsewhere -as illustrated in figure 3.5.

What kind of a chain do we actually have? Figure 3.6 attempts to portray the conclusions reached in this chapter in catenary terms. Let's look at each link in turn.

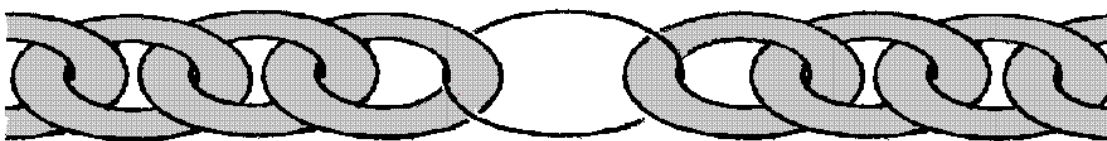
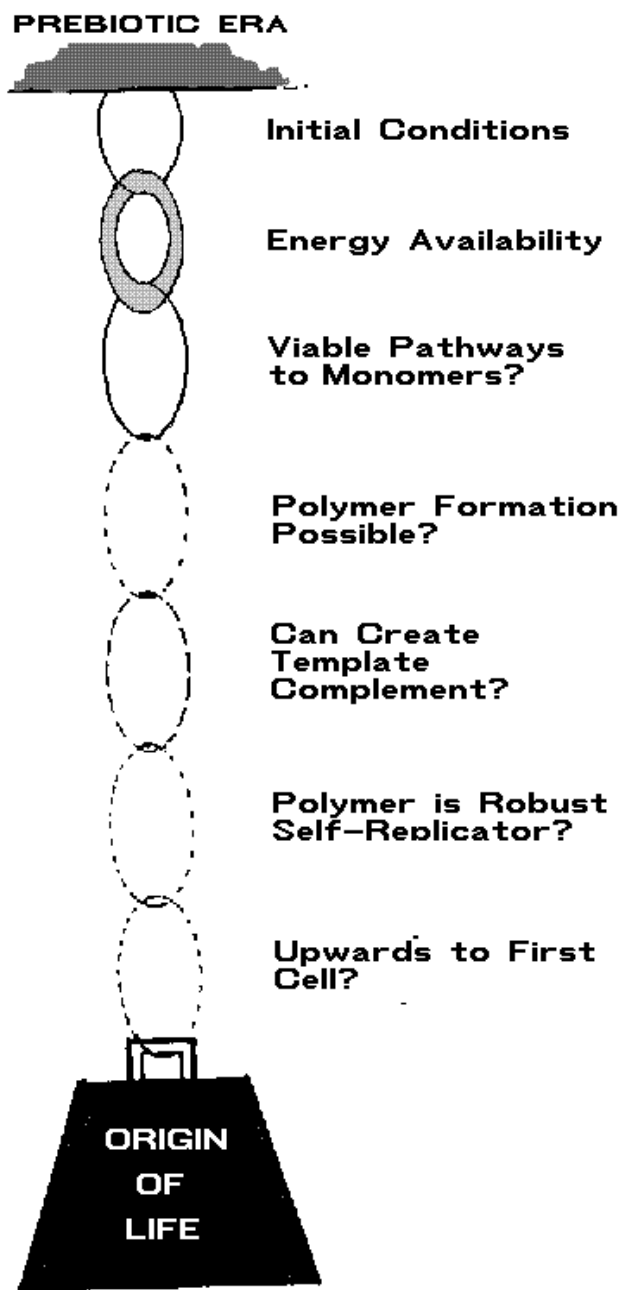


Figure 3.5  
Unbalanced Chain

The first link is certainly weak; some -including Stanley Miller- still hold out hope that the initial conditions may have been sufficiently reducing, but little support is forth-coming from geologists.

The second link is secure enough; energy was available almost everywhere on the surface -from sunlight- and from deep-sea hydrothermal vents. To affirm its presence is not, however, to imply it is accessible for the purposes at hand.

For the 'pathways availability' link to hold, all of the needed pathways must have been demonstrated to exist. As we have seen, there are some gaps here (including that very special channel which delivers the available free energy to the points where it is needed), so that this link lacks the necessary strength.



The remaining links -which stand for the credibility that each of four successive processes -leading to the first cell- are weak to the point of non-existence. A robust link 4 demands that the 'soup' molecules from which the transformations needed to bring forth nucleotides are present in sufficient and maintainable concentrations, and in a reasonable state of purity. It is hardly credible that this could be the case. It is also about as improbable, given the 'racemic' character of 'soup' chemistry, that any nucleotides which might have been brought forth would be of a single enantiomorph. This hopelessly undermines the patency of the links which follow. Links 4, 5 and 7 cannot hold in the absence of the kind of 'staging management' which scalar 'soup' chemistry is in dire need of, but which is conspicuously absent. The stages of links 5 and 7 and perhaps also 6 additionally call for processes which must run counter to the second law of thermodynamics, hence these links are doubly afflicted. Given that the monomers are taken to be energy-primed (thanks to the polyphosphate tag), polymerization without enzymes is not quite so forbidding a problem as would be the synthesis of proteins. What of link 6? In view of the fact that no one has demonstrated that a self-reproducing polymer (in the absence of enzymes) could exist *at all* under anything the conditions contemplated, let alone that any polymer put together by chance could possess this property, this link thins into quasi-nonexistence.

Figure 3.6  
Actual Chain of Evidence

And finally, the integrity of the chain as a whole is fatally compromised by the lack of any sense of direction guiding the life-origin process as a whole.

Whatever benefits either natural selection or 'complexology' might confer are simply not available.

The above analysis is made with respect to the scenario favourite, but much the same applies to the various alternatives which have offered. All are afflicted with the four fatal

weaknesses: they all call for an up-hill coherence movement running counter to the depredations of thermodynamics; they are saddled with scalar -and at least to some extent racemic- chemistry; and finally there is no staging management or macro-guidance of any kind. The relative strengths of the links shifts a bit, but there is no material difference. To reiterate, a chain is no stronger than its weakest link. But what is one to say when 6 of the seven are weak to the point of non-existence? We don't even have a paper chain but simply a catenation mostly of phantoms floating within the mental space of the faithful. It would be an understatement to say that the intellectual has chosen to take his stand beneath the sword of Damocles. For there is not even the slenderest of silken threads present to provide the needed support.

What we would seem to be confronted with here is a spectacular instance of epistemological overkill. Again, one searches in vain for any current theory generally accepted by the scientific community which stands on such shake ground. The Principle of Perpetual Motion sounds reasonable and promising and the flat-earth advocates appear as champions of rationality by comparison<sup>5</sup>.

Despite the many difficulties which he makes no attempt to conceal, Orgel concludes his Scientific American article (1994) on an up-beat note. To be sure, we have a long way to go before we can bring the whole process into adequate focus, but we are off to a good start, and it's only a matter of time. However, to this reader, the article could hardly have been more eloquently put together if its express intent had been to disclose the utter bankruptcy of the whole business. I am somewhat disarmed, and indeed humbled, by the way in which the courage to proceed is maintained and spirits kept up under such depressing circumstances. As paragraph succeeds paragraph, it is as though nail after nail were being driven home into the coffin of a stillborn child.

The intellectual has been skillful in his resort to camouflage in concealing the awful truth from himself. This takes a great many forms; the smoke-screen is multicoloured. For a start, he points to the wealth of ideas out there which are under active exploration.

".....'I'm excited', says James P. Ferris, a chemist at Rensselaer Polytechnic Institute.....'we have all sorts of new ingredients in the pot'. Sooner or later, Ferris suggests, a convincing explanation of genesis is bound to come crawling out."  
Horgan (1991, p.118)

Perhaps one of the implications here is that straws in the wind may be able to do the job provided only that one has enough of them. But I fear there is no way that these can be woven into the robust sail-cloth needed to propel the theory onto the high seas. At the same time, discussing the relative merits of the many ideas being touted has the fringe-benefit of drawing attention away from the many fatal weaknesses *common to all*. Much recourse is being made to computer simulation (for example within an institute located less than a million miles from Santa Fe); unfortunately many of those so engaged seem to have lost sight of the harsh realities of a chemistry which must be both racemic and scalar. The organic chemistry lab bears little resemblance to the interior of the computer; its wetness and messiness slip through the cracks in the simulation code. Ignoring the distinction invites the decay of a potentially useful discipline into computer hacking -and there seems to be plenty of this around.

The act of replication has come to be invested with a kind of magic. The implication is that once something surfaces which succeeds in *an* act of self-replication, a kind of phase change occurs which immunizes the polymer or system against the depredations of the hoary second principle of thermodynamics. The Rubicon has been crossed; from thereon out mutations and modifications may be either helpful or deleterious, but thanks to the divergence and efficiency of the reproductive process, we are safely on our way; progress is taken to be inevitable; the only question is -how fast?

".....Once an autocatalytic process was set in motion over 3.5 billion years ago, there was very little that could stop life from expanding, diversifying, and filling every conceivable niche on the surface of this planet....."

Encyclopedia of Microbiology (1992, [page ?])

This investment of self-replication with 'emergent' vitality is but one example of the covert importation of principles which are so urgently needed if the program of neoDarwinism is to be sustained, yet which nowhere reside within the reductionist metaphysic upon which it, and the biology over which it presides, are grounded. In defiance to its loudly proclaimed anathematization, something close to vitalism seems to have quietly gained admittance by the back door.

One finds everywhere a S-T-R-E-T-C-H-I-N-G of discoveries of every kind, a hopeful exaggeration or extrapolation from meagre findings to a promised success. Findings of almost homeopathic epistemic density are urged as 'promising' -if we but persevere along the same lines, and those only slightly less far-fetched as 'even more promising'. One has learned to be very wary concerning reports of the occurrence or creation of key metabolites -all too often, details about the actual, often miniscule concentrations- get left out. Findings are presented in terms of upper limits: '....as much as....' with the added assurance that this is only the beginning; we have but scratched the surface of a new and promising technique. This is invariably the case by time the news media pass on the information to the general public.

".....Cyril Ponamperuma detected the five bases used in DNA and RNA in both the Miller-Urey type of mixture, and a meteorite. The compounds occurred to an extent of perhaps 2ppm, yet Ponamperuma in a news conference called it 'almost an awesome result'. The awe must lie in the eye of the beholder. Nothing within the result compels it."  
Shapiro (1986, p.108)

Of course, life *did* somehow bootstrap itself into existence, but this does not at all prove that the gamut of inorganic physical laws was up to the job. Life's origin may seem to call for something close to a miracle, but after all, the intellectual might say, isn't much of in vivo chemistry quasi-magical. Thus consider the astonishing machinery of the oxidation chain within mitochondria, or the almost error-free replication of great lengths of DNA. What this line of argument overlooks is that it is very far from being proved that living metabolism can be reductionistically maintained at all, let alone brought into existence by such slender resources. But the intellectual is adamant in his conservatism; the answer must be out there somewhere, perhaps staring us in the face:

".....'We just haven't learned the right tricks yet.....when we find the answer, it will probably be so damned simple that we'll all say 'why didn't I think of that before?'"  
(Ibid, quoting Stanley Miller) [page ? ]

There are fascinating similarities between the ways in which the reductionist regards the Mind/Brain and the Origin of Life problems. In both cases, his metaphysic demands that he view things 'from the outside' because that's all there is. It is true that he has recently come to accord mind and consciousness a grudging presence, but only upon terms which do not disturb the autonomy of cerebral functioning. But in regarding life as a whole, the possibility is never granted that consciousness in some form might be an essential attribute of all organisms, rather than something which comes into existence as a *deus ex machina* when some organizational plateau is reached (e.g. when brains make their appearance). The acknowledgement of such a possibility is, I believe a necessary first step in coming to terms with the mystery of life's origin.

But the resemblance bites deeper. Within mainstream belief there are many who support the doctrine of 'strong AI' which asserts that any contraption which delivers the same performance

as the brain would be *automatically* conscious. What this amounts to saying is that consciousness depends only upon *form* and not at all upon the *substratum* underwriting the phenomena. So, if a computer could deliver the brain's performance, then it would be conscious, despite its running on silicon rather than protoplasm. This claim takes on surrealistic proportions when it be considered that it is possible, in principle, to assemble an equivalent computer from wires and pulleys and to implement some of its elementary functions in terms of pneumatics and hydraulics, and to distribute its components over the globe, interconnected by high bandwidth optical fibres.

So also with respect to life and its origins. For a start, here's what Chris Langton has to say:

".....Our belief is that we can put sufficiently complex universes into computers so that they can support processes which, with respect to that universe, must be considered alive. But they wouldn't be made out of the same stuff....It raises the awesome possibility that we are going to be creating the next living things in the universe."  
Davies (1992, p.115)

-To which we may add these comments of Poundstone's (1985):

".....If nontrivial self-reproduction is used as a criterion of life then self-reproducing Life patterns would be alive.....they would be *literally* alive by virtue of encoding and manipulating information about their own makeup. The simplest self-reproducing systems would be alive in a sense that the virus is not."  
Davies (Ibid. p.226) [My emphasis]

Davies (1992, p.115) goes on to report that ".....John Conway even goes so far as to suggest that advanced Life forms could be conscious." (the 'Life' here referred to is Conway's extensions to Von Neumann's concept of the 'cellular automaton'.) Davies (1992, p.111 et seq)

Here and there, despairing voices are to be heard, but most of the skeptics would rather contemplate an importation of life from elsewhere in the cosmos than consider that perhaps the time has come to reexamine the natural law upon which it is grounded. Francis Crick (1981) was moved to write an entire brief volume on the subject -and who more qualified than the co-discoverer of the DNA spiral? Crick is almost unique in the intellectual honesty with which he approaches the enigma of the Origin of Life. He has refused to allow his capture by the Regulation Metaphysic to blind him to the endless problems and improbabilities involved. At the end of the volume, he presents an updated version of the 'Theory of Panspermia' (proposed originally by the Swedish physicist Arrhenius during the last century). Arrhenius had postulated that life on earth was of extraterrestrial origin, having arrived here in the form of bacterial spores propelled by the pressure of light falling upon them. His theory was to fall into disfavour -if only because of the improbability that viable spores could survive the long journey. Crick's alternative version was one of 'Directed Panspermia' in which he contemplates that rocket delivery would have a better chance of success. Crick's train of thought was partly channeled by the perceived need for a reducing atmosphere at the beginning -which was probably absent in the case of planet Earth. Such need not at all be the case for all otherwise suitable planets elsewhere in the cosmos. However, this would remove only one of the many hurdles blocking the road up; also, for his scenario to hold, life elsewhere would not only have had to have gotten a foothold, but would have had to have brought forth intelligent at a level at least equal to our own.

Hoyle (1991) has also leant weight to the concept of Panspermia -though in contrast to Crick, he has something more on his mind than the Regulation Zeitgeist.

Let me close with a few words about the direction in which I believe we ought to be moving, in coming to terms with this ultimate challenge. I am not alone in calling for exotic

extensions to physics, nor in suspecting that such will involve a new field analogous, say, to the electromagnetic, which can become manifest wherever matter is appropriately organized -as it obviously is in protoplasm. However, it is unlikely that emergence is so dependent; other substrates might serve, and certainly something efficacious must have been there in the inorganic realm very early in life's origin -indeed from just about the very beginning. I feel very much at one with Kauffman in his intuition of holism, except that in his adherence to physicalism he was attempting to make bricks without straw. In my view, life didn't snap into existence through something like a phase change, but rather came progressively into focus. Again, I share Oparin's intuition that life had a colloidal origin -but not under his rules. In particular, I think that the earliest chemistry was 'soft' -that it was of hydrogen bond and ligase-type rather than covalent because of the precision needed to execute most of the transformations where these are other than those which can occur spontaneously. I do not feel the same urgency in the drive towards replication and reproduction, because I do not look to 'natural selection' to provide needed guidance -which I take, rather, to be of internal origin. I suspect, instead, that quite a bit of organization preceded such an invention; what I am proposing, instead, is perhaps a soft metabolism with an ontogenetic aim initially.

Nor do I look to the proposed exotic fields to be enlisted in support of any such ribozyme-first theory, to add a needed quickening ingredient. My intuitions have an opposite sense of direction; I think that the necessary organization was 'top-down' rather than 'bottom-up' from the very beginning.

Such fields may be expected to make two kinds of contribution. First, because of their substrate-wide distribution, they are enabled to act upon the emerging organism as-a-whole, thus liberating the process of organization from an exclusive dependence upon contact forces and events. I find it hard to watch an active amoeba at work without being overwhelmed by a sense of such a presence -it fairly shouts at one.

And secondly, I take them to be the source of the organization itself. No less an assumption can possibly account for either the origin of life or its continuing progress.

I believe that the kinds of fields I have in mind are reasonably compliant with regard to metaphysical and ontological presuppositions -provided only, of course, that one be prepared to give up physicalism. The drift of one's thought here will no doubt be guided by one's wider framework of beliefs, that is to say will more 'philosophically' than empirically directed.

Those of theistic persuasion will look to a guiding orthogenesis -and be prepared to sustain this belief in face of the fact that the kind of teleology with which evolution seems to be imbued is not quite what one might expect from the surpassing intelligence and foresight of a supreme deity. But the secular panmonadologist must find himself in a much more uncomfortable position. The mind which he takes to have been present from the start must somehow have been rendering double duty; it had to be acting in both a somatic and a germinal capacity -a situation which was to continue virtually up to the emergence of eukaryotes a couple of billion years later. The panmonadologist, then, finds himself confronted by the disturbing inference that the presumably extremely primitive mind present at the start was somehow to come into possession of an implicit knowledge of biochemistry which challenges that which it has taken so many of our first-class brains a century or more to acquire. Yet the neoDarwinian is in even worse shape in that he is required to believe that primitive life must somehow have acquired this same knowledge in the *complete absence* of mind. And a mastery of biochemistry was but the beginning; our grasp of aerodynamics and hydrodynamics still falters behind that manifest by nature in the design of the insect wing, or in the unbelievably efficient impedance-matching of dolphins to their aqueous environment.

In speaking of his critical analysis of origin of life scenarios, Thaxton (1984, p.185) notes: ".....the sharp edge of this critique is not what we do *not* know, but what we *do* know. Many facts have come to light in the past three decades of experimental enquiry into life's beginnings. With each passing year, the criticism has gotten stronger. The advance of science itself is what is challenging the notion that life arose on earth by spontaneous (in a thermodynamic sense) "chemical reactions".

In other words, time is hardly on their side. Interestingly enough, I independently came to a precisely equivalent conclusion concerning physicalist theories seeking to account for the whole of human behaviour in terms of the brain in general, and the cerebral cortex in particular, acting as some kind of network. [Harrison 1997]

All of the enigmas of evolution are brought into the sharpest and most poignant focus at life's origin; speaking for myself, I have found it hard to confront them without flinching. I do not believe that any of the philosophical frameworks which have so far received currency are up to the job, and that nothing less than an across-the-board novel philosophical reconstruction is called for. The mainstream intellectual will compulsively dismiss this as back-sliding into the vitalist heresy, but in so doing he is but disclosing his own limitations; to him *anything* which seeks to break out of the case-hardened mould of physicalism 'counts' as vitalism. Something particularly driving me to enter upon such speculations is that where all 'bottom up' schema are concerned (in which a self-replicating molecule is taken to be the first vital step), it is far from clear that *any* such molecule exists *at all* -i.e. is there to be discovered by nature's random blundering. Perhaps we need to consider an entirely novel scenario of colloidal, rather than covalent sort in which evolving colloidal masses rely principally upon 'soft' bonding of hydrogen, ionic and van de waals sort, with some covalent consolidation in some such form as sulphydryl links. The kind of colloid chemistry which I am proposing (and which is described in some detail in a later chapter) is taken to be driven by field forces associated with exotic states of matter which can only arise in the presence of critical masses of molecules bearing aromatic moieties plus freely available Pi electrons.

## FOOTNOTES

<sup>1</sup>The following is from Arne Fredga's presentation speech at Woodward's Nobel award ceremony:

".....It is sometimes said that organic synthesis is at the same time an exact science and a fine art. Here nature is the uncontested master, but I dare say that....Dr Woodward is a close second." Wasson (1987)

<sup>2</sup>He refers to Morowitz's study of minimum cell requirements -see Godfrey (1985).

Here's how two renowned enzyme experts view the same situation:

".....Let us now suppose that in some way proteins did come into existence; even if they had enzymatic properties there is no reason why their activities should be related, and it is highly improbable that they would form a continuous chain such as we have seen is necessary for the trapping of energy and its utilization for the biosynthetic reactions which constitute life. Yet the occurrence of a single gap would prevent the development of the system. It is possible of course that a chain may grow out of a successive induction process, but this presupposes a 'going concern' with a whole complex system for the inductive synthesis already operative."

"The inherent instability of the vital mechanism is also a difficulty, since it requires a continuous supply of available energy to maintain it. Until a complete functional system is produced, capable of producing the energy of its own maintenance, it might have a strong tendency to disintegrate, as do living cells as we now know them when the energy supply is cut off."

"A further difficulty is that of holding the components of the system together until a cell membrane is formed, assuming life to have begun in the ocean. Unless the ocean contained throughout a fairly high concentration of the components (thus being itself one gigantic living cell!), the components would rapidly disperse, as happens when a cell membrane is ruptured. The system would then perish by 'lethal dilution', But the formation of a cell membrane implies a system which already has a high degree of organization."

<sup>3</sup>So-called 'Directed Molecular Evolution' is of related interest. Back in the 1960s Sol Spiegelman had been studying the bacteriophage Qbeta whose genetic material is an RNA strand containing only four genes, one of which codes for the RNA replicase essential for the proliferation of the virus. If the phage RNA is mixed with its replicase protein in a solution containing nucleotide monomers, fresh copies of the RNA strand are made. But because this replicase enzyme is a rather sloppy performer it makes copying errors from time to time, thus introducing 'mutations'. Such a situation offers the possibility that ongoing replication might be subjected to a lab-controlled Darwinian selection with respect to some attribute. As a simple test of the notion, Spiegelman allowed replication to proceed for a long enough period of time for substantial amplification of the original RNA strand -including mutant copies- to have occurred. He then transferred a small sample to a fresh supply of enzyme and the four nucleotide molecules and repeated the process. Obviously, a sequence of such repetitions will automatically favour mutants which can be more rapidly copied. He discovered that after the 74th cycle, speed of replication had increased 15-fold -though admittedly at the expense of dumping 83% of the initial

strand. Joyce (1992) feels that some version of such 'directed molecular evolution' might be enlisted in the search for that magical self-reproducing molecule with which life is supposed to have started. He ends his article: "...It would be ironic if directed molecular evolution, which began as an attempt to imitate life, turned out to be a way of reinventing it."

<sup>4</sup>Kauffman describes a complex graph of N nodes (each of which can exist in one of two states) each of which is connected to k others. At each successive instant, the new state to be taken by each node is determined by a specified Boolean function. Examples of three such functions -in terms of their truth tables- are given below Kauffman 1995 p84

With reference to these tables, Kauffman derives a parameter P describing the constraint imposed by the boolean function. It is at a minimum where the truth table yields 50% zeros and 50% ones -as in the first table in the figure- and is at a maximum for both of the remaining tables (the first corresponding to Logical-And and the second to Logical-Or).

It follows directly from the principles of combinatorics, that the number of possible states of such a network is  $2^N$  - which clear becomes huge as N becomes large. Kauffman found that for large N with P = 0.5:

- When k = 1, Nothing happens (hardly surprising!)
- When k = N (i.e., the graph is totally connected), the system settles into one of a number of cycles each of which encompasses a sequence of states equal to  $\sqrt{\text{(total of States)}}$ . For an N of 200, each such cycle would be approximately  $10^{30}$  -huge, but still small compared to the grand total of  $2^{200}$  states.
- But if k = 2, the length of the cycles shrinks most dramatically to  $\sqrt{N}$  !! In other words, if N = 100,000, then the system will settle down to a cycle (which cycle depending upon the initial state of the system) of a mere  $\sqrt{100,000} = 317$  states (out of a total of  $2^{100,000} = 1/10^{29,998}$  of the total number of states).

| A | B | C | D | E |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 1 | 0 | 1 | 0 | 0 |
| 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 0 |
| 1 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 |

a

| A | B | C | D | E |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 1 | 0 | 1 | 0 | 0 |
| 1 | 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 0 | 0 |
| 1 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 |

b

| A | B | C | D | E |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 | 1 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 1 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 |

c

With reference to the latter, he says "I hope this blows your socks off. It does mine". Yes it does, Dr Kauffman, but I fail to see that it has anything to do with the origin of life.

He goes on to elaborate on this idea, showing that for values of K > 2, the value of P may be fine-tuned to the point where the system is neither rigid nor random, but hovers at the significant interface between the two -at the 'edge of chaos'.

<sup>5</sup>This leads me to propose a second epistemological principle. If it is true that no theory can be weaker than one which may be definitively despatched in several distinct ways, then there

are none stronger than those which are securely and completely upheld by each of a variety of avenues of enquiry, lines of argument and empirical confirmation.

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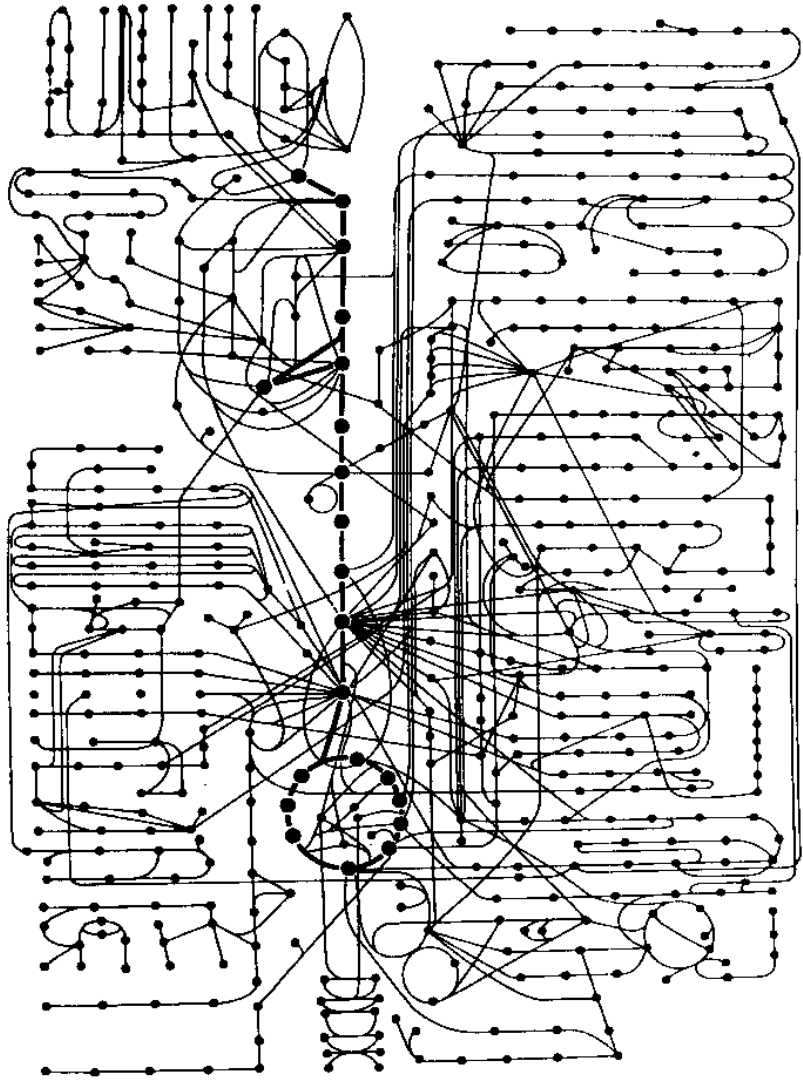
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".....The work of Prigogine has indicated that a highly constrained system can produce an order analogous to that found in crystals, but that is a far cry from the information intensive macromolecules characteristic of living systems. Furthermore, the order produced in prigogine systems *is of the same magnitude as the information implicit in the boundary conditions.*" [my emphasis] Bradley 1996 p8

+.....[Kauffman's] theory of autocatalysis is potentially a convincing explanation of how life began, lacking *only* [sic!] a detailed analysis of chemical kinetics".  
S/A May 1996 review of Kauffman's book by Seth Lloyd p107

[-----The Chapter ends here. What follows are some odds & ends which might be needed elsewhere-----]

[----the following is from the original 'to first cell' material-----]

"....It is believed that RNA must have been very close to the origin of life because it is chemically more active than DNA and can uniquely act as both self-reproducer and catalyst. But RNA is difficult to make and could not have come into existence by a chance combination: unless there is a guidance mechanism ,it does not reproduce itself accurately...There had to be a set of protein structures to permit nucleic acid to replicate, yet nucleic acid was necessary to make needed proteins. A membrane was needed to contain interacting proteins and nucleic acid, but proteins and nucleic acid were needed to make the membrane. Moreover, it had to be semi-permeable from the outset to admit useful materials and permit waste to diffuse out." (Wesson 1991 p55)

-And from such nucleic acid, the whole of the rest of evolution had to emerge. Pierré Grasse comments:

".....To attribute such power to a single substance, however complicated and exceptional its molecular structure may be, is in my view aberrant".  
page # ?

We had to wait another half billion years for multicellular [eukaryote] forms -with the vastly increased morphogenic and behavioural complexities which such makes possible, and, as Wesson has pointed out, the step-up seems to demand a stratagem which runs counter to the principle of the natural selection of the individual:

".....Some offspring of a mother cell have to surrender their capacity for reproduction in order to help a few sister cells make more reproductive cells in the long run. That is, the organism has to remodel its genome in such a fashion that most of its descendants are programmed to reproduce only for a limited number of generations. Cells, moreover, must turn off parts of the genome and activate other parts in order to make specialized tissues and organs." (Wesson 1991 p48)

-In passing, one cannot but speculate whether the emergence of cancer is evidence of the incompleteness of this unnatural suppression of individuality. If so, then obviously the rebellion is a deep-seated one which has become very highly organized; metastasizing cancer cells have a good implicit knowledge of how the host soma (for so it has become) is put together, and how its resources may be plundered and its counter-offensive