

# 10 The Origins of Life and Mechanisms of Evolution

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Julian Huxley (1964) defined life in the following way: 'Life is not a thing, it is not a separate entity, it is the word used to describe the properties of living substance as observed in plants and animals.' This definition does not satisfy us, it states what we all know, it says nothing new, it does not explain life the phenomenon to us in terms of other, simpler phenomena which we comprehend, nor does it relate life in a quantifiable way to other phenomena such as gravity, time or energy. Why can't Huxley, who is truly one of this century's greatest scientific thinkers, do better than that?

The reason for Huxley's failure is that neither he nor anyone else knows what life is, beyond the expression that it is the unifying property of living things. We do not recognize any component parts, we have no words to describe it, we cannot measure it, we do not know how it began, we do not know how it ends. Yet, we are very much aware that the earth is a unique body in the universe, or, at least a very rare one, being surrounded by a shell of matter which is totally structured and restructured into what we call a 'biosphere', all because of the appearance on earth of life. All the oxygen and most of the nitrogen of our atmosphere is the result of life processes, our oceans are so full of living aggregates of matter that all water molecules are constantly under the influence of life, and all the soil and much of our rock is shaped and reshaped by life.

For man, life as a phenomenon has of course been a particularly important mystery, because we are ourselves alive, and, having an awareness of time, we know also death, and are aware of many of its implications. The history of philosophy provides us with three totally different trends in thinking about life (Simpson, 1956). The simplest is known as materialism, causalism or mechanism. This philosophy looks upon life as an automatic expression of a particular arrangement of matter, in a particular energetic state - nothing more, therefore, than matter and energy. Another philosophy, known as vitalism, adds to the matter and energy a third entity, belonging to a different, non-commensurate dimension: 'entelechy'. Just as fire to the alchemist was more than matter and energy, but was considered to possess 'phlogiston', living matter has 'entelechy'. A third philosophy, finalism, sees life as a logical step in a sequence from chaos to the eventual divine goal for the universe, a goal of eternal good and beauty. We are alive in order to achieve this goal!

Each of these three philosophies is unpalatable in some way. Our egos find it very hard to live with mere causalism. Such highly valued expressions of life as emotions and morality must be more than an automatic expression of an aggregate of matter in a specific energetic state. Yet, vitalism does no more than what Huxley did, except that it tells us to accept entelechy as an act of faith with life itself as its only proof. Finalism is, of course, totally unscientific; it states that a preset goal is the cause of what is happening today. It may appeal to the mystical side of our mind, but logically it is totally unacceptable, and scientifically totally unworkable.

We must face it: life is the essence of biology, but we do not know what is the essence of life. It is therefore foolish to say that biology is the scientific study of life, because life does not lend itself to scientific study, at least not as yet. Fortunately we can study, and study scientifically, implications of life, and properties of living things: their structure, their relationships with one another and with the non-living world, their behaviour and their evolution.

I would, as a biologist, and as a teacher, shirk my duty if I did not at least attempt to give you a working definition of 'life', a definition which works because it implies certain properties of life which will lead us to a scientific approach. Such a definition could be:

*Life is the property of any quantity of matter which is structured in such a way as to be able to maintain itself*

*in that structure, and to be able to duplicate itself.*

I do realize that certain crystals that are certainly not alive, and also fire, could fit this definition. Extra clauses can be inserted to rule these non-living systems beyond the definition, but such clauses would clutter up the definition. The general nature of this definition allows us to include as alive not only those systems known as plants and animals here on Earth, but also a variety of hypothetical 'life-forms' such as Fred Hoyle's 'Black Cloud' (Hoyle, 1971). This definition leads immediately to a number of implications. Firstly, we can say something about that 'structure' - namely, that we have only found alive highly complex structures of complex carbon chemistry. Not all complex carbon-based structures are alive, but simple aggregates of matter are never alive - we can't prove this, but empirically it is always so. The fact that some highly complex aggregates are not alive (e.g. a corpse or fossil) makes us realize that a body can only be alive when it is structured in a highly specific arrangement of matter and energy.

It is here that we face our first scientific dilemma. If indeed a certain aggregate of matter can maintain itself over a period of time within probabilistic limits of a specific, non-random, arrangement of matter and energy, it appears to be violating the second law of thermodynamics.

On closer examination, however, living things do not violate any laws. On studying living organisms, one notices that they are constantly absorbing low entropy energy and emitting high entropy energy. This means that living organisms can never be a complete system in themselves, but can only be considered a closed system together with a quantity of energy, the size of the quantity depending on the time over which one wants to consider the system. For example, take a cow and a haystack (see Fig. 1). One can consider the cow and the haystack (and a quantity of oxygen) a closed system. Between time  $t_0$  and  $t_x$  the cow maintains itself in a highly specific arrangement, thus staying alive, and at the same time it changes the hay into heat,  $CO_2$ ,  $H_2O$  and dung. The total system, therefore, gains entropy, but the cow doesn't! Of course, when the cow grows or reproduces during the period of observation, we can even witness an extension of the living part of the system, but here also, the total system gains entropy. In summary, therefore, we can say that an organism can only maintain itself and stay alive if allowed a constant energy-flow through its body.

The next question I would like to pose, is 'How complex must a



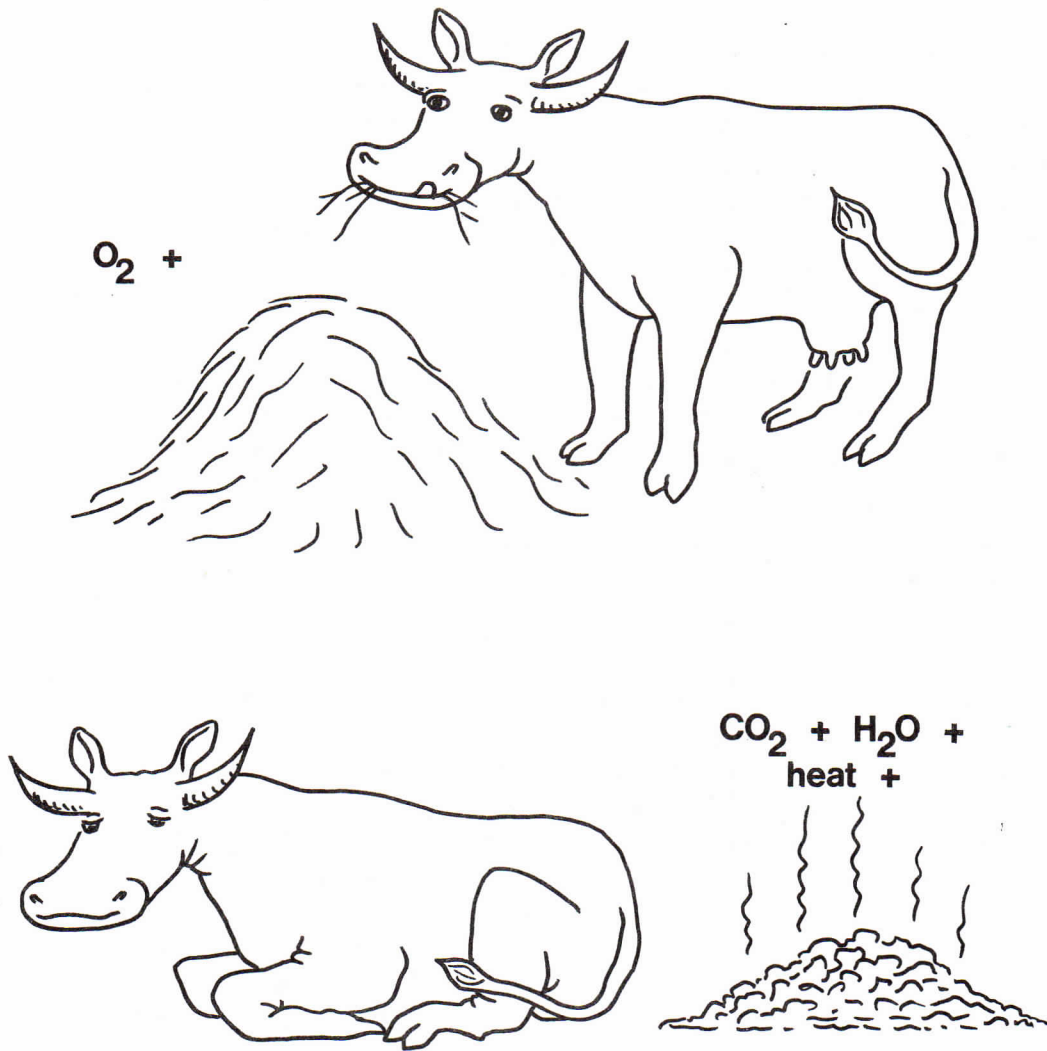


FIGURE 1. THERMODYNAMIC LAWS ARE NOT BEING 'VIOLATED' BY LIVING ORGANISMS, BUT ONE CAN NOT CONSIDER A LIVING ORGANISM ALONE AS A CLOSED SYSTEM.

material arrangement be before it can be alive?' Here again, the answer is 'We don't know'. We can study the structure and complexity of the simplest known living unit. The least complex of all organisms are the plant viruses, e.g. tobacco mosaic virus. But even such a plant virus is vastly more complex than any non-living structure of its size (see Watson, 1970).

Nowadays, all living material grows out of other living material, and we have never witnessed nor found evidence for spontaneous generation of life: the occurrence of life beginning in non-living matter (Keosian, 1968). Yet, the dream of synthesising life in the test tube is still very much a part of our scientific philosophy, and more than that, we know that life has not always been on earth, and therefore, by implication it must have arisen at least once. How did it happen? Could it happen again? Unfortunately, the biologist cannot answer these questions; all we can do is read the evidence for the changes that have occurred in the crust of our planet earth, and superimpose upon this geological picture a number of plausible hypotheses concerning the origin of life. Although a great deal of controversy still remains concerning the early geologic history of the Earth, we can put together a fairly comprehensive story which runs approximately as follows: When the solar spiral condensed into the solar system as we know it, the gravitational centre of the system became the sun, and the earth was a small secondary body of condensed matter. Whatever small (gaseous) molecules were originally part of the earth soon left, as our gravity was not strong enough to keep them here at high temperature. However, by approximately 4 billion years ago the earth cooled enough to gain a solid crust. The inside stayed hot, but the crust now cooled more rapidly, at first producing a barren, atmosphere-lacking planet, like a giant moon, but soon Earth started to acquire an atmosphere. The gaseous molecules either 'boiled' out of the still hot centre via volcanism, or were trapped out of space into our gravitational sphere. With further cooling, water started to condense, and we thus acquired a planet with an atmosphere and a hydrosphere. The composition of the atmosphere, however, was very different from today. The prevailing gases were probably various Nitrogen-Carbon compounds,  $H_2O$ ,  $CO_2$ ,  $CO$ ,  $H_2$ ,  $NH_3$ ,  $CH_4$  and several minor compounds based on Nitrogen, Sulphur, Halogens, etc. Many of these gases dissolved in the primitive oceans, as did many soluble solids (for a more detailed discussion of the origin of the Earth, see Lectures 1 and 2). Venus is probably still in this stage, as are the larger, colder planets. Earth is the only one that

changed, and it was the origin of life that changed it. The questions now are: what made the origin of life possible, how did it happen, and how did it affect the earth? In 1933 Haldane proposed a theory. In essence this theory says that in the kind of ocean as described above, hard radiation and electrical discharges will result in 'damaged', charged molecules (free radicals) being formed, and these molecules will often react with one another to produce larger molecules carrying much potential chemical energy. Many of these molecules would have been the kind that we would nowadays recognize as organic molecules. Such organic molecules are only stable when protected within living systems or in an environment free of oxygen. The early Earth oceans were free of oxygen, and therefore, given time, the oceans would slowly accumulate complex 'organic' molecules of ever-increasing complexity. Eventually, some of these molecules reached such proportions of complexity that they started to display life characteristics. It was not until twenty years after Haldane's 'way-out' theory that the first experimental evidence arrived. In their now-famous experiments, Urey and Miller showed in 1953 that in the test-tube, stage-one of Haldane's theory could indeed take place. A sealed container with water, ammonia, methane and hydrogen could anorganically yield amino acids, short chain fatty acids and urea (see Keosian, 1968). Since then, much evidence has been added to these early experiments, and we now know that highly complex molecular aggregates such as hydrogen-bonded polypeptides, fatty acids polysaccharides and nucleotides can indeed be synthesized anorganically under conditions very similar to those which the geologists tell us existed on earth some 4 billion years ago.

Now, allow me to do some theorizing as well, and let me produce a graphic model of what, in my mind, probably happened in Earth's distant past. In the first section of this model we merely plot the density of low entropy-high potential energy containing, anorganically produced, 'organic' molecules (SOUP) against time, and on the same graph also plot the 'chance of life originating' against time (see Fig. 2). We see how at time 0 (when the oceans first formed) there was no SOUP, but as time went by, SOUP started to increase, and after a while the rate decreased, as the giant molecules themselves were hit by hard radiation and/or became oxidized, releasing their energy as heat. What is imperative in the model, however, is that the chance of life occurring also increased, and that it increased non-linearly as it depended not only on the density of SOUP, but also on the interaction of the various components of SOUP. What is also imperative in the model is that the



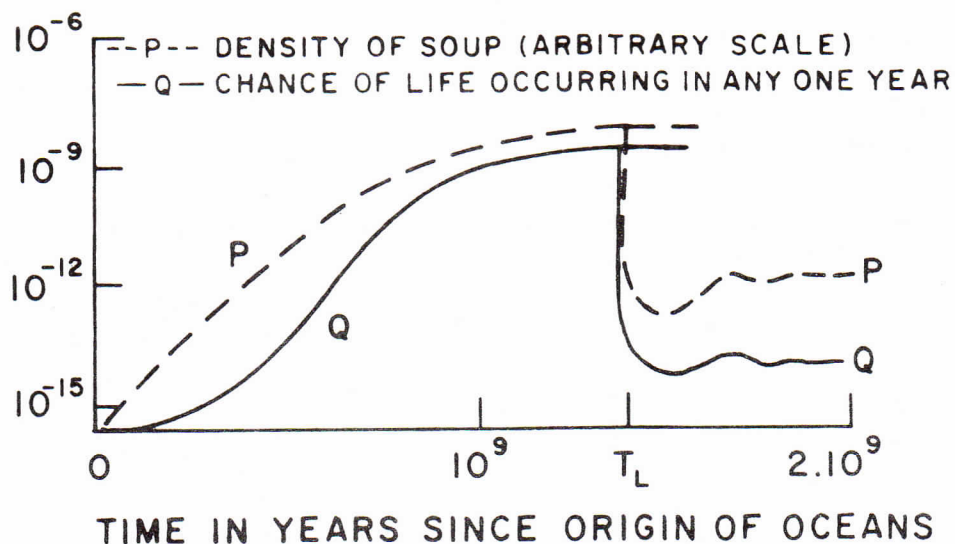


FIGURE 2. GRAPHIC REPRESENTATION OF THE ORIGIN OF LIFE, AS A FUNCTION OF THE CONCENTRATION OF ABILOGICALLY FORMED 'ORGANIC' MATTER AND TIME. SEE TEXT FOR DETAILS.

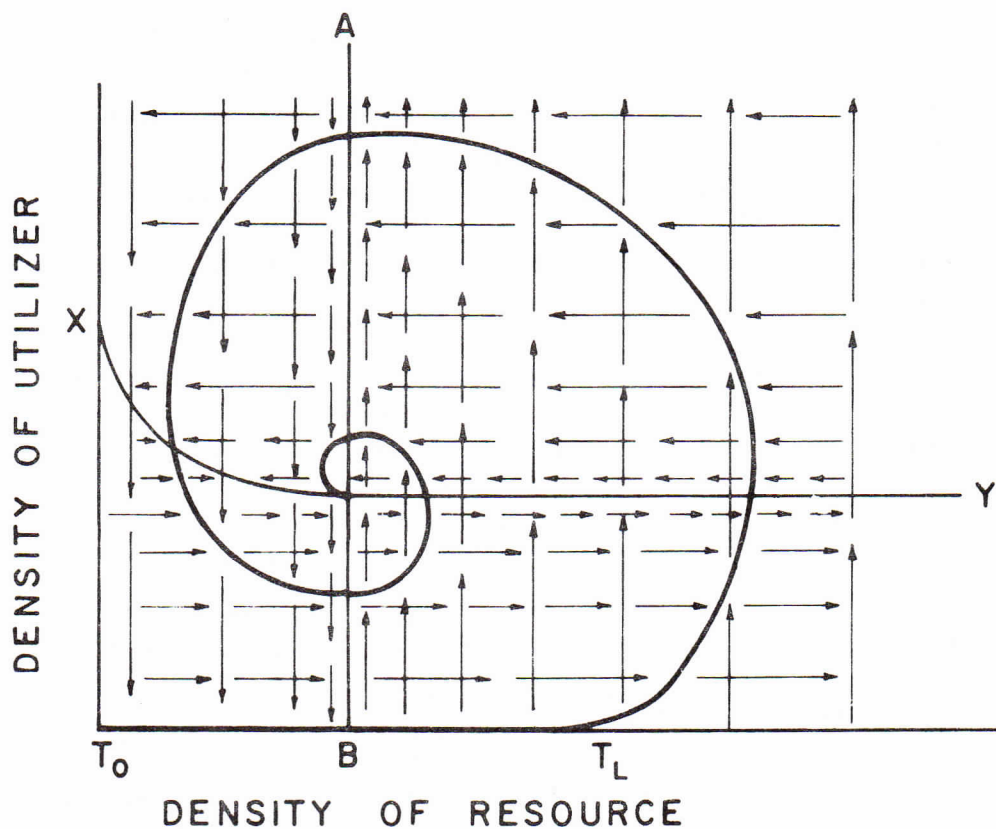


FIGURE 3. PHASE-PLANE DIAGRAM SHOWING DYNAMIC RELATIONSHIP BETWEEN A LIVING UTILIZER AND AN ABILOGICALLY FORMED RESOURCE. SEE TEXT FOR DETAILS.

chance of life occurring became high enough for life actually to occur within the time scale of the model. The rates of SOUP accumulation and SOUP interaction are, of course, unknown to us, but one can assume that these rates were several orders of magnitude lower than similar rates found in present day living systems. At time  $t_L$  we assume life began. We will see on Fig. 2 that the onset of life was still of very low probability, but the long time element would change such a very low probability into a certainty. At that time a configuration of matter arose which could not only maintain itself at the cost of other similar bodies, but could also duplicate itself. We can safely assume that the doubling rate of the new population was very rapid in relation to previous rates, and we can assume that the concentration of SOUP quickly diminished, and with it diminished the chance of life occurring a second time.

One feature of this graph needs further explanation. Why does the density of SOUP not plummet down all the way to zero instead of levelling off at level P? Here we have the first truly biological question, in that it involves the behaviour of living matter, and I will try to give a truly biological answer.

Let us turn now to part two of the graphic model, in an attempt to predict the rate of SOUP utilization by our early life forms, and the ultimate density of SOUP. We may discover why the latter will not be zero.

Let us ask what factors determine the rate of SOUP utilization. In answer we can list two obvious ones: the number or density of utilizers and the utilization efficiency of the utilizers. The first one forms a simple linear relationship - twice as many utilizers consume twice as much of the resource. The second, however, is not a simple linear relationship. The utilization efficiency of a utilizer depends partly on intrinsic factors of the utilizer, but otherwise it is a function of the density of the resource - but not a linear function. With rising resource density, utilization efficiency goes up at first, but soon it levels off as the utilizers reach the limit of their assimilation capacity.

Balancing the resource utilization is a resource resynthesis. In our case of the SOUP, that is a constant rate, depending on the relatively constant level of solar bombardment of the Earth with hard radiation. In the presence of life forms the concentration of SOUP remains so low that the abiological breakdown of SOUP can be ignored. Let us now turn to Fig. 3. Here we have a phase-plane diagram, illustrating the inter-



relationship between the density of the utilizer (here early life forms) and the density of the resource (here SOUP). The units on either scale are arbitrary, and of no importance, in that they do not affect the essence of the relationship.

Since the growth in resource density is a constant, there is a certain utilizer density (line XY) above which the utilizers will deplete the resource faster than the resource replenishes. Below this line the reverse is true. The upswing in line XY near X is the result of the reduced utilization efficiency at very low resource densities. Similarly, line AB divides the field. To the right the resource density is sufficient for the utilizer to reproduce itself in excess of its mortality, to the left it is not. All the little arrows are a rough indication of the direction and magnitude of movement for each of the parameters in each locality of the total field.

Let us now go back to time zero, when the oceans were just formed (consult Figs. 2 and 3 simultaneously). At first there is a slow but steady increase in SOUP (resource), but none of it is living; no cannibalism nor utilizer has as yet appeared. Close to Y on Fig. 3 we can see a reduction in arrow size, commensurate with the drop in slope of curve P on Fig. 2. Then, at time  $T_L$  life originates, and we see an accelerating growth in utilizer density. We also witness a slowdown in resource density growth, and after we cross line XY even a reversal. Now, as the density of the resource diminishes at the hands of the utilizer, the growth of the utilizer slows down, and after we cross line AB it reverses. We now witness the first famine in the history of Earth: the only-recently originated living organisms are starving to death, and probably cannibalizing one another. As a result we rapidly fall to line XY again, but once underneath this line, the resource starts to gain, and once past AB again, the cycle repeats itself. There are good reasons to believe that the curved interrelationship trajectory never reached either the ordinate or the abscissa, and that it did not maintain a wide loop cycle either. Except for minor fluctuations it settled in near the equilibrium point: the intersection of AB and XY. It is this equilibrium point on Fig. 3 which represents the new low equilibria of Q and P on Fig. 2.

One further aspect of the origin of life needs mention here. The reader may ask where the present large quantity of living matter comes from; we are certainly well above the equilibrium described in the previous paragraph.

The life forms we have described so far are heterotrophic; that is, they derive their energy from low-entropy energy concentrations found as potential chemical energy in organic molecules. Some living organisms have the ability to trap radiant photo-energy and transform a percentage of it into potential chemical energy within their own body. Such organisms are called autotrophic, and the process is called biophotosynthesis; it is vastly more efficient than abiotic photosynthesis, the original process responsible for the synthesis of SOUP. In a world which includes autotrophs, therefore, resource resynthesis is much more rapid, and the equilibrium between resource utilization and resource resynthesis is at a much higher level of resource concentration than in a world with only abiotic photosynthesis. A very important question arises: did biophotosynthesis arise before or after self-duplication? In other words, were the original organisms heterotrophic or autotrophic? If the answer is autotrophic, then the graphs presented in this essay will change considerably, but the essence of my arguments will be the same.

Within the last section of this essay I would like to concern myself with the question 'What will happen to life so originated?' or phrased more empirically, 'What did happen to our earliest life forms?' Before we can consider these questions, however, we must briefly pause to describe our early life form - not in such mundane terms as size, colour, appearance, etc., but in terms of functional arrangements. We must look upon this first living organism as a functional system - a living machine one could call it. It performs work in its continual quest for concentrations of low entropy energy, and it is of a specific structure: a system, with interacting constituent parts and with an input and an output. But unlike our man made machines, this living machine can duplicate itself, and is capable of growth. The implications of a functioning system growing at the same time are very interesting, but beyond the scope of this discussion. One aspect of our early life form needs yet further attention: its ability to duplicate itself. In its strictest form our definition of life is untenable; if 'maintain itself in that structure' implies no change whatever in its structure, then obviously it can neither function nor grow; therefore, 'its structure' implies a stochastic concept of variability within certain limits. Empirically, we can say with certainty that some of these limits are very tight (e.g. live mouse and dead mouse) but others are very stretchable (e.g. virus particle and elephant). Now, if such a living unit duplicates itself, how does it do it? It is beyond the scope of this



essay to go into the actual genetic mechanisms, nor will I go deeply into the concepts. Let it suffice for me to state that the mechanism of self-duplication for all living organisms on Earth is essentially the same and probably the only one available in the universe: a small part of each organism is no more than a chemical blueprint, a package of specific structure and composition, which in itself cannot maintain life, but when surrounded by the right kind of living matter, can control and shape this living matter into a specific organism. When such an organism duplicates itself, first this blueprint duplicates itself, and then the two blueprints will separate, each taking part of the organism with it - each part to subsequently grow into a complete organism.

Now, to come back to the question of what will happen to a population of such organisms.

During self-duplication an organism can either do a perfect job, i.e. both blueprints are molecule for molecule, atom for atom, identical, or something can go wrong, and one of the blueprints is slightly different - resulting in a slightly different organism being shaped. Such an error in blueprint duplication is called a mutation by biologists. Some mutations are lethal, in that they result in the organism shaping itself beyond the limits allowed for life to be. Others are not lethal, resulting in organisms that are genetically (by blueprint design) different. It is this intra-population variability that is probably the most important biological phenomenon in that it supplies us at once with the raw material for natural selection to act upon, and with the main selective force itself! In other words, we have all the essential factors for evolution to occur, and we can now see that where there is life, there is evolution.

At this stage I may have lost my audience; I can now see, but for you to see as well takes a little more explanation.

A population of individually diverse organisms that reaches a point of starvation faces competition for resources. Obviously, if individuals differ, they are bound to differ in such aspects as utilization efficiency, growth rate, ability to cannibalize, ability not to be cannibalized, etc., etc. It is here where natural selection comes in. Personally I prefer the word natural elimination, in that selection implies a goal, elimination merely a result of past performance. When mortality occurs, therefore, it is not a random process. Certain types are eliminated, whereas others survive. After a period of time we will find that the genetic composition of a population has changed -



and changed in such a way as to produce a population better adapted to cope with the environment it faces.

The previous paragraph started with a statement about resources. In a world where all the resources themselves are very diverse, one would expect natural selection to favour not one kind of utilizer, but a very diverse series of utilizers, since one's utilization efficiency is greatest for a homogeneous resource. Finally, the more diverse the utilizers become the more diverse the world becomes, since no utilizer is beyond being utilized himself.

All the different phenomena related to natural selection, adaptation and diversification can be phrased into a series of laws: laws of the evolution of living matter. I will not bore you here with phrasing these laws. The essences of them have been explained. These laws did apply to the first living organisms, and have applied to the living world ever since. The incredibly diverse living world, including man and his expressions, is the result of this evolution.

How such a diverse living world interacts and what further general biological laws we can extract out of the living world we will deal with in the next essay.

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