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Life, Energy and Light

1.1 The Definition of Life

Since the Big Bang, the Universe went on a path of losing energy density, gaining entropy and expanding, which causes continuing separation of its elements in space. Life seems to be engaged in fighting these fundamental developments in the world’s fate by:

a. making the universal stuff more ordered, complex and predictable, hence defying the laws of entropy, and

b. making the universe smaller by enabling the information flow and exchange constituting the multitude of reflections of matter via living creatures by their multiplication, proliferation, memory of the makeup (genetic code), condensing matter; creation of hypermolecules, as if exploring the potential and yet unknown properties of collectives of the elements of matter.

In order to be successful in its apparently feeble refusal of matter’s fate, life is trying to expand constantly in space and change in time. In spite of extreme environments, it designs various ways to sustain this expansion process and invents new adaptations in order to exist and continue to ‘harmonize’ the matter. In ordered and smaller space myriads of choices can be realized, creating zillions of combinations of molecules, nonrepeatable events which are often perceived as increasingly deterministic as if there is a clever plot behind it all. Instead, life is a chain of reflections copying matter, building more complex matter and reproducing it. In order to do these unorthodox performances life needs energy: a fundamental means to enable reflection, memorizing, building in its work and multiplying.

Another feature of life is the ability to recycle biomolecules within the organism, ecological niche and the entire Biosphere. Mankind generally does it, however, only in
extremely confined environments such as travel vessels: ships, submarines or spacecraft. Life always uses the recycling principle.

Life is difficult to define in one or two simple sentences. Therefore, taking into consideration all arguments provided previously we can present them in the ordered fashion in form of a number of statements.

- Life is existence of protein and nucleic acid-containing autonomic open systems exchanging energy and substance with environment in order to maintain their higher levels of negative entropy (order) and proliferate in time and space.
- Life is largely based on molecular affinity, dialectics of attraction and repulsion forces of the Universe, replicating itself using simple molecular coding principles, resulting in constant evolution of dynamic molecular forms.
- In a way, life is a complex and far from equilibrium path towards condensing of matter. It exists at rather low temperatures on the temperature scale achievable in the Universe. Therefore whilst the high temperature irreversibly kills life the low temperature has a tendency to preserve and even stimulate it in some cases (winter crops, Snowball Earth theory, etc.).
- Currently, life seems to be impossible to create from the non-living substance, apparently due to a long-term requirement for the evolution and selection of systems working against the second law of thermodynamics. It is, however, likely that the selection process which led to the creation of life forms is based upon a nonlinear chain of events and of a fractal nature, that is can be characterized by sudden emergence of an infinite regularity from some apparently chaotic and unpredictable trends. It cannot, therefore, be ignored that tomorrow science would succeed in creating at least a primitive artificial life form.
- An essential prerequisite of life was the incidence of unlimited amount of easily transferred in space energy (radiation), gradual cooling and condensing matter processes
- Life is a form of ‘revolt’ against the second law of thermodynamics achieved by very unstable, ‘vulnerable’ (soft matter) systems, a fragile lip of matter towards order and high organization on the way to the thermodynamic equilibrium and energy drain in the expanding Universe.
- Life is an inherent property of our Universe and therefore is potentially as old as it is.

It is important to think of life origins from the thermodynamic point of view. In the end, energy supply is a decisive factor for life in general and mankind, in particular.

1.2 The Energy of Matter

Energy equals matter and matter carries a lot of energy:

\[ E = mc^2 \]  \hspace{1cm} (1.1)

And this little formula means a lot for the Universe and life. Of universal energy, life requires very little. If the energy hidden in a tiny nucleus is about 1 GJ per mole, the
energy stored in the most common biological energy carrier, ATP, is 30.5 kJ per mole, which is nearly 200,000 times smaller than the energy carried by tiny nucleus. Hence, the question of energy supply to life should not be such a big deal. In a world of forces building the very blocks of the Universe; nuclei, atoms and molecules, the forces enabling life are the weakest:

-1 GJ mol⁻¹  -1 MJ mol⁻¹  500 kJ  ------  2–20 kJ  - <1 kJ mol⁻¹  
Nuclear  Atomic  Molecular (covalent)  Hydrogen – van der Waals

Forces of life

Fortunately for life, elemental and atomic energy transformations generate one of the by-products – electromagnetic radiation – a broad range, speed-of-light travelling patches of energy, capable to interact with matter. This is the best wireless and custom-addressed (not all matter stuff can get it) form of energy ever known to man. Quanta of electromagnetic radiation are spanning our Universe. Stars are the major sources of them. We sometimes look at them at night, just registering small coloured sparkles of light – all energy is left for us on the path of billions of years of its travel, just barely enough to cause a simple photo-biological act of the retinal isomerization initiating the chain of the events of vision in our eyes – all that remains for us from the mighty energy of a star.

1.2.1 The Source of Life’s Energy

What if the star can be brought to us a little bit closer, say a few light years or so? The one we see every morning – the weather permitting – our Sun. People always wondered if they have to thank it for something a bit more than just daylight, a suntan and warm weather. Indeed, the Sun is giving to Earth 100,000 TJ of energy every second, a little more than that required to tan our skins. It is actually enough to boil 100 thousands of billions (10¹⁴) of kettles, roughly 10 thousands per capita of the planet’s population. For someone preferring a Bugatti-Veyron to tea, this is enough to run 20 Bugattis per person; mind you, it has got to be a car driving on a ‘green’ fuel! But here comes the limited amount of space on our planet to host not only all those cars but us, mankind with our tendency to scavenge the nature which brought us into this world.

1.3 Energy for the Future

The point is that the Sun was, is and will be for some time, a very charitable body in the sky: it gives us all this energy for free, unlike the energy supplying companies. The question is how can we use just a tiny fraction of it in order to be alive and happy, driving our modest vehicles, being curious about the word around us? Let us leave the question of our lifestyle for a moment and think of how we can use the Sun’s generous energy? Naturally, from solar cells: the devices capable of converting the light energy into electricity, a variety of photovoltaic gadgets, which use the principles of photon energy conversion into the
energy of moving electron or electric current. The industry is growing, in some countries faster than in the others, and is certainly the way towards the era of recycling, renewal of goods and energy for the future generations to come. Returning to life we may guess as well how it has solved the question of energy supply in order to exist in the luxury of the Biosphere: a carefully settled thin film of organic matter around the globe. Indeed, the key to fixing all global crises is not just to find a quantity of matter or energy but to find the ultimate way to live in balance in limited space and conditions. Indeed, the laws of Biosphere do require the kind of lifestyle that is based not only upon the renewable energy utilization but also uses a great biological principle of recycling substances. Without acknowledging these laws one cannot succeed in sustaining life, including our species, *Homo sapiens*. We have to find the solutions Nature found some 3 billion years ago. This solution was building the living matter using the energy of Sun and later its most successful variety; *oxygenic photosynthesis*.

1.4 Photosynthesis by Life

Photosynthesis is a process of conversion of energy of light into chemical energy of organic compounds, carbohydrates. Oxygenic photosynthesis uses water as an electron donor for redox reactions involved in the primary light energy stabilization.

\[
CO_2 + H_2O + hv = (CH_2O) + O_2
\]

(1.2)

Photosynthesis is a process by which organisms capture and store energy of light by a series of events that converts it into biochemical form of energy. Photosynthesis is a process that is directed to increase levels of negative entropy (order) of living forms.

\[
(-S) = K_bln\left(\frac{1}{W}\right).
\]

(1.3)

where \((-S)\) is negative entropy, \(k_B\) is the Boltzmann constant and \(W\) is a number of possible states the system can exist. \(W\) is also proportional to amount of information required to describe the whole system and its dynamics. The more disorganized it becomes, and hence, it will require a lot of information in order to describe all possible states the system can adopt and/or move into in time. Biological matter needs input of negative entropy in form of energy and substance: hence, it must exist in an open form. The energy type needs to be an ‘organized’ one, not just thermal or mechanic (lowest types) but electromagnetic and/or chemical – ‘organized’ forms. The ‘organized’ character of these forms comes from their specificity: they can be addressed to a specific atom, molecule or group of molecules and cannot be ‘felt’ by the rest of the cell or organism. Input of substances brings chemical form of energy as well as the material required for the organism growth and reproduction.
Photosynthesis has emerged on the very early stages of evolution. It remains one of the most complex biological processes, which is not surprising, since it holds the key to the very heart of life: it is the means of fighting the universal entropy. How is the energy of a tiny particle/wave, photon, used for this? The dualistic nature of something as casual as light often appeared puzzling to scientists. A photon exhibits properties of both particle and wave. Sometimes it is capable of propagating through two distant slits on the dark chamber at the same time. Moreover, it has no rest mass. As Confucius said: ‘The hardest thing of all is to find a black cat in a dark room, especially if there is no cat.’ Photosynthesis by living organisms seems to be well-equipped to deal effectively with such an elusive form of matter as light.

Photosynthesis is, first of all, a sequence of reactions of light energy transformation that is evolved to solve two major tasks:

a. slowing down the reaction or rather the energy source, photon, and
b. stabilizing the captured energy, so that it cannot escape from the organism.

This looks something like catching a wild cat, making sure it gets calmer, slowing down and is put safely into a space (cage, etc.) it cannot easily escape from. Catching a photon is no lesser task for photosynthetic organisms. The principal difficulty here is to catch something, which has no mass when immobile, meaning that at rest it vanishes and ceases to exist. How does life manage to slow the photon without killing it? Nature has found a neat solution by using means of rapid transformation of photon energy.

### 1.4.1 Photon Energy Transformations

To catch the photon the pigment molecule’s optically-active electrons must react very quickly, within 1 femtosecond (10\(^{-15}\)s). Excited by light pigments can easily exchange their energy of excited electron. This occurs via the electromagnetic resonance events, which cause excitation energy wondering from one pigment to another, exciting without direct molecular interaction. The energy is kept among the ‘collective’ of pigments and is waiting for its fate, which can be various. The photon can reappear again, having less energy than the absorbed one. Alternatively, the energy of a pigment can simply be wasted into heat, contributing to the rise in the Universe’s entropy. Also, the electron spin can change to the opposite creating so-called tripled excited state. Finally, the energy can be trapped by the photochemically active pigment of the reaction centre to initiate the chain of electron and coupled proton transport events leading to the chemical storage of light energy in the two final products of the light phase of photosynthesis, ATP and NADPH (Figure 1.1). Those can later be used elsewhere and when light is no longer present. These two substances are the universal biological currency, always in demand for the ‘dark’ photosynthesis to fix carbon from carbon dioxide of the air or just a synthesis of biological matter. Light harvesting is therefore a staged process of photon-exciton-electron-proton transformations, handling the most elementary and fundamental forms of energy and matter. Light harvesting is the essence of photosynthesis in our planet. Remarkably, this energy transformations and stabilization occur in one tiny kind of site, more specifically, surface, called the photosynthetic membrane.
The Photosynthetic Membrane

This book will talk about the composition, structure, variety of functions, adaptations, assembly, biological importance and ways to study and to understand the photosynthetic membrane as the oldest and, so far, greatest light-harvesting nanostructure ever existed on our planet that supported and continues to support all its life.

Reference


Bibliography