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The origin of life is rhythmic repair

or

Macrocosmic rhythms created life

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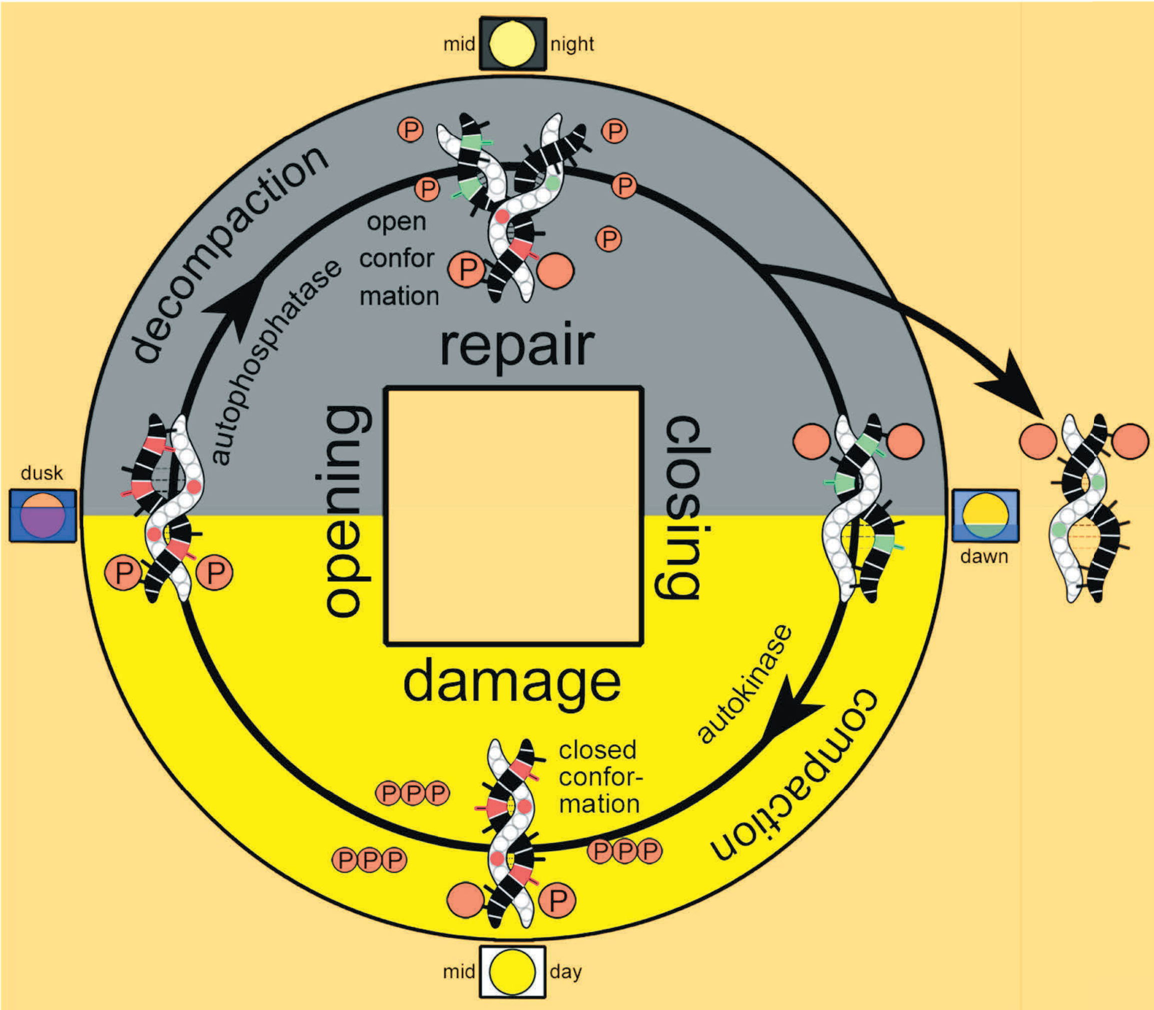
The origin of life is rhythmic repair



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The origin of life is rhythmic repair

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Macrocosmic rhythms created life

To survive, complementary primordial life molecules had to become self-repairing timers oscillating in harmony with the macrocosmic environmental rhythms on Earth

Legend to the cover illustration

Rhythmic repair is the original organisation of life

Microcosmic ribonucleopeptides and macrocosmic rhythms are oscillating in harmony. The background design of this illustration derives from an ancient Chinese coin with a central quadratic hole, symbolising square earth, and a circular outer contour, symbolising round heaven. From begin on the primordial life molecules were sandwiched between the habitats available on the early Earth and the macrocosmic rhythms of light and dark mainly caused by the sun and the moon, and the Earth's rotation. To achieve survival or a 'duration across change' the first mutually complementing ribonucleopeptide molecules inevitably had to fit the macrocosmic constellations prevailing on the early Earth, above all the rhythm of day and night symbolised by the yellow and grey half-circles, respectively. This basic yin/yang-like division of two inextricably linked and mutually complementing elements: non-damaging nocturnal darkness and damaging high-energy daylight, further subdivided into four parts the beginning of which is marked by dawn, midday, dusk, and midnight, respectively. Likely, the environmentally induced damage itself drove the primordial ribonucleopeptides to become an oscillating, self-repairing reflection of the macrocosmic rhythms on Earth. Later on, the endogenous anticipation of dawn and dusk and corresponding preparatory rhythmic compaction and decompaction, effected through changing from a closed to an open conformation, considerably reduced the amount of immediate damage. Only the coupling of basic life processes, primarily repair and replication to that diurnal, regularly alternating closing and opening of the ribonucleopeptide structure allowed the microcosmic primordial life molecules to oscillate in harmony with the macrocosmic rhythms on Earth and, thereby, to survive. Under this perspective, life arose as an earth-bound molecular pattern instructed by rhythmical celestial changes. In other words, time has been an integral part of life right from the outset.

This book is dedicated to

my deceased parents, Centa and Werner Kaffenberger,

Michelstadt im Odenwald,

to my late academic teacher in evolutionary biology and PhD supervisor

at Freiburg University, Germany, in the 1980ies,

Günther Osche, and

to late Walter Bock, formerly Columbia University New York, who, after

having read my PhD thesis, wrote a letter of support

without knowing me personally.

Mottos

In many of today's "leading" societies consumption has become the dominant aspect of individual lives. Used things are discarded and new things are bought instead. The consumer society opposes to the repair of things, preferring the new to anything old. This attitude causes short lifespans of produced items. Some have inbuilt failures that occur shortly after the warranty period has ended. In contrast, repair is a set of techniques that prolong the life of objects. Formerly, up to the second half of the 20th century approximately, a culture of repair, documented by thousands of repair shops (for shoes, clothing, domestic appliances, furniture etc) was found in many countries including, e.g., Germany and Russia. In Russia, this kind of repair culture has been termed '*remont*' (ремонт). In Estonia, in the old-town of Tallin, there is still (2017) an active, tiny *remont* business that has been on Nunne Street since 1920, and is the oldest of its kind in Estonia. Sort of a curiosity today, such residues of a culture of repair remind us of repair as a practice that establishes continuity, endurance, and sensitivity toward materials. Innovative repair often requires performing a large number of diverse tasks and making do with whatever is at hand. Therefore, it conforms to the concept of '*bricolage*', the opportunistic rearrangement and recombination of existing elements. Frequently, a dedicated *bricoleur* accumulates an immense amount of things in a mostly small cabinet. If asked, why he keeps all these things, which to most people look like scrap and waste, the bricoleur would respond: "because I could need one of these pieces at some point in the future." Under this perspective, repair can be understood as an opportunistic process of change along a time scale and, thus, bears resemblance to the 'tinkering mode of evolution' as an inherent principle of evolutionary transformation. This insight could teach us a way to a sustainable future by restoring and renewing a culture of repair through remembering a time when things were fixed instead of being discarded (Jacob 1977; Benjamin 1999; Jordan 2006; Bock, G 2007; Laubichler 2007; Bock, WJ 2009; Gerasimova & Tchoukina 2009; Heckl 2013; Martínez 2017; Schultz 2017; Hanstein et al 2022).

"I keep thinking of the old Japanese practice of *kintsugi* or 'golden repair'. The idea behind this ancient ceramic art includes the sense that when something valuable cracks or breaks, it should be repaired carefully and lovingly in a way that adds to its value. Thus, the cracks and fault lines in a valuable bowl would be fitted with a laquer made of resin containing powdered gold. Such a golden repair does not try to cover up the cracks in the vessel or deny the fact of the matter. Rather, the cracks and splits and broken places become filled with gold. Beauty appears exactly where the worst faults previously existed and the golden scars add to the living story and to the value of the container" (Meade 2015).

In the context of this book, it appears as if we could learn a lot for our modern societies from the 'molecular repair culture' that has been an indispensable feature of life from the beginning and still is in guaranteeing life's ‘duration or continuity across change’.

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Prologue

At the beginning, it should be clearly stated that this book does not attempt to provide an explanation for the evolutionary origin of the molecular building blocks of life. The two basic building blocks used in nature are remarkably well conserved across all cellular organisms: proteins made of amino acids and nucleic acids made of purines, pyrimidines, sugars and phosphate. Rather, the existence of amino acids and nucleotides originating from prebiotic evolution on the early Earth is assumed (cf. Lahav 1993; Lahav & Nir 1997; Unrau & Bartel 1998; Kunin 2000; Altstein 2015; Patel et al 2015; Becker et al 2018; Motsch et al 2020; cf. Lewis & Hanawalt 1982; Lee, DH et al 1996).

Diverse potential habitats have been proposed as sites where the molecular building blocks of life could have originated, e.g. extreme terrestrial environments (Rothschild & Mancinelli 2001; Diokic et al 2017), deep sea serpentinising hydrothermal systems (Martin & Russel 2003; Nakagawa & Takai 2008; Sousa et al 2013), terrestrial hydrothermal systems (Becker et al 2018), rhythmic patterns of tidal cycling where sea and land meet (Lathe 2004, 2005, 2006; van der Gulik & Speijer 2015), moderate diurnal or annual surface wet/dry cycles (Saetia et al 1993; Lahav & Nir 1997; Rode 1999; Forsythe et al 2015; Patel et al 2015; Becker et al 2018, 2019), merging downhill aqueous rivulets and shallow ponds (Mulkidjanian et al 2012; Patel et al 2015; Chu 2019, Ranjan et al 2018, 2019); water-ice systems (Trinks et al 2005; Wieczorek et al 2013; cf. Le Vay et al 2021), vapor-dominated terrestrial, anoxic geothermal fields (Mulkidjanian et al 2012) and others.

In the context of this book it is assumed that the two basic biological polymers, oligopeptides (as the precursors of proteins) and oligoribonucleotides (as the precursors of nucleic acids, probably RNA), were exposed to the rhythmical impact of the macrocosmic oscillations of light (high temperature) and dark (low temperature), perceptible in a habitat at the surface of the Earth, possibly some sort of a vapor-dominated, wet/dry alternation scenario as occurring in anoxic terrestrial geothermal fields. Such a terrestrial origin of pre-cellular, molecular life forms would imply that life started as a local event, confined to a restricted terrestrial, perhaps hydrothermal volcanic area suitable for generating the first oligomers and subsequent polymerisation reactions. Later, the evolution of increasingly tighter cellular envelopes, probably in connection with initial ion pumps, allowed for invading seawater ocean habitats and the distribution of life on a planetary scale (cf. Lahav & Nir 1997; Liu Y et al 1998; Mulkidjanian et al 2012; Bowman et al 2020).

The pronounced and alternating damaging (light) and non-damaging (dark) periods of the solar day provided the selection pressure for evolving a primordial self-repairing circadian timer as the first living thing. Rhythmically alternating contraction to prevent damage during daytime and expansion to allow self-sustained repair during nighttime constituted the ancestral oscillation of the primordial biological timer as a molecular reflection of the macrocosmic time on Earth impacted by the light/dark rhythm. Under this perspective, life arose as an earth-bound molecular pattern instructed by celestial changes. In other words, life has been a timer from begin on, or else time has been an integral part of life right from the outset. The macrocosmic temporal pattern dictated the evolution of a corresponding microcosmic molecular temporal pattern and only this resonance guaranteed survival. Already Plato considered time as being born in the motion of the celestial bodies, in the perpetual and mostly unchangeable cyclic motion of the moon and planets, as observable from the Earth (Foster & Kreitzman 2005, p. 12; cf. Walker & Zahnle 1986).

In the beginning, this 'life-timer' probably was directly instructed by light and dark and passively followed the rhythmically changing environmental conditions, whereas later on it was capable of anticipating the predictably oscillating macrocosmic changes by evolving an endogenous microcosmic molecular representation of those exogenous macrocosmic rhythms, i.e. by becoming an oscillator itself. To be of any biological use, the self-repairing molecular timer had to oscillate in harmony with the macrocosmic environmental rhythms on Earth. The setting mechanism that linked the microcosmic primordial 'life-timer' with the macrocosmic oscillations was the 'celestial clockwork' of the earth/moon/sun system (cf. Walker & Zahnle 1986). Regular predictable changes at dawn and dusk enabled the microcosmic molecular clockwork to adjust itself to the macrocosmic clockwork and, thereby, to survive. Later in evolution, this basic principle of a self-repairing molecular timer turned out to be so essential that it was retained in every cell (cf. Millar 1998; Foster & Kreitzman 2005, pp. 40, 128f; Hardin & Panda 2013).

A central issue at the transition from prebiotic to biotic evolution regards the provision of energy. Molecular life ultimately arose from components that were synthesised abiotically via spontaneous exergonic chemical reactions sometime during the history of early Earth (prebiotic synthesis). Based on this premise, it seems to be generally accepted that reactions catalysed by small, simple molecules and inorganic compounds preceded complex metabolic reactions catalysed by large enzymes. Life is an energy-releasing process far from thermodynamic equilibrium. Therefore, survival means carrying out exergonic reactions that provide the energy for staying far from equilibrium. In low-energy environments, where survival becomes more important than growth, supplying maintenance energy becomes the main process of life. Together, at the origin of life, primordial life molecules tapped inorganic environmental supplies of biologically relevant compounds provided by spontaneous (exergonic) chemical reactions.

Since organic origins of energy had not yet evolved on early Earth, primordial life molecules had to rely on alternative inorganic sources of energy. In the reconstruction of the ancient autotrophic core metabolism, the number of central reactions depending upon the hydrolysis of high-energy phosphate bonds suggests that the core metabolism required a readily available and highly exergonic chemical reaction capable of continuously synthesising high-energy phosphate bonds, both before and after the origin of enzymes. As such a reaction, H_2-dependent CO_2 reduction to acetate, forming acyl phosphate bonds, has been proposed. Primitive forms of methanogenesis and acetogenesis without cytochromes and quinones (e.g. in bacterial Clostridia and archaeal methanogens) may represent energy metabolic relics from the earliest phases of biochemical evolution on the Earth before anaerobic respiratory chains had evolved (Thauer et al 2008).

Acetogens and methanogens are both very strict anaerobes and thought to represent very ancient forms of microbial physiology. They subsist on the reduction of CO_2 with H_2, using the acetyl-CoA pathway at the core of their carbon and energy metabolism. Acetogens and methanogens utilise very modestly exergonic reactions that are close to the thermodynamic limits of life (Decker et al 1970; Martin & Sousa 2016); Sousa et al 2016; cf. Russell et al 2007).

Here, considering its diverse functions, its ubiquity in all three kingdoms of life, plausibly from the beginning, and the myriads of phosphorylation reactions in modern cells, inorganic polyphosphate (polyP), produced by volcanic action on early Earth, is preferred as an ancient energy carrier. Therefore, primordial life molecules might have used inorganic, abiotically acccumulated polyP as long-term sources of inorganic phosphate ($P_{i)}$ and energy and, at the same time, as a compound critically involved in stress resistance and protective biofilm formation.

Degradation of polyP, by providing the anhydride bond energy and trivalent phosphate residues, potentially allowed production of all vital molecules, such as amino acids, nucleobases, sugars and lipids (Jones & Lippmann 1960; White 1980; Westheimer 1987; Kornberg 1995; Kornberg et al 1999; Martin & Russell 2003; Brown & Kornberg 2004, 2008; Zhu Y et al 2005; Ferry & House 2006; Fuchs 2011; Preiner et al 2019; Sanz-Luque et al 2020; Xavier et al 2020; cf. Morowitz et al 2000; Sousa et al 2016; Ralser 2018).

It is this scenario, in which small primordial proteins (oligopeptides) and nucleic acids (oligoribonucleotides) are already present, and an ancient inorganic energy source is in place at the Earth's surface, that provides the starting point of this book. Its central hypothesis assumes an enormous impact of the macrocosmic rhythms prevailing at the Earth's surface on the molecular organisation of the primordial life molecules, first of all the rhythm of day and night, comprising a damaging phase (daylight hours, coinciding with high intensity UV and blue light irradiation from the sun and high ambient temperatures) and a non-damaging phase (night hours, coinciding with lacking or low intensity irradiation from the moon and low ambient temperatures).

One 360° rotation of the Earth relative to the sun produces 180° (12 h) sunlit time and 180° (12 h) dark time at the equator (observed as the apparent movement of the sun from sunrise to sunset intercalated by nights of equal duration on average). (With higher latitudes the lengths of day and night become more variable, producing the seasons: longer days/shorter nights in summer and shorter days/longer nights in winter on the northern hemisphere.) As a consequence, there is a link between the rotational movement of the Earth (measured in degrees) and the time that elapses during this movement (measured, e.g., in hours). A day can be defined as the period from one sunrise to the next, corresponding to one revolution of the Earth, and divided into halves by light and dark each comprising 180° on average.

If given the task to subdivide the period of one day (360°) into easily handable shorter pieces, symmetrically throughout and using whole (integral) numbers only, you may get:

360°/2 = 180° (halves)
(determined by daytime and nighttime, corresponding to dawn - dusk, dusk - dawn)
180°/2 = 90° (quarters)
(corresponding to dawn - noon, noon - dusk, dusk - midnight, midnight - dawn)
90°/2 = 45° (eighths)
(corresponding to after dawn, before noon, after noon, before dusk, after dusk, before midnight, after midnight, before dawn)
or, alternatively,
90°/3 = 30° (twelfths)
(after dawn, early morning, late morning, early afternoon, late afternoon, before dusk, after dusk, early evening, late evening, early night, late night, before dawn)
45°/3 =15° (twentyfourths)
or, alternatively,
30°/2 = 15° (twentyfourths)
(corresponding to one third of the 45°or one half of the 30° subunits or one twentyforths of 360°, respectively).

Therefore, under the above instruction, one day can be subdivided into 24 equal-sized sections that each corresponds to one hour of a solar day and one hour corresponds to 15° angular movement. Probably, the subdivision of the circle (360° - approximating the ≈ 365 days of the solar year) into 24 hours, each comprising 60' (minutes), each minute made up of 60'' (seconds) dates back to the sexagesimal system of the old Babylonians. However, there are several ways of subdividing one day into smaller units and different cultures came to different solutions (cf. Landes 2000; Lippincott 2003; Sôma et al 2004).

Consequently, the predictably fluctuating photic environment on Earth, with two strongly opposing faces (light & dark), becomes imprinted on the structure and any primitive non-enzymatic metabolism of the primordial life molecules. The central hypothesis outlined in this book provides a plausible explanation for how the rhythmic macrocosmic