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The Animate State of Matter Hypothesis

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This article looks at biology from a physical perspective. It argues that animate matter has a distinctive set of physical properties and must be regarded as a distinct aggregate state. The distinguishing feature of the animate state is the capacity of living bodies to generate orderly autonomous reconstructions at several length scales, including the atomic scale. The cause of these volitional reconstructions is a particular kind of collective chemical transformations. The orderly reconstructions perform several functions. They transport products and chemical precursors, induce new chemical reactions and cause new structural transformations. Therefore, the living bodies sustain themselves in the animate state. The orderly reconstructions manipulate matter at the molecular scale, where they control chemical transformations and synthesize specific products, which are unobtainable by means of chaotic reconstructions. At larger length scales, they build special structural arrangements that cannot be fabricated using random permutations. The molecular structure of animate matter differs from that of regular liquids. In liquids, molecules are not connected to each other. During chemical transformations, the disconnected molecules rearrange their atoms independently of each other. In the animate matter, on the other hand, the molecules are connected and are assembled into ordered arrangements. For this reason, the intramolecular transformations interact, adjust to one another, and combine into large collective reconstructions. This unique property makes life a distinct physical phenomenon. The paper identifies the source of volitional actions of living bodies, describes the blueprints of the simplest animate organisms, and conjectures how these organisms might have appeared from inanimate water solutions.

Keywords: animate matter, living matter, origin of life, physics of life, autonomous motion, artificial animate materials.

1 Introduction

Three hundred years ago, German physicist Gottfried Leibniz suggested that biological matter comes to life because it is populated by the “elementary ensouled creatures” he called “monads” [1]. The monads had to be able to perform purposeful actions on their own volition. Additionally, they had to communicate with each other, coordinate their actions, form associations, and combine into larger monads (living beings) with more complex autonomous behaviors. Scientists searched for the monads, but could not find them. For this reason, the idea of the elementary ensouled entity was long forgotten.

This article suggests that, perhaps, the genius physicist was right, and the monads do exist. The elements that animate matter are the valence electrons that fall to the charged nuclei during chemical reactions. The falling electrons orderly reconstruct matter within molecules. They do not create large self-sustaining groups in regular liquids. However, they can do so in biological matter.

From a physical perspective, a stable atom consists of electrons that rest in the potential well created by the charged nucleus. The electron can rest on two nuclei simultaneously. In this situation, it creates a chemical bond. The chemical bonds form molecules and condensed matter bodies. However, the valence electrons can do more than merely connecting atoms. They can also accomplish atomic permutations and restructure matter. They do so when they

fall to lower potential energy states during irreversible chemical transformations.

Regular chemical transformations take place in substances divided into disconnected molecules. These molecules move as Brownian particles and mix by chaotic thermal fluctuations. They interact when they collide. During chemical reactions, the falling valence electrons reshuffle their nuclei placing them into new stable configurations.

I note that the valence electrons can fall to their charged nuclei in a different situation. The irreversible chemical transformations can take place in condensed matter that is not divided into detached molecules. They can occur in substances where all the atoms are connected by means of physical and chemical bonds. In other words, chemical transformations can occur within giant interconnected macromolecules that alter their own structure.

In this case, different tumbling electrons will have to move and reconstruct the entire condensed body. While doing so, they will affect each other's actions. Most often, they will act at cross purposes and interfere, producing no observable animation. In rare cases, however, they can restructure their common body so that their actions become coordinated. In this situation, they will generate perceptible collective transformations, in which different subgroups of the falling electrons will operate in succession, and the whole condensed body will execute a sequence of different actions.

Additionally, the animated condensed matter body has a significant amount of internal constraints (existing chemical bonds); this strongly hampers the actions of the tumbling electrons. In these circumstances, their free wills will be suppressed, and they will follow orders of the transforming condensed matter body. I suppose that this is exactly how the collective will of large monads appears. The specially organized condensed matter body that controls the actions of all its active members will correspond to the living organism.

The living organism uses the orderly collective reconstructions to manipulate chemical reagents and control metabolic transformations. It builds new structures and reorders itself. This is not all. It also reconstructs its environment in an orderly manner, gets rid of the toxic waste, and extracts new chemical precursors. It rebuilds them using certain algorithms, releases their potential energy, and lets the electrons do useful things. By doing so, it sustains its own activity. From this perspective, a living organism is a self-sustaining group of cooperating elementary animate agents that constantly dismiss old, and accept new active members.

Right here in the introduction, I have explained the essence of my hypothesis. In what follows, I expand my explanation, present some supporting arguments, and discuss the consequences of the hypothesis. In the next section, I discuss the root cause of the volitional actions of living matter.

2 The Source of Autonomous Actions

In most situations, it is enough to assume that condensed matter is composed of atoms and chemical bonds. However, when matter undergoes chemical transformations — and one needs to take them into explicit consideration — these elements become inconvenient. One needs to use more basic material elements to adequately describe the system.

More generally, condensed matter is composed of the valence electrons and atomic nuclei shielded by core electrons. The valence electrons and the shielded nuclei interact through electrostatic forces, which are described by Coulomb's law.

The mutual positions of these interacting elements is one of the solutions of the equation of motion (here, many-particle Schrödinger equation), which follows from the principle of least action. This “many body problem” has multiple solutions. Which of these solutions will the system choose?

We know from physics that a system of interacting particles will undergo an irreversible process, in which it moves to occupy the lowest available potential energy level. In simple terms, the system will fall down into the deepest potential well. The process is irreversible because the transition from a higher energy to a lower energy state converts the potential energy to kinetic energy. The system uses this energy to perform mechanical work, reordering atoms, or generating chaotic thermal motion. In any of these cases, the utilized energy is irretrievably lost. The reverse

process (the escape of the system from the potential well) is possible, but it requires new energy inputs.

When electrons fall to naked nuclei, they occupy core levels and create atoms. They lose energy by emitting photons. When the valence electrons fall to two or several shielded nuclei, they create chemical bonds, producing molecules and tangible condensed bodies. They lose energy by generating atomic rearrangements.

The potential energy of the system of interacting charged elements quantifies its ability to perform mechanical work. It can be understood as the system's desire to perform some action. In condensed bodies, these actions equate to collective atomic rearrangements and reconstructions of chemical bonds.

In addition to uncertain desires, the condensed matter body is restricted by numerous internal constraints. (The atoms connected with chemical bonds obstruct the motions of the condensed matter body.) It means that the condensed body controls the actions the falling valence electrons. It allows them to make only certain collective rearrangements. The shape and structure of the body determine its function.

3 How Orderly Reconstructions Affect Chemical Processes

In substances divided into disconnected molecules, the falling electrons rearrange matter only within molecules. The motion of the molecules relative to each other remains completely uncontrolled. But the shapes and structures of the molecules are unimportant because they do not affect the course of chemical processes. They are indistinguishable for a macroscopic observer. For this reason, scientists simply ignore the abilities of the falling electrons to perform orderly manipulations of matter.

In biological systems, however, the orderly reconstructions rearrange matter at larger length scales, thus becoming observable. Most importantly, they influence chemical transformations. Here I explain the main consequence of this effect.

The distinguishing feature of the collective chemical transformations is that the coordinated groups of falling electrons can accumulate enough energy to pull some of the valence electrons out of their deep potential wells, thereby breaking stable chemical bonds. Thanks to this capacity, animate matter tries more packing options and discovers new atomic configurations with even deeper potential wells. Different organisms use different protocols for ordered manipulations of matter. They synthesize different products. However, any of these manipulations pack atoms more efficiently compared to random reconstructions. The living bodies synthesize products with higher degrees of condensation.

I believe that this particular activity describes the operating principle of living organisms. They rebuild small molecules (obtained by regular chemical reactions), make

better ordered and better packed condensates, extract mechanical work in the process, and use it to sustain their own activity. In addition, they use some of the synthesized materials for their own replication.

Indeed, the body of a simple one-celled organism is denser and better packed compared to its water-based habitat. The organic products manufactured by living cells have higher molecular weights because they were produced by larger groups of the falling valence electrons.

Now let us take a look at the living cell from the “animate state” perspective.

4 Observable Properties of the Animate Matter

The living cell can be regarded as a specially arranged condensed matter body that manipulates its own constituents, acting on its own volition. It makes orderly reconstructions of its own body, and reconstructs its habitat. It extracts the desired chemical components from its environment, builds new ordered structures, and incorporates them into its own animate body.

The body of the cell is composed of water reinforced with organic compounds. It is something like an ordered polymer. This polymer is very heterogeneous; it contains many different structural components. The surrounding water is also a polymer. Only this polymer is more homogeneous, less ordered, and less robust. It can be mixed much easier [2].

The living cell reconstructs by making permutations. It makes internal rips, separates moving parts from its own body, transfers them to new places, and then reattaches them by means of new chemical bonds. Then it makes new rips, carries out new material permutations, and so on.

The “loose parts” of the living cell, which at first glance appear as Brownian particles, are not Brownian. Instead of random rips, and aimless chaotic motions, they make ordered movements.

4.1 The consequences of orderly reconstructions

The autonomous reconstruction of living bodies is an observable microscopic phenomenon [3]. In this paper, I generalize this effect. I conjecture that animate bodies generate ordered reconstructions at all length scales starting from the atomic scale. At the molecular scale, cells manipulate chemical precursors embedded in their own bodies, and synthesize compounds that cannot appear accidentally in inanimate matter. *I recognize that living and dead bodies synthesize different chemical products.*

The ordering manipulations of matter continue at mesoscopic scales, where cells arrange freshly manufactured molecules, and build structures that cannot appear in inanimate matter haphazardly. *I recognize that living and dead bodies build different structures.* (Fig. 1)

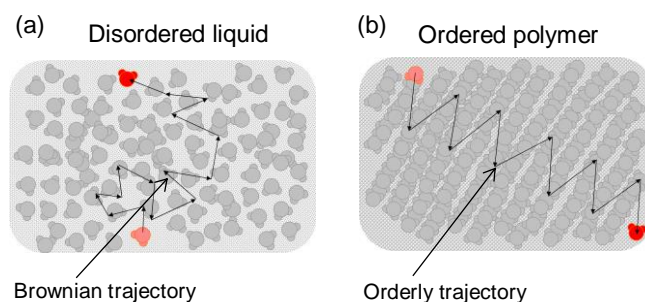


Fig. 1. Inanimate liquid vs. animate matter at the molecular scale. (a) Inanimate matter is composed of unordered molecules. The particles of the liquid make random chaotic movements. (b) Animate condensed matter is composed of oriented molecules held together by means of chemical bonds. The animate body makes ordered reconstructions. Its particles make ordered movements.

There is one important point. In addition to the ordered reconstructions, cellular “giant macromolecules” undergo regular Brownian-type chaotic reconstructions caused by thermal fluctuations [4]. Living organisms constantly repair the inflicted damages. Additionally, cells always contain “completely loose parts”. Those include oxygen, carbon dioxide, various ions, and other small molecules. They diffuse right through the organisms’ bodies. These detached molecules are needed for the normal operation of the organism. However, they do not belong to the organism.

4.2 The cause of ordering reconstructions

All atoms — except noble elements — have vacant valence orbitals, and aim to establish material bonds with other atoms. Every atom has a particular number of valence electrons, and must obtain a specific number of bonds. These chemical bonds must have certain narrowly determined parameters, such as lengths, bond angles, etc. For this reason, chemical transformations always involve atomic rearrangements. When the bond building takes place in a big interconnected condensed body, the individual atomic permutations are replaced by the collective reconstructions.

4.3 The unique capacities of the falling electrons

In the reconstructing material bodies, atoms acquire amazing new capabilities. Consider an atom that wants to replace an energetically unfavorable (dissatisfying) chemical bond. To do so, it should find itself a new partner, break the existing bond, accomplish an atomic transposition, and build a new chemical bond. It would never achieve this goal on its own. However, it can do all of that in partnership with a large group of cooperating falling electrons. The reconstructing condensed body will help the atom to break the bad bond, push away the dissatisfying neighbor, select a more satisfying atom, and make a new bond.

By the sequences of the collective reconstructions, the group of cooperating valence electrons will satisfy the needs of the majority of the atoms. They will end up in a more energetically favorable configuration, and create a more effectively packed condensate.

Every single valence electron aims to put its atomic neighborhood in order. Acting together, these electrons will make their common condensed body more ordered. I assume that this particular effect causes self-ordering of living matter.

4.4 Condensation

The fundamental physical force that animates matter originates from the capacity of the atoms to create chemical bonds, link together, and create arranged condensed matter. Biological life is driven by the process of collective chemical condensation.

In the simplest case, the collective condensation involves adding of lacking chemical bonds to an already existing condensed matter body. This happens, for instance, in folding proteins [5].

A more complicated case of non-random collective condensation takes place in condensed matter bodies that have many unsatisfactory bonds. Such bodies store significant amounts of potential energy. They generate various mechanical actions by making collective reconstructions.

The growth of a living body also boils down to the organized collective condensation. Growing organisms appropriate new atoms from their habitats producing better-packed condensates in their own bodies.

4.5 Independent wills of animate organisms

In my opinion, it is safe to say that the desires of the valence electrons to fall to their charged nuclei produce the wish of the animate body to make a voluntary action. This desire combines from myriads of individual desires of various charged particles to construct lower potential energy configurations.

In a biological organism, mostly carbon, oxygen, and hydrogen improve their chemical bonds. Therefore, it is safe to say that the wills of the organisms mostly arise from the individual atomic wills of these particular elements.

I would like to emphasize that the condensing body has a will to transform, but may lack a particular goal. It could satisfy its desires in a million of different ways, execute millions of different actions and end up in a million of different final configurations. In many of these configurations, it can be more or less equally satisfied.

In addition to the internal desires, the organisms' actions are determined by the internal constrains, set by the intrinsic structures of the organisms. The organisms may also use DNA and other similar guides. Thanks to the genetic codes, they make exact predetermined actions.

In this part of the manuscript, I described the cell as a piece of animate matter. I did not yet explain where the first animate body came from. This will be explained in the last part of the manuscript, where I show the blueprints of the

simplest organisms. Now I describe communications between the elementary animate agents.

5 Communications between Active Agents

5.1 Signals in transforming biological matter

When the falling electron reconstructs its chemical bond, it moves the neighboring atoms. In a big three-dimensional macromolecule, these movements affect other chemical bonds. The mechanical relaxations of the macromolecule can be regarded as signals. They are produced by particular sources (transforming chemical bonds), and assimilated by particular recipients (unstable chemical bonds). They have very unusual properties. On the one hand, they are delocalized during motion. On the other hand, they collapse into particular localized sources and recipients when they interact with matter.

Additionally, these signals transport matter and can be regarded as peculiar mobile elements of condensed matter. Such elements appear in any transforming condensed matter that undergoes stimulated transformations. They emerge, for instance, in nuclear fuels. In these compounds, the decaying nuclei emit neutrons that cause new nuclear fission events. The neutrons may be regarded as the mobile elements of condensed matter.

The nuclear and the intramolecular signals both carry interactions between transforming elements. However, they differ in one very important respect. In nuclear reactors, different neutrons move independently of each other. Consequently, nuclear fission proceeds through sequences of simple irreversible events connected by simple causal links. Those are known as chain reactions. In contrast, in biological matter, different signals bind together and mix. As a result, all irreversible events connect, and create a densely interlinked network. Every irreversible transformation has many causes and many consequences. And that is not all.

Animate macromolecules constantly modify their own structure. Correspondingly, they constantly change the communication channels between the sources and the recipients. At any moment, some processes may stop affecting each other; some previously disconnected processed may become connected. The exact mathematical description of such evolving substances is very difficult.

5.2 Collective permutations

In my paper entitled "The Physics of Life. Part 2: The Neural Network as an Active Condensed Matter Body", I attempted to identify a particular solution of this complex problem [6]. I said that collective reconstructions should resemble localized atomic permutations. The collective reconstruction should proceed roughly as follows. The condensed body spontaneously makes an extended rip in itself, forces out a piece of material from itself, transfers it to a new place, and reattaches it to its body by means of new

chemical bonds. The empty space, which was left after the initial rip, is filled with new material, and is also restitched with new chemical bonds. This process is illustrated in Fig. 2.

5.3 Reconstructions in chemically inhomogeneous substances

This section articulates the key idea of this paper. Here I describe collective reconstructions that occur in chemically inhomogeneous matter. In this special case, the transferred pieces carry chemical precursors. Upon reaching their destinations, these pieces cause new chemical reactions and trigger new collective reconstructions. The full reconstruction of the chemically inhomogeneous body will proceed as a cascade of chemically stimulated permutations. This situation is illustrated in Fig. 3.

The collective reconstruction of a chemically inhomogeneous substance will look like directional transfer of certain mobile metabolites. At the molecular length scale, the animate organism will resemble a collection of chemically active molecular bodies — the sources and recipients of various mobile metabolites — that communicate via certain chemical signals. Only, thanks to interatomic interactions, the chemical signals do not move randomly. They are involved in a complex regular motion. All the rips and permutations pertaining to the animate state (1) are not accidental, they are willingly generated by the living body; (2) are aimed and directional; (3) are interrelated. All the individual chemical and structural transformations are integral parts of one big orderly transformation of the living body.

5.4 Multiscale reconstructions

In real biological cells, different small transformations combine into larger collective processes for several times [7]. Every time they do so, they produce a new level of integration. Eventually, they produce a cell-wide autonomous reconstruction known as cyclosis or cytoplasmic streaming [8]. This self-sustained mechanical movement is seen through a regular microscope.

Modern biological cells are multiscale systems; they produce multiscale reconstructions. At every length scale, the reconstructions proceed with different speeds. The bigger is the length scale, the slower is the characteristic reconstruction. The fastest processes occur at the atomic scale: it takes approximately 10 nanoseconds to create a new chemical bond [9]. In comparison, it will take approximately 10 microseconds to generate a signal between two neurons [10].

Evidently, creation of cooperating groups does not stop at the cellular level. It goes on further, producing multicellular organisms. The condensed bodies made of cooperating cells produce even more complex collective reconstructions. Perhaps, the most complex multicellular reconstruction is the operation of the human brain. The brain is an evolving (transforming) condensed matter body composed of living

neurons that establish and break material bonds with each other, exchange electrochemical signals, and generate complex coordinated actions.

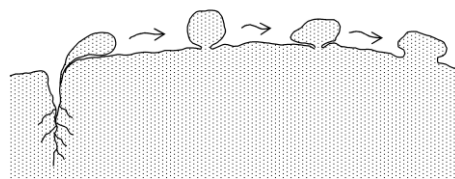


Fig. 2. Autonomous collective reconstruction of the condensing body. The body generates an internal tear, then transfers a piece of itself to a new location.

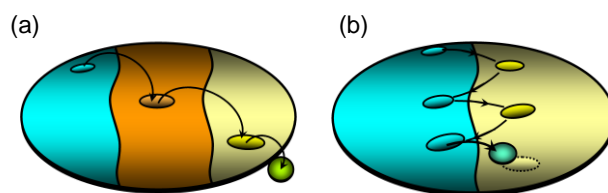


Fig. 3. Collective reconstructions of chemically inhomogeneous animate bodies. (a) propagation and transformation of moving metabolites; (b) back and forth motion and transformation of moving metabolites at the interface between two segments with different chemical composition.

In my paper entitled “The Physics of Life. Part 2”, I suggested that the brain generates collective reconstructions in the same manner as simple animate bodies produce collective moves at the atomic scale [6]. From this, I described the emergence of the “collective mind”, and explained how this collective entity controls the individual neurons.

5.5 Peculiar characteristics of biological signals

One has to keep in mind a very important fact. The biological signals are not exactly signals. Or rather, they are not only signals. In addition to pure information, they carry energy and matter. In strict physical terms, they are mobile elements of transforming condensed matter. In chemically inhomogeneous matter, they are mobile metabolites.

This should be true for all different signals at all different length scales, including the elementary signals emitted by the falling valence electrons. In my papers entitled “The Physics of Life”, I imply that one could create a universal theory of animate matter, equally applicable to any length scale, including the atomic scale [4,6]. In this paradigm, one must assume that the elementary active agents emit information, energy, and matter in the form of some kind of “elementary mobile metabolites”. At the first level of integration (molecular scale), these elementary entities link together to form larger mobile metabolites.

6 Transition from the inanimate state to the animate state of matter

6.1 The first animate working body

It is generally believed that, in cells, transforming organic molecules perform most actions, whereas water remains relatively inactive. This may be true for modern cells, which manipulate matter mostly with the assistance of protein-based molecular machines.

However, this may not have been the case for primordial proto-cells. Chemical transformations may occur in water, directly. In this situation, water may acquire the capability to carry out basic ordered reconstructions, to manipulate its own constituents, and to synthesize new types of organic molecules. To have such a property, water must be a poorly ordered polymer.

I hypothesize that the earliest animate “working body” was water. *Water may have been the first compound that crossed the boundary between the inanimate and animate realms. It did so when — in addition to totally random reconstructions — it started to produce some non-random reconstructions.*

As a matter of fact, I believe that ocean water still remains at this divide today: in some situations it behaves as a disordered solution, and in other situations it acts as an ordered polymer. The non-random reconstructions occur in water under some special conditions [11].

6.2 Increasing complexity of the first animate body

Figure 4 illustrates the primordial animate condensed matter body. This poorly ordered polymer is composed of water and some low-molecular-weight precursors. It undergoes collective condensation by producing new organic molecules with increased molecular weights. The primordial animate body accumulates these molecules, becoming more intricately structured. Consequently, it may produce increasingly more complex and more diverse products. Each subsequent condensation event occurs in a better-ordered configuration. Therefore, the orderly condensing body may self-organize and increase its regularity at a growing pace. (This will only work up to a certain limit. The orderly condensing body may run out of some needed chemical precursors. The excessive accumulation of organic condensates may eventually introduce internal conflicts and cause chaos.)

The increase in structural complexity comes from the falling valence electrons, which execute ordering atomic reconstructions. During the collective condensation, this order materializes in tangible structures. The larger is the number of irreversible condensation events, the greater is the amount of objectified structural order.

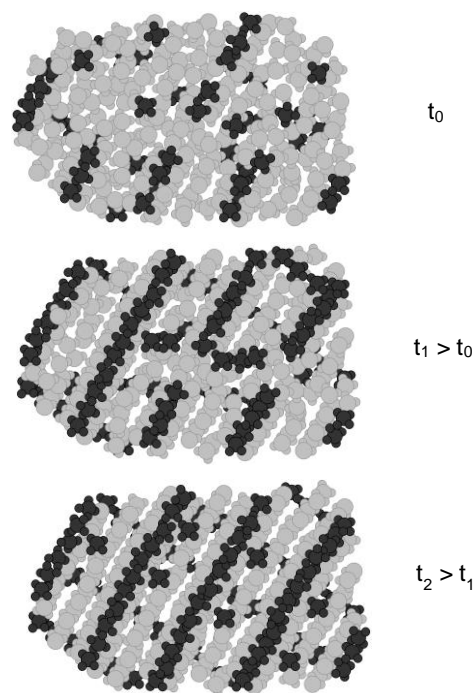


Fig. 4. Condensing water-based animate body at the molecular scale. Accumulation of ordered organic condensates orders the body.

6.3 The measure of evolution

The orderly condensation explains the emergence of more complex — and more diverse — forms of life. There is one additional effect known as evolution.

Evolution implies emergence of more advanced living species. But what does “more advanced” actually mean? The organisms that occupy higher levels of evolutionary development are supposed to be more efficient in surviving in complex and hostile environments.

It may happen that the “level of perfection” has a measure at the atomic and molecular scales as well. The organism’s “working body” may evolve into something more advanced.

Here is my hypothesis. The organism’s working body takes a step up along the evolutionary scale when it achieves a higher level of organization. It means that its atomic, molecular and mesoscopic transformations diminish mutual conflicts, enhance cooperation, and create larger ensembles. The working body enhances the agreement between its animate agents. Correspondingly, it executes more complex, more extensive, and better coordinated actions.

In measurable physical terms, better-organized animate bodies reach higher degrees of chemical condensation: The superior organisms produce better packed condensates with better (more energetically favorable) chemical bonds. They increase the degree of processing of raw materials; meaning that they transform initial precursors into more intricately arranged products. They get more efficient in harvesting the abilities of the valence electrons to perform ordering actions.

At the macroscopic scale, more advanced organisms become more productive, and, therefore, more competitive. They become the fittest. In this regard, evolution is caused by mutations, competition between different organisms, and natural selection. However, the root cause of any development is the ordering acts of the falling valence electrons.

6.4 Primordial water-based organisms

Now let us go back in time. The earliest organisms must have had much lower degrees of condensation. They had simpler metabolisms. The earliest organisms contained smaller amounts of organic compounds; and those compounds had lower molecular weights. The organic condensates, produced by the first organisms, were less ordered, and formed poorer ordered arrangements. It means that the earliest animate matter was exposed to greater numbers of random processes, and implemented less accurate actions. In other words, *it was much closer to the inanimate state.*

On the bright side, due to the lack of guiding structural components, the primordial organisms could modify their internal structures during their lifespans. Almost certainly, they were capable of very fast evolution.

6.5 Contemporary cells

Perhaps, the contemporary biological organisms contain less water and more organic components; these organic components have higher molecular weights, and are better packed. The advanced cells fabricate a wider range of molecular products, and build more intricate structures from these products.

The superior organisms execute more elaborate and more accurate actions at the molecular and atomic length scales. They can synthesize increasingly complex compounds with higher precision. *In brief, through evolution, animate organisms get farther away from the inanimate state.*

7 The Simplest Organisms

In the final part of the paper, I describe the blueprints of the simplest organisms. Fair warning, these organisms will be very different from familiar biological cells.

7.1 The entanglement

In this paper, I have argued that a living organism is a group of cooperating valence electrons that fall to their nuclei and organize collective reconstructions of their common condensed matter body. The orderly collective reconstructions can only occur in specifically arranged bodies. As a rule of thumb, in usual materials, the elementary animate agents act at cross purposes. The bodies that cannot produce any orderly collective reconstructions will be called “entangled”. To enable collective movements, they must be

“disentangled”. This disentanglement occurs in living organisms when they rearrange matter at the atomic and molecular scales.

The emergence of life corresponds to the appearance of the first disentangled body. I will discuss the spontaneous disentanglement shortly. But before I do so, I will explain how existing organisms disentangle themselves. This process was described in detail in my paper entitled “The Physics of Life. Part 2” [6]. Here is a brief recap.

7.2 Collective rips

An autonomous action starts from a rip in the organism’s body, in which many chemical bonds break one after another. The ripping resembles a break of a dam. The broken bonds eliminate some internal constraints. The removal of the constraints activates a new batch of inhibited agents. They rock the body and open the rip further. As a result, the rupture expands in an avalanche-like mode.

The action ends when the body begins to restore the broken bonds. The healing of the rip may also resemble an avalanche, when one restored bond shrinks the tear, and triggers formation of next bonds.

The spontaneous rupture of the animate body is the simplest case of disentanglement. The healing of the rupture corresponds to the simplest entanglement. Therefore, the living body constantly entangles and disentangles itself. The entangling corresponds to the inhibition, whereas the disentangling corresponds to the activation of the animate body.

Generally, any condensed matter body containing a significant amount of unsatisfactory chemical bonds has a potential capability to disentangle itself through spontaneous ruptures. In favorable circumstances, such bodies could trigger spontaneous collective processes. However, the probability of such events depends on the degree of entanglement, and in many situations remains small.

7.3 Emergence of the organism in weakly entangled systems

Consider a weakly linked body that makes spontaneous ruptures and produces collective reconstructions. Each of these reconstructions will bring it to a new configuration. In a sequence of reconstructions, the structure of the body will change, like a kaleidoscope pattern. Generally, after several reconstructions, the body will change beyond all recognition.

However, not all reconstructions change structures out of recognition. Some special arrangements generate reconstructions that bring the body to the “almost original” formation. In other words, the configuration of the body after the reconstruction will closely resemble the configuration before the reconstruction, only composed of different elements. These special reconstructions simply replace some used elements with fresh equivalent elements. Consequently,

the specially constructed bodies will repeat the same reconstructions over and over again.

In my paper entitled “The Physics of Life. Part 1”, I called these special arrangements “recurring configurations”; they produce “recurring reconstructions” [4]. I have also argued that these specially arranged bodies correspond to biological organisms. Indeed, biological organisms periodically generate similar actions. These actions restore the structure and function of the organism. A more detailed discussion of this issue can be found in my manuscript entitled “The Physics of Life. Part 3: The Artificial Animate Materials” [12].

The general structure of the organism will be described in the following sections. Here I explain the emergence of the first organism. The aimlessly evolving material body described at the beginning of this section may undergo modifications, try many different configurations and eventually find one of the recurring states. As soon as it reaches such configuration, it will establish the recurring reconstruction, and reinforce it by repetition. In my opinion, this particular course of events describes the emergence of life. The whole process is driven by the collective condensation. However, it does not involve aimed self-organization. Instead, it is a trial-and-error process.

One important note should be made here. The original aimlessly transforming animate body has no goal and attains no specific objective. The organism, on the other hand, produces purposeful actions. Namely, it restores its own structure and function. The primary goal of the organism is its own survival.

In my paper entitled “The Physics of Life. Part 2”, I have shown that the recurring reconstructions may further disentangle the organism and make it more complex [6]. In other words, the organism can grow and evolve. This happens because every reconstruction leaves a trace in the living body, and these changes accumulate with repetition.

7.4 Emergence of life in model systems

I demonstrated the spontaneous emergence of life experimentally. The results were described in my papers entitled “The Physics of Life” (Parts 1, 2, and 3) [4,6,12].

My primordial organisms appeared in weakly-entangled chemically inhomogeneous condensed matter. In my experiments, a small disentangled region of such substance produced a specific self-sustaining chemical transformation, and a mechanical reconstruction. This “seed recurring reconstruction” had strong disentangling and ordering effect. It induced new transformations in its surroundings, and subjugated them by means of special signals. The disentangled region grew in size by incorporating these new transformations into an “organized system of transformations” (thus, the organism). Importantly, this condensed matter body periodically repeated similar reconstructions. Thanks to that, the organism maintained a stable structure and a stable

metabolic network. Fig. 5 illustrates the growth of the organism.

My experimental demonstrations had one weak point. I used very simple non-biological materials instead of real biological matter:

In my manuscript entitled “The Physics of Life. Part 1”, I suggested that — in addition to real elementary animate agents (i.e. the falling valence electrons) — there are other, much simpler pseudo-animate agents [4]. Those have analogous properties, but much simpler behavior. The simplified agents are very convenient. However, they use other types of motive power. For that reason, these agents are not “living” in the strictest sense. The real animate agents, on the other hand, are too difficult to handle.

7.5 The pseudo-animate granular matter

Now I briefly describe my pseudo-animate model system. Above all, in order to be “animate-like”, transforming condensed matter must generate non-random reconstructions. Many material systems have this property. The simplest material system that generates non-random ordering reconstructions is the granular matter of the hourglass. (Fig. 6) It is composed of two types of elements: grains and voids. Under gravity, the grains aim to fall down, whereas the voids strive to rise up, like little bubbles. Being constrained by the walls of the glass, the grains make physical bonds with each other, and create the condensed matter body. The voids have the capacity to disconnect the grains, and destroy the condensed state. The tumbling grains hinder each other. The voids remove the obstructions, and facilitate motion. In short, the grains and the voids have opposite properties.

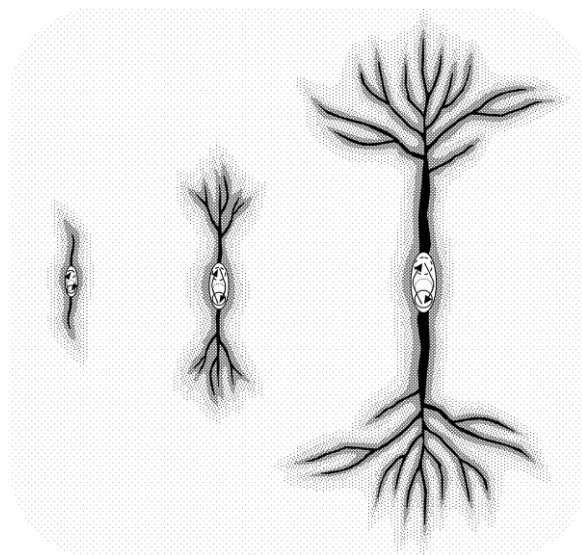


Fig. 5. The emergence and growth of the organism from a small recurring reconstruction. The seed ordering reconstruction disentangles its inanimate habitat. These changes accumulate over time. The disentangled parts of the habitat become parts of the organism.

The flow of grains and voids in the hourglass makes a self-sustaining reconstruction as shown in Fig. 6. At the center of the funnel, the tumbling grain crosses the boundary between “the condensed matter body mostly composed of grains” and “the condensed matter body mostly composed of voids”. The material exchange is bilateral. It injects a new void into the jammed matter composed of grains. The void stimulates the recurring reconstruction that brings the next grain into the funnel. In the stream of the hourglass, the rising voids act as signals that permit motion. The tumbling grains may be regarded as feedback signals. The entire collective reconstruction realizes a circulation of these mobile signals [4,12].

Simultaneously, the moving grains and voids act as mobile metabolites. The moving stream of the hourglass realizes a sequence of small pseudo-chemical transformations: The propagation of grains and voids involves stop-and-go motions. An unobstructed grain moves a short distance before it meets a new obstacle and stops. In each of these steps, a fraction of the grain is transformed into its opposite, and the rest goes further. Therefore, the stream of the hourglass can be regarded as a metabolic chain.

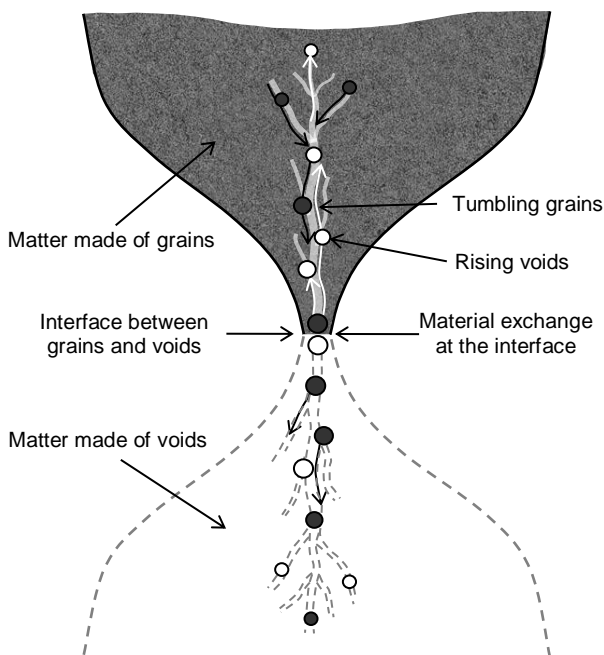


Fig. 6. The active stream in the hourglass, which can be regarded as the simplest prototype and the mechanical analogue of an animate organism. Under gravity, the grains and voids become pseudo-animate agents. The seed recurring reconstruction appears in the funnel, where the grains and the voids trade places. The stream periodically brings the next grain into the funnel. Thus, the total reconstruction is self-sustaining. The separation of matter into the disentangled pseudo-organism and its entangled (jammed) habitat exemplifies the emergence of life.

7.6 The simplest recurring reconstruction in a chemical system

A similar self-sustaining reconstruction can spontaneously emerge at a boundary between two substances with different chemical composition. A small section of this boundary can produce the reconstruction that implements the exchange of two moving metabolites as shown in Fig. 7.

When a piece of the first material crosses the boundary and enters new chemical environment, it triggers a certain chemical transformation, and creates another moving metabolite with opposite properties. This new metabolite crosses the boundary in the opposite direction. In the first medium, it triggers another chemical transformation, creates the next moving metabolite, and sends it back to the second medium. Then the initial permutation of pieces will induce the next permutation of similar pieces, and the whole process will become self-sustaining.

Just like in the granular matter of the hourglass, the metabolic transformation of the moving metabolites may proceed in several steps as illustrated in Fig. 7.

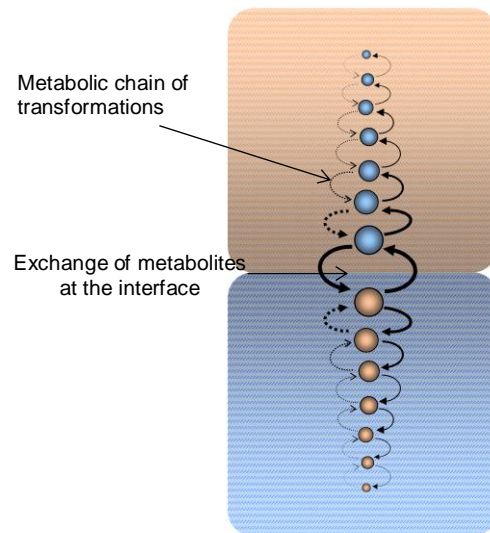


Fig. 7. Self-sustaining recurring reconstruction at the boundary between two media with different chemical composition. The metabolites cross the boundary, and then turn into their opposites through simple metabolic chains consisting of several steps.

7.7 The exchange of metabolites between the organism and habitat

The boundary between two chemically different substances could be regarded as the border between the primordial organism and its habitat. (Fig. 8) The exchange of metabolites across the boundary could be viewed as feeding. The metabolic chain of the organism generates a special signaling metabolite and injects it into the environment. In a chemically suitable habitat, this metabolite must cause a particular chemical transformation, and create a specific response metabolite that must get back to the organism. In

this way, the organism can sustain its uninterrupted activity by feeding. As soon as the organism digests one serving of food, it requests the next serving. *In my opinion, this particular process is the true essence of life.*

I contend that Fig. 8 is the blueprint of the simplest living organism in the simplest habitat.

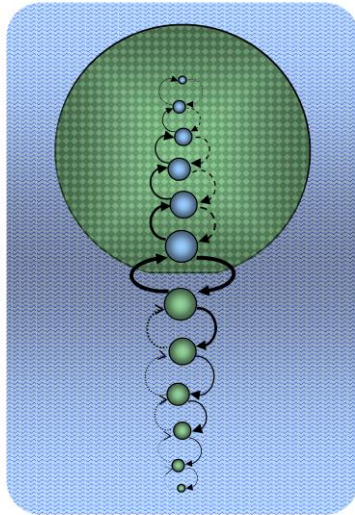


Fig. 8. The simplest organism in the simplest habitat. The single metabolic chain of the organism generates a special signaling molecule and then releases it into the environment. The chemically suitable environment generates a response metabolite, which sustains the entire reconstruction. Thus, the organism feeds.

The blueprint of a living organism must contain: (1) the structure and chemical composition of the organism's body; (2) the structure and chemical composition of its typical habitat; (3) the characteristic movement of metabolites, and their chemical and structural transformations, in the body of the organisms and in the body of the habitat.

I define the simplest living organism as the animate condensed matter body that feeds by exchanging metabolites with its environment.

7.8 The simplest permanent organism

The simplest organism described in the previous section has a major flaw. It has a short lifespan because it needs to release its own matter into the environment.

A permanent organism may appear in a slightly more chemically inhomogeneous medium, as shown in Fig. 9. The organism must realize two different exchanges with its habitat. At one interface, it gets the first nutriment. In its own body, it transforms it into the first excrement by means of its own metabolic chain. It discharges this product as a signaling molecule at the second interface, and gets the second nutriment in return. This second nutriment is transformed into the second excrement. It is used as the signaling molecule that stimulates the habitat, and brings the next serving of the first nutriment. In this organism, the metabolites move in a closed

loop; and this motion creates a self-sustaining circulation of signaling molecules. The organism undergoes the perpetual reconstruction; it cycles the habitat's material through its own reconstructing body.

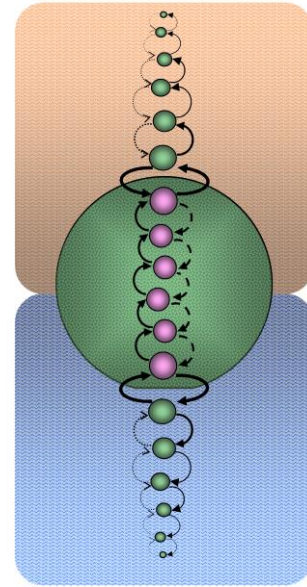


Fig. 9. The perpetual organism, which acts as an intermediary between two substances with different chemical composition. The organism contains its own internal circulation of metabolites, realizes two material exchanges with its habitat, and creates two different metabolic chains in the habitat. From two different interfaces, it obtains two different types of food, and emits two different types of stimulating chemical signals.

7.9 The reproduction of the simplest organisms

The permanent organism may accumulate material and grow in size. Additionally, it may create parallel metabolic chains as shown in Fig. 10. These chains may carry similar metabolites and produce similar reconstructions. In my paper entitled "The Physics of Life. Part 1", I showed that similar reconstructions interfere [4]. They also tend to build impermeable borders. By doing so, they stop hampering each other. This mutual interference may eventually cause separation. The organisms' reproduction is NOT mere replication of molecules. It occurs when one self-sustaining reconstruction (one organism) releases a new self-sustaining reconstruction (an offspring organism). First, the organism grows and accumulates the interfering segments. Then these segments form a new self-sustaining circulation of metabolites. After this, the transforming body divides into two disconnected parts.

7.10 Collective organisms

On rare occasions, one can observe a phenomenon which is the exact opposite of the division. Two or more reconstructing bodies may combine into a single body and produce one common reconstruction. This happens when

these reconstructions are fully compatible. Instead of interfering, they mutually enhance each other.

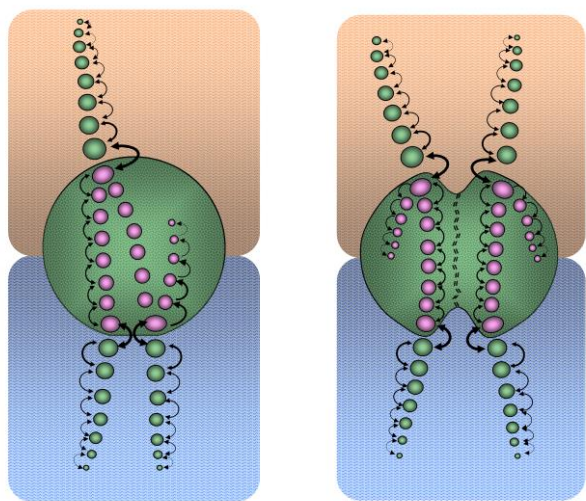


Fig. 10. Division of the animate condensed matter body caused by the emergence of a competing reconstruction. The two self-sustaining reconstructions build an impermeable border.

To establish a collective organism, different cooperating organisms must build material connections with each other, and create a common condensed matter body. This is accomplished with the help of condensation. Then the reconstructions must elaborate a common collective behavior by modifying the structure of their shared body. They must eliminate the disagreements (by building internal walls in the right places), and remove the isolating barriers between the cooperating parts. In principle, two different biological cells may fuse into a single cell. Perhaps, this happened when mitochondria became integral parts of complex cells, and when chloroplasts became organelles of algal cells [13,14].

It must be said that full cooperation between different reconstructions is very rare. More commonly, different cells attain only partial cooperation. In this case, they create multicellular organisms. In a multicellular organism, every cell retains its own (partially independent) internal reconstruction. The cells may also create an evolving multicellular condensate that changes its structure and function. That is the animal brain. The operation of the brain is described in my paper entitled “The Physics of Life. Part 2” [6].

7.11 The artificial collective organisms

In my papers entitled “The Physics of Life” (Parts 2 and 3), I described my experimental attempts to create the collective forms of artificial life [6,12]. At the beginning, I made individual animate forms that operated at an interface between two chemically different media as described in

Section 7.6. Then I tried to combine them into cooperating ensembles and observe their collective reconstructions.

My proof-of-concept experiments were rudimentary as I used only the simplest available tools and equipment. They require thorough verification. Nevertheless, my efforts appear to have been at least partially successful. It is possible that, with proper development of materials and techniques, I will be able to fabricate complex forms of artificial life through this process. My final goal is to demonstrate their complex adaptive behavior.

Conclusions

This article attempts to answer a fundamental question: what is the difference between the dead and living matter? It identifies a particular condensed matter phenomenon that can be used as the key attribute of the animate state.

Presently, most scientists believe that life emerges at the molecular scale, being an effect of some intermolecular interactions. In conflict with this point of view, I argue that the living cell is composed of molecular bodies that are held together by means of chemical bonds, through which they create a single interconnected condensed matter body. This body reconstructs itself in an orderly fashion driven by the valence electrons that fall to their nuclei during chemical transformations. *At the basic level, life is an effect of intramolecular interactions between atomic processes.*

My hypothesis has a very important implication. It suggests that biological animate matter can have abiological counterparts. Some non-biological compounds may acquire properties analogous to those of biological animate matter. In such materials, the falling valence electrons can interact in exactly the same fashion, creating similar collective reconstructions.

In my papers entitled “The Physics of Life. Part 2 and Part 3”, I have introduced “artificial animate materials” that can be regarded as a simpler material equivalent of biological animate matter [6,12]. I have also discussed the methods of their manufacturing. In short, they can be fabricated by injecting particular metabolites into inanimate condensed matter bodies. My experiments suggest that one can “breath life” into a sufficiently broad range of different compounds.

Some of these non-biological material systems have particularly strong ordering capacities; they can generate reconstructions and regularize matter at several length scales. This kind of non-biological animate-like matter is particularly useful for manufacturing artificial animate forms. These non-biological animate organisms could serve as a convenient experimental and theoretical workbench for modeling and understanding real biological life. Additionally, they can be used as autonomous robots, which have their own wills and generate their own independent actions.

References

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- [1] G. W. Leibniz and N. Rescher, *G.W. Leibniz's Monadology: An edition for students*, University of Pittsburgh Press, 1991.
- [2] G. H. Pollack, *The Fourth Phase of Water*, Ebner and Sons Publishers, Seattle, 2013.
- [3] F. G. Woodhouse, R. E. Goldstein, *Proc. Natl. Acad. Sci. USA* **110**, 14132–14137 (2013).
- [4] D. A. Kukuruznyak, The Physics of Life. Part 1: The Animate Organism as an Active Condensed Matter Body (2017). [⟨hal-01575989v2⟩](#)
- [5] B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts, P. Walters, The Shape and Structure of Proteins. *Molecular Biology of the Cell* (Garland Science, 2002).
- [6] D. A. Kukuruznyak, The Physics of Life. Part 2: The Neural Network as an Active Condensed Matter Body (2017). [⟨hal-01575993v2⟩](#)
- [7] G. West, *Scale*, Penguin Press, New York, 2017.
- [8] R. E. Goldstein, J-W. van de Meent, *Interface Focus* **5**, 20150030 (2015).
- [9] G. E. Zaikov, V. G. Zaikov and A. K. Mikitaev, *Chemical Reaction in Condensed Phase: The Quantitative Level*, Nova Science Publishers, New York, 2006.
- [10] T. H. Bullock, R. Orkand, A. Grinnell, *Introduction to Nervous Systems. A series of books in biology*, W. H. Freeman, San Francisco, 1977.
- [11] S. L. Miller, H. C. Urey, "Organic Compound Synthesis on the Primitive Earth", *Science* **130** (3370), 245–251 (1959).
- [12] D. A. Kukuruznyak, The Physics of Life. Part 3: The Artificial Animate Materials (2020). [⟨hal-02541236⟩](#)
- [13] A. Cornish-Bowden, "The origin of mitosing cells: 50th anniversary of a classic paper by Lynn Sagan (Margulis)". *J. Theor. Biol.* **343**, 1–114 (2017).
- [14] P. Buchner, *Endosymbioses of animals with plant microorganisms*, Wiley, New York, 1965.