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The Mystery Surrounding the Beginning of Life

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Life is a storm (in a teacup) in the stream of entropy
Ulrich C. Schreiber, February 11, 2019

For Karin, Hanna, and Sebastian

Preface to the English Edition

The following book tries to offer a comprehensive model for the formation of the first living cell. Its ideas have been formed during cooperation between the two authors over many years. The original edition, appearing as a non-fiction book in German, described the complex topic from a personal perspective of one of the authors (U.C. Schreiber).

The idea to write a non-fiction book on the topic of the origin of life was born on the results of laboratory experiments which prove the occurrence of a chemical evolution under environmental conditions. These experiments opened an opportunity to follow the development from simple organic molecules up to complex structures with particular functions. Based on this stage during the completion of the first edition, it was planned to extend the contents of this book with new developments and new ideas. This led to this second English version in which C. Mayer acts as a coauthor. C. Mayer essentially developed and performed the key laboratory experiments and lately opened a fundamental discussion on a new perspective of the definition of life. The latter is now included in this book as a new chapter (Chap. 9) on life in the context of order and complexity.

Preface

It's risky starting a project about the origin of life. In the search for approaches and solutions, hurdles quickly become apparent that appear insurmountable—above all those concerning your own knowledge. The origin of life is not a research object that in its fullness can only be assigned to biology, chemistry, or biochemistry. The sum of all questions that arise in the search for answers concerns a large number of scientific disciplines and, as it quickly became apparent, especially those of physical chemistry and geology. Perhaps this is also the reason why the answers that science has offered so far have been so unconvincing. Often a broad-based research group is lacking, which is absolutely necessary for dealing with all the aspects involved. All this quickly became clear once the idea of pursuing a completely new approach to researching the formation of organic molecules in the continental crust's fracture zones, and ultimately of life, was born in 2003 and 2004. It was Oliver Locker-Grütjen, Head of the Science Support Center at the University of Duisburg-Essen, whose attention I first drew to this consideration. We quickly agreed that specialists from all the natural sciences were needed to have any chance at all of gaining new insights into this question or finding answers to it. Embarking on such a venture on our own was unthinkable. Oliver Locker-Grütjen knew numerous colleagues from a variety of departments at the university and was able to assess who might be willing to take an unconventional approach to this topic. After a short while, more than ten professors came together who were so interested in the question of the origin of life that they were willing, at intervals of several months, to take part in privately organized evening meetings despite having full schedules, and thus, the Essen Origin of Life research group was born.

A lot has happened since then. This book presents the current state of research and—let us anticipate this much—shows, on the basis of a hypothetical model, a completely new path to the formation of the first divisible cell—and this under conditions that are realistic and to some extent still occur in the same environment today. It makes no claim to being complete or exclusive. What it can do, however, is help to develop an understanding of the processes required that lead to new experiments and a sound approach to this extremely complex matter. Because this much is certain: besides the beginnings of the universe since the beginning of the scientific age, no scientific question has remained as unresolved as the one concerning the origin of life.

Now it can commence.

Essen, North Rhine-Westphalia, Germany
March 2019

Ulrich C. Schreiber

Acknowledgments

A non-fiction book like this one that addresses such an extensive range of themes has a long history in its formation. In addition to research in the laboratory and field, it is based on numerous meetings and discussions with colleagues, at the university, at conferences, and in the private sector. I would like to express my sincere thanks to all those who gave information, made corrections, and provided support in the drafting of this non-fiction book, as well as all those who have made contributions to discussions and provided assistance over the past few years. Listed below, in alphabetical order, you will find the many colleagues and other harbingers of information who have provided constructive commentary on this subject over the years: Prof. Peter Bayer, Prof. Steven A. Benner (Florida), Prof. Volker Buck, Dr. Maria Davila Garvin, Prof. Gerald Dyker, Prof. Matthias Epple, Prof. Hans-Curt Flemming, Prof. Daniel Hoffmann, Prof. Gerhard Jentzsch, Prof. Frank Keppler, Prof. Ute Klammer, Prof. Ralf Littke, Dr. Oliver Locker-Grütjen, Prof. Franco Pirajno (Perth), Prof. Agemar Siehl, Prof. Torsten Schmidt, Prof. Oliver J. Schmitz, Prof. Heinfried Schöler, Prof. Jörg Schröder, Prof. Bernd Sures, and Dr. Jonathan Williams. I would like to express my special thanks to the management team at Duisburg-Essen University, who showed great commitment in their support for the project.

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1

Introduction

Abstract Nothing is as complex as life. And although we now know quite a lot about it, one crucial question has still remained unanswered since time immemorial: how did life come into being? Did it happen according to scientific laws, here on earth, elsewhere, or by the hand of a supernatural creator? This question has moved mankind for thousands of years. The answers provided by science have so far been unsatisfactory.

A group of scientists from the University of Duisburg-Essen has tackled this question of what the biggest unsolved problem in science is perhaps and may be able to make a decisive contribution to solving it. They are searching for the beginning, the very first cell from which all other cells originate. Their quest is about the definition of life, entropy, energy, information storage, and how everything began.

An overview of the conditions on earth after its genesis, the general conditions for life, and the position that scientific research takes in the history of mankind provides an introduction to the topic, which is one of the most exciting in scientific research.

1.1 The Origins of Life: What Makes This Question So Important to Us?

Can't we as human beings simply accept that what was formed a long time ago exists today without knowing exactly how and why? Well, the simple answer is no, we can't. The development of human beings and hence the development

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of an abstract thinking organ, our brain, inevitably lead to questions about everything that happens in the environment of our brain. This has always been the case since a certain point in development. Questions exist that could be answered instinctively. The most obvious one is why does game recognize that a hunter is approaching shortly after they move closer? While in a similar situation under the same cover and at the same distance, it continues grazing without a care as is an easy kill. Experience provided the answer to this dilemma, which, after many repeated scenarios, demonstrated that wind direction plays the decisive role. Other questions about what causes lightning and thunder or rainbows, illness, death, and a lot more besides were unanswerable and were simply accepted as a given. They found their place in the realm of the uncontrollable, the divine, something superior to man. This represented a very successful method of reducing the burden on the psyche with regard to questions that could not be answered at that time.

The approach to answering such questions and many more besides changed with the establishment in human thinking of scientific principles. A coherent answer required proof that was reproducible and universal. A statement about the gravitational pull of the earth had to be valid on every continent or also on ships in the case of the oceans. It goes without question for us today that objects everywhere on the earth accelerate in free fall toward the center of the earth. The physical law associated with this, which Newton formulated in the second half of the seventeenth century, is known as the law of gravitation and was supplemented by Einstein's general theory of relativity in the twentieth century. These scientific laws mean that we know that masses attract each other, everywhere, throughout the whole universe. No salvationist or conspiracy theorist, no matter how charismatic, can deceive the general public into thinking today that this is not the case on the moon or any other planet.

This scientific way of thinking meant that things that had long been accepted as a given were gradually removed away from the realm of the divine. Thanks to the natural sciences, we only have a few things left in our world of thought whose explanation is still considered by some to be the creation of God. One aspect here is the Big Bang, which established itself as an explanatory model for the origin of the universe a few decades ago and has special character. And it is only thanks to physics that this aspect found its way onto the agenda at all. It opens up a dilemma based on the following fact: the explanation model for the Big Bang is the result of a consistent physical examination of the processes that took place after the Big Bang, postulated up to the present day, without any divine influence. Some scientists even take the difficulties involved in physically describing the actual start of the Big Bang as a reason to claim it as being God-given, since there is still no clear explanation for this. In the meantime, however, alternative ideas have been developed to explain the emergence of the universe. These ideas involve an infinitely vibrating expansion and contraction without the need for a single Big Bang as the initial stage [1, 2]. This theory has not made things any easier.

The second aspect which remains unanswered is the question posed at the beginning of this book on how life on earth originated. This question has probably moved humanity since we had the ability to ask questions. Directly connected with this are the "why?" and the "where to?" and the reflection on the meaning of life in general. In a world where intelligent thinking beings exist, but where scientific principles still remain unknown, solutions to answering major questions like this have to be found in other ways. From the beginning, the solution was called religion. It gave and still gives answers to topics that no one can understand through their simple experiences of the everyday world. The truthfulness or reproducibility of the statements is of no import here. What is important is to calm your own insecurities and fears, which inevitably arise when thinking in these "incredible" spheres.

1.2 What Exactly Is Life?

In addition to providing gains in fundamental knowledge, only natural science has contributed to depicting the complexity of life and has raised a wealth of seemingly unanswerable questions. It showed that life, which is so natural in its existence for us, is surprisingly difficult to define.

Don't we just have to take a look around us to see what life is? No, because it's not as simple as that. In science, an all-encompassing definition still does not exist that explains life and hence the starting point of life as well. This is a big difference to chemistry and physics, where, for example, theories exist to explain matter or forces that act. That said, we can at least specify criteria or characteristics that are key features of life and are accepted by all natural science disciplines. These are inevitably the physicochemical characteristics that make up a living biological system. And here you can already see that it should be a system that corresponds to our knowledge of biology. Some of the characteristics can also certainly occur in nonbiological systems; the combination and simultaneity sharpen the definition of a description of life.

At the top of the list of criteria is the existence of at least one cell, a compartment enclosed by a cell membrane. This is where the biochemical reactions take place that prevent the cell from dying or, in other words, ensure that it stays alive. Biochemical reactions require information storage, a metabolism for absorbing energy and for exchanging molecules from the environment, and catalysts for efficient chemical reaction chains. With a precisely tuned regulation, the interaction of all the components leads to the reproduction of cell components, and to growth, and the proliferation of the cell through its division. Added to this is the ability to adapt to changing environmental conditions and to develop into more complex molecular groups.

A small note in the margin in relation: what if we put all the functioning cell components of trillions of cells (except their cell membranes) in a large vessel or an almost closed hole in the earth and supply them with energy and add and remove the necessary molecules? All the processes that would otherwise take place in a cell (but without cell membrane-related reactions) would continue in this vessel. The products multiplied thus could enter other space through flow paths and multiply overall. Would we call this system life? We could simply take the position that we do not need this to any thought, because the molecular cocktail cannot multiply, of course. But the idea is still important, because the end of this book gives us model ideas about the beginnings of organic chemistry up to the formation of vesicles and cells, which come close to such a situation and therefore need to be isolated.

As early as in 1980, the theoretical physicist Gerald Feinberg and chemist Robert Shapiro tried to make the principle of life universally applicable to other possible forms of life in space. They concluded that life originates from interactions between free energy and matter. In this way, matter is able to achieve a greater order within the common system [3].

Today, we can imagine a colony of robots that extract the raw materials from which they are made on their own, process them into components, and use them to reproduce themselves. They would be controlled by a computer, and each would have outer shell and solar cells on their body to generate energy. The metabolism would be defined by the entire colony, and artificial intelligence would ensure adaptation to changing environmental conditions. Most of the components could even consist of organic chemical components. In contrast to biological life, which developed itself on a physicochemical basis, a colony of robots would be the result of human creation. Would we attribute the facet of life to this colony?

It becomes apparent that borderline areas exist that require longer discussion. From a certain point onward, the step toward life as we know it was taken. In the period prior to this, a transition from purely physicochemical to information-driven organic molecule formation must have taken place. This important period is narrowed down further in Sect. 8.3. Two further examples should show you how difficult it is to clearly describe life in just a few words. A group of experts around the chemist Gerald Joyce coined the definition: "Life is a self-sustaining chemical system with the capacity for Darwinian evolution" [4]. The US space agency NASA also uses it as a working definition. Stuart Kauffman, a US American theoretical biologist, on the other hand, focuses on self-organization: "Life is an anticipated collective asset of catalytic polymers for self-organization." [5].

The definitions by Joyce and Kauffman focus on chemical systems, which consequently exclude technical forms of self-organization. Kauffman's definition, however, would allow the thought experiment involving molecular soup in a larger vessel to be considered life. The robot community, which ultimately could be created by humans, would from a biological point of view almost approach what we consider to be life.

From the point of view of astrobiology, the search for a definition is important, because, in the search for life in space, the question could arise as to what signs of life we can accept as such (see more in Chap. 9).

1.3 Who Was LUCA?

On the basis of biochemical data, we have good reason to assume that all living beings on earth descend from just one ancestor. It must have been a cell that managed to grow and divide for the first time, actually leading to surviving daughter cells. The descendants needed to survive until they themselves divided again—a process which continues to this day. This first cell is called LUCA (Last Universal Common Ancestor), the last common ancestor of all living plants, fungi, and animals, including humans. For LUCA to form, a continuous production of molecules must have taken place long before that, which provided the necessary basic building blocks for the experiment we call life. These include organic bases, such as adenine or guanine, and amino acids or the lipids required for building cell membranes.

But building blocks alone are not enough. Spaces for reaction were also required where attempts to assemble more complex connections could take place. Small caverns or pores were sufficient in which the molecules could accumulate. Their concentration must have been at least high enough for them to meet and react with one another sufficiently frequently. A very large number of tiny labs were required, all linked to one another against a background of changing conditions, material replenishment, and the disposal of unusable components. That said, however, high-molecular concentrations also pose a new problem: the variation and the number of different molecules are so large that special selection processes are required to crystallize functional connections for life. The biological cell LUCA must have formed under such conditions as the most successful system that has ever been created on earth. From then on, planet earth entered into a unique development.

The composition of the atmosphere changed significantly as a result of photosynthetic bacteria and plants. While the level of carbon dioxide (CO_2) reduced, the oxygen content rose continuously. Organic acids and later on plant roots and the activities of animal contributed to increased weathering. On the one hand, this resulted in increased erosion, but, on the other hand, with the onset of soil development and the formation of plant cover, a delay in erosion processes. This changed the water balance in the rivers, and also the type of sediments and their transport. Organogenic sediments such as coal and reef limestone were formed, which again had a direct influence on the composition of the atmosphere through the carbon dioxide balance.

And finally, human beings appeared on the stage, who brought about changes over a short period of time, the scope of which can only be compared to the impact of a large meteorite. Ultimately, everything we see today on the hard surface of the earth is the result of the successful propagation of LUCA. Without LUCA, even mountains would look different today, free of biogenic limestones and oxidized iron minerals, manifesting other forms of erosion, and free of lichen and bacteria films. One small exception may exist that is still evident to us, however. These are the very young volcanic structures that protrude from the earth void of vegetation. But here, too, LUCA has had its fingers in many pies. The frequently red surfaces of the lavas, which contain ferrous minerals that have been oxidized by atmospheric oxygen, can be seen from afar. They are evidence of a change in the atmosphere that began more than 2.4 billion years ago, when the mass production of oxygen caused by cyanobacteria led to a constantly increasing concentration in the atmosphere.

1.4 The Beginnings

"How did life actually come about?" This question was posed to the small group of scientists who had gathered for the first time in the university cafeteria in Essen. Everyone looked at each other and shrugged. The opinion of everyone present was unanimous: "It's much too long ago to find out; we can only speculate; there's nothing really tangible; the general conditions are hidden in the fog of the past". "But's that the reason why we're meeting now, so we can talk about it in the first place," interjected one of the colleagues present. "I have a slight suspicion", I offered tentatively and began to sketch the model of a tectonic fracture zone on a napkin with a pencil…