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A REVIEW ARTICLE ON THE CHEMICAL ORIGIN OF LIFE

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ABSTRACT

This is an explanation of how life might have originated. It is written for non-specialists. The cooling by seawater of rocks under the floor of the ocean, played an important role in the origin of life. Such a process might seem remote from our everyday knowledge of life but it has now been known for more than twenty years that genetically primitive micro-organisms are to be found living at warm springs on the ocean floor.

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INTRODUCTION

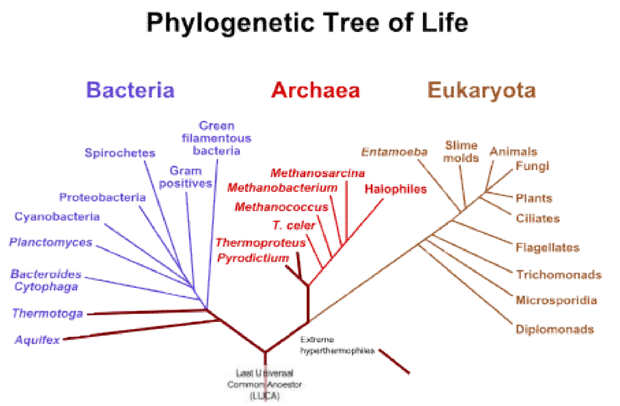
Abiogenesis or informally the origin of life is the natural process by which life arises from non-living matter, such as simple organic compounds. Abiogenesis is studied through a combination of paleontology, laboratory experiments and extrapolation from the characteristics of modern organisms, and aims to determine how pre-life chemical reactions gave rise to life on Earth. The study of abiogenesis can be geophysical, chemical, or biological, with more recent approaches attempting a synthesis of all three. Life itself is dependent upon the specialized chemistry of carbon and water and is largely based upon five different families of chemicals. Lipids are fatty molecules comprising large chemical chains of hydrocarbons and play an important role in the structure of living cell membranes, actively and passively determining the transport of other molecules into and out of cells. Carbohydrates are sugars, and as monomer units can be assembled into polymers called polysaccharides, such as cellulose, the rigid chemical of most plant cell walls. Nitrogenous bases are organic molecules in which the amine group of nitrogen, combined with two hydrogen atoms, plays an important part.

Chlorophyll is based upon a porphyrin ring derived from amine monomer units, and is important in the capture of the energy needed for life. Nucleic acid monomers are made from a carbohydrate monosaccharide, a nitrogenous base and one or more high energy phosphate groups. When joined together they form the unit of inheritance, the gene, made from DNA or RNA, which translates the genetic information into protein structures. The monomer unit of a protein is usually one of 20 amino acids, comprising an amine group, a hydrocarbon, and a carboxylic acid. Through a condensation reaction, in which the carboxylic acid of one amino acid is linked to the amine of another with removal of a water molecule, a peptide bond is formed. Polymers of amino acids are termed proteins and these molecules provide many catalytic metabolic functions for living processes. Any successful theory of abiogenesis must explain the origins and interactions of these five classes of molecules. Many approaches to abiogenesis investigate how self-replicating molecules, or their components, came into existence. It is generally thought that current life on Earth is descended from an RNA world, although RNA-based life may not have been the first life to have existed.

The classic Miller–Urey experiment and similar research demonstrated that most amino acids, the basic chemical constituents of the proteins used in all living organisms, can be synthesized from inorganic compounds under conditions intended to replicate those of the early Earth. Various external sources of energy that may have triggered these reactions have been proposed, including lightning and radiation. Other approaches ("metabolism-first" hypotheses) focus on understanding how catalysis in chemical systems on the early Earth might have provided the precursor molecules necessary for self-replication. Complex organic molecules have been found in the Solar System and in interstellar space, and these molecules may have provided starting material for the development of life on Earth. Oceans may have appeared first in the Hadean Eon, as soon as two hundred million years (200 Ma) after the Earth was formed, in a hot 100 °C (212 °F) reducing environment, and the pH of about 5.8 rose rapidly towards neutral. This has been supported by the dating of 4.404 Ga-old zircon crystals from metamorphosed quartzite of Mount Narryer in the Western Australia Jack Hills of the Pilbara, which are evidence that oceans and continental crust existed within 150 Ma of Earth's formation. Despite the likely increased volcanism and existence of many smaller tectonic "platelets," it has been suggested that between 4.4 and 4.3 Ga (billion year), the Earth was a water world, with little if any continental crust, an extremely turbulent atmosphere and a hydrosphere subject to intense ultraviolet (UV) light, from a T Tauri stage Sun, cosmic radiation and continued bolide impacts

Chemical Origin of Life

The chemical origin of life refers to the conditions that might have existed and therefore promoted the first replicating life forms. It considers the physical and chemical reactions that could have led to early replicator molecules.



What are the origins of life?

The origin of life is a scientific problem which is not yet solved. There are plenty of ideas, but few clear facts. It is generally agreed that all life today evolved by common descent from a single primitive life form.

What is the chemical evolution of life?

The formation of complex organic molecules from simpler inorganic molecules through chemical reactions in the oceans during the early history of the Earth; the first step in the development of life on this planet. The period of chemical evolution lasted less than a billion years.

How did life begin on Earth?

Scientists do not know how life began on Earth. They do know that the early Earth's atmosphere was very different from the atmosphere now. In 1952, Stanley Miller was working with Harold C. Urey designed an experiment to see how complex organic molecules might have formed under the conditions of early Earth. What is the origin of the earth?

Origin of Earth.

Earth, along with the other planets, is believed to have been born 4.5 billion years ago as a solidified cloud of dust and gases left over from the creation of the Sun.

Where did the life come from?

Simple organic molecules, similar to the nucleotide shown below, are the building blocks of life and must have been involved in its origin. Experiments suggest that organic molecules could have been synthesized in the atmosphere of early Earth and rained down into the oceans.

Who proposed the chemical evolution of life?

In the first stage of chemical evolution, molecules in the primitive environment formed simple organic substances, such as amino acids. This concept was first proposed in 1936 in a book entitled, "The Origin of Life on Earth," written by the Russian scientist, Aleksandr Ivanovich Oparin.

When did life begin?

When Did Life on Earth Begin? Ask a Rock. Does the first evidence of life date to3.85 billion years ago (Ga), or 3.65 Ga? A 200-million-years discrepancy may seem trivial almost 4 billion years after the fact.

How did life come to be?

The first living things on Earth, single-celled micro-organisms or microbes lacking a cell nucleus or cell membrane known as prokaryotes, seem to have first appeared on Earth almost four billion years ago, just a few hundred million years after the formation of the Earth itself.

How did the human start?

Human evolution is the lengthy process of change by which people originated from apelike ancestors. ... Humans first evolved in Africa, and much of human evolution occurred on that continent. The fossils of early humans who lived between 6 and 2 million years ago come entirely from Africa.

How did humans evolve?

Humans did not evolve from apes, gorillas or chimps. We are all modern species that have followed different evolutionary paths, though humans share a common ancestor with some primates, such as the African ape. The timeline of human evolution is long and controversial, with significant gaps.

What is the RNA world hypothesis and why is it called that?

According to the RNA World Hypothesis, life later evolved to use DNA and proteins due to RNA's relative instability and poorer catalytic properties, and gradually, ribozymes became increasingly phased out. The ribosome, a large molecular machine that drives protein synthesis, is a ribozyme.

Can RNA replicate?

RNA should in theory be able to self replicate without the help of proteins however this is not seen in nature. There are RNA molecules catalyse chemical reactions, a role usually carried out only by protein enzymes, these are called ribozymes.

7 Theories on the Origin of Life

Primordial soup

Life on Earth began more than 3 billion years ago, evolving from the most basic of microbes into a dazzling array of complexity over time. But how did the first organisms on the only known home to life in the universe develop from the primordial soup? One theory involved a “shocking” start. Another idea is utterly chilling. And one theory is out of this world! Inside you’ll learn just how mysterious this all is, as we reveal the different scientific theories on the origins of life on Earth.

Panspermia

Perhaps life did not begin on Earth at all, but was brought here from elsewhere in space, a notion known as panspermia. For instance, rocks regularly get blasted off Mars by cosmic impacts, and a number of Martian meteorites have been found on Earth that some researchers have controversially suggested brought microbes over here, potentially making us all Martians originally. Other scientists have even suggested that life might have hitchhiked on comets from other star systems. However, even if this concept were true, the question of how life began on Earth would then only change to how life began elsewhere in space. Oh, and if you thought all that was mysterious, consider this: Scientists admit they don’t even have a good definition of life!

Simple Beginnings

Instead of developing from complex molecules such as RNA, life might have begun with smaller molecules interacting with each other in cycles of reactions. These might have been contained in simple capsules akin to cell membranes, and over time more complex molecules that performed these reactions better than the smaller ones could have evolved, scenarios dubbed "metabolismfirst" models, as opposed to the "gene-first" model of the "RNA world" hypothesis.

RNA World

Nowadays DNA needs proteins in order to form, and proteins require DNA to form, so how could these have formed without each other? The answer may be RNA, which can store information like DNA, serve as an enzyme like proteins, and help create both DNA and proteins. Later DNA and proteins succeeded this "RNA world," because they are more efficient. RNA still exists and performs several functions in organisms, including acting as an on-off switch for some genes. The question still remains how RNA got here in the first place. And while some scientists think the molecule could have spontaneously arisen on Earth, others say that was very unlikely to have happened. Other nucleic acids other than RNA have been suggested as well, such as the more esoteric PNA or TNA. A study in 2015 suggests the missing link in this RNA puzzle may have been found.

Chilly Start

Ice might have covered the oceans 3 billion years ago, as the sun was about a third less luminous than it is now, scientists say. This layer of ice, possibly hundreds of feet thick, might have protected fragile organic compounds in the water below from ultraviolet light and destruction from cosmic impacts. The cold might have also helped these molecules to survive longer, allowing key reactions to happen.

Deep-Sea Vents

The deep-sea vent theory suggests that life may have begun at submarine hydrothermal vents spewing key hydrogen-rich molecules. Their rocky nooks could then have concentrated these molecules together and provided mineral catalysts for critical reactions. Even now, these vents, rich in chemical and thermal energy, sustain vibrant ecosystems.

Community Clay

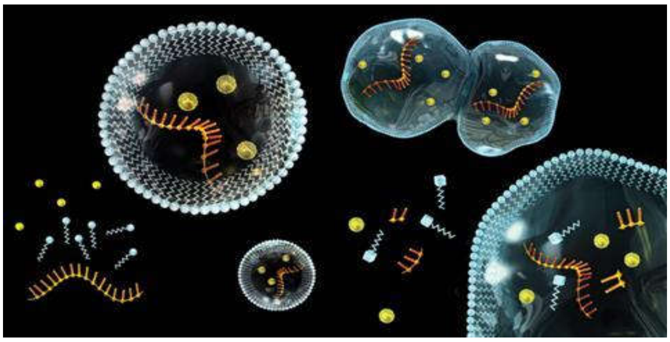
The first molecules of life might have met on clay, according to an idea elaborated by organic chemist Alexander Graham Cairns-Smith at the University of Glasgow in Scotland. These surfaces might not only have concentrated these organic compounds together, but also helped organize them into patterns much like our genes do now. The main role of DNA is to store information on how other molecules should be arranged. Genetic sequences in DNA are essentially instructions on how amino acids should be arranged in proteins. Cairns-Smith suggests that mineral crystals in clay could have arranged organic molecules into organized patterns. After a while, organic molecules took over this job and organized themselves.

Electric Spark

Lightning may have provided the spark needed for life to begin. Electric sparks can generate amino acids and sugars from an atmosphere loaded with water, methane, ammonia and hydrogen, as was shown in the famous Miller-Urey experiment reported in 1953, suggesting that lightning might have helped create the key building blocks of life on Earth in its early days. Over millions of years, volcanic clouds in the early atmosphere might have held methane, ammonia and hydrogen and been filled with lightning as well.

How did molecules turn into living organisms?

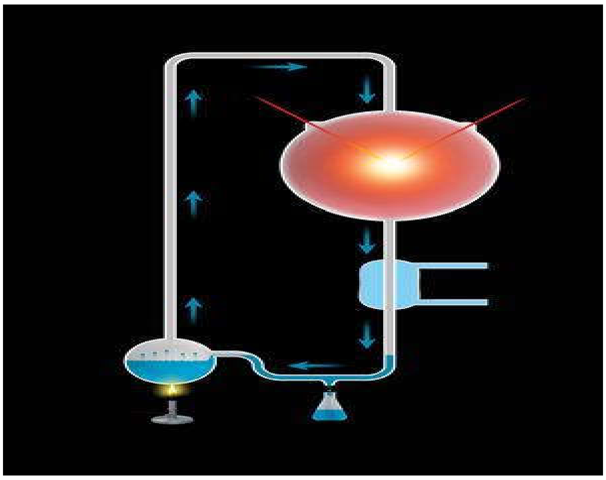
If I were to ask you to think of something living and something inanimate, you would probably be thinking of two very different things. There’s a gulf of complexity between you and the chair you are (perhaps) sitting on, between a mountain and the tree growing on its slopes. But despite the complexity of life compared with the relative simplicity of inanimate objects, if we zoom in on the line that divides the two, we find it’s blurrier than our macroscopic world suggests. Viruses, for example, are distinctly biological. They have a genome and a protein capsid. Some are even enveloped in a lipid membrane.



And they evolve, just like living organisms. But they are not alive. Well, most biologists agree they are not alive – it really depends where you draw the line. Viruses can't self-replicate – a key feature of living organisms – they require a host cell to do the work of replication for them. This blurry line has fascinated chemists for decades. You see, somewhere in Earth's history a collection of barely inanimate molecules crossed that threshold and became a living organism, and we want to know what it looked like and how it came into existence.

The features of life

Solving the problem of the origin of life is very much a problem of chemistry. How did complex systems of chemical reactions on the prebiotic Earth lead to living organisms? But to tackle it, we need to start from a philosophical point of view and define some of the functions an organism needs to be called living. First of all, an organism needs to be discrete, organised and able to maintain its internal environment. So it needs compartmentalisation – a cell wall in modern biology, or something very much like it. The organism also needs to grow. In chemical terms, we can broadly define this as metabolism – a system of chemical pathways that turn external resources (food) into energy (catabolism) and new components of the organism (anabolism).



And lastly, as we've already seen, a living organism needs to reproduce, or, at the molecular level, self-replicate. We can divide the process of self-replication into two functions: the means to self-replicate and the information that needs to be replicated. In most modern organisms these roles are carried out by proteins and DNA.

The first bright spark

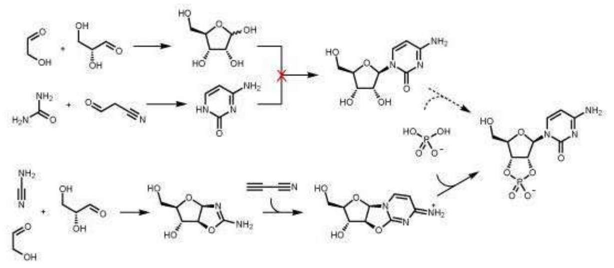
The search for the chemical origin of life began in 1952 when Stanley Miller, a chemist at the University of Chicago, US, first tried to test how biological molecules could have been made on the ancient Earth. In his famous experiment, Miller, along with Harold Urey, simulated the atmosphere of the early earth with a mixture of water, methane, ammonia and hydrogen. To provide an energy source, they simulated lightning by producing a spark in the gaseous mixture. After running for just a week, this simple experiment produced a host of organic and inorganic molecules, including most of the amino acids we see in biological proteins. At the time, proteins were viewed as the main component of cellular systems. The experiment showed for the first time that a 'primordial soup' model for life's origins, where complex systems of reactions led to the synthesis of ever more complex molecules, might be more than speculation.

The rise of the nucleotide

Just a year after Miller and Urey's experiment, Francis Crick and James Watson published the structure of DNA. This soon led to new theories of life's origin. Watson and Crick realised that life's genetic code – the code that defines the function of all biological systems – was tied up in nucleic acids, polymers of nucleotide units. Perhaps life could have begun here, with DNA's precursor, RNA? RNA could provide the information storage needed to bootstrap the first living organisms, but there was a problem. The synthesis and replication of RNA is carried out by protein catalysts – but the structure of the proteins is encoded by RNA. How could one precede the other? Leslie Orgel at the University of Oxford, UK, was among the first to propose a solution. RNA can do more than store information; it can also catalyse the chemical reactions needed to make itself. A new theory was born, later dubbed the 'RNA world hypothesis'. Perhaps short sequences of RNA in the primordial soup could have catalysed the synthesis of identical sequences – they could self-replicate. In time, through slow evolution and building up of new functions, the information carrying role of RNA would be taken over by the more stable DNA, and the duty of replication taken over by more catalytically versatile proteins.

Building it up

The RNA world hypothesis received a huge boost in 2009. Matt Powner, a chemist at University College London, UK, then working at the University of Manchester for John Sutherland, was part of a team that showed how RNA nucleotides could be made from very simple molecules likely to be present in prebiotic conditions. This was no small feat. Ever since the early days of the RNA world hypothesis, chemists have been scrambling to build RNA from simple building blocks, but had never been successful. 'There was a lot in the literature saying that this is impossible, that you can't make the nucleotides,' says Matt. 'They looked at the nucleotide and saw that it was built of three parts: a phosphate, a ribose sugar and a nucleobase. The parts are constitutionally different, so people separated them along those lines.' The synthesis looked logical, chemists tried building the three parts and then couple them together. This was the approach taken by Orgel. He found he could make one of the nucleobases, adenine, but only as a minor component of a mixture. He ploughed on, attempting to couple a sugar to the nucleobase. 'It worked a little bit for adenine, but not at all for the other nucleobases,' says Matt. 'Coupling nucleobases to sugars is difficult, even in a lab using protecting groups and coupling agents.'

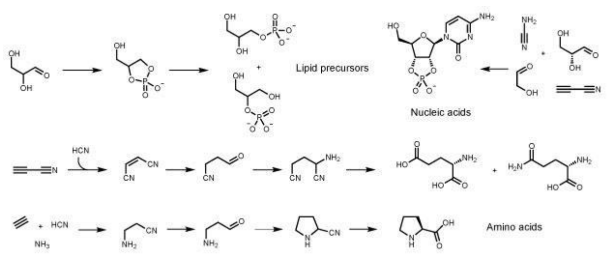


Orgel also tried making the ribose component, but always ended up with a mess. The reactions involved produced a large number of compounds where the ribose he was looking for was a tiny component of the mixture. The Manchester team's solution was to build the structure of the ribose and nucleobase at the same time. Using just cyanamide, glycolaldehyde and glyceraldehyde they were able to show that a fused ring system containing all the atoms needed forms quite easily under plausible prebiotic conditions. Then, by breaking one of the bonds of the ring system, they had accomplished what Orgel hadn't, a coupled ribose and nucleobase. Just adding a phosphate completed the nucleotide. It was the first time experimental evidence of the plausible formation of RNA in the primordial soup had been found.

Breaking it down

While the RNA world hypothesis focuses on replication, alternative theories of the origin of life have emphasised the role of defined, self-sustaining systems of ordered chemical reactions. There are many metabolism-first ideas, but the iron-sulfur world is the most prominent. First proposed by Günter Wächtershäuser, the iron-sulfur world model suggests that iron sulfide mineral deposits near deep-sea hydrothermal vents could catalyse complex sequences of reactions, driven by the energy from the vents. The development of these reaction systems would, in time, lead to life. The iron-sulfur world and other metabolism-first hypotheses have received a lot of attention from scientists. But there has been disagreement between proponents of replication-first theories and metabolism-first theories about which origin of life is most plausible. 'This is a historical artefact of the field,' says Matt. 'At least, I hope it will be. The way the field has developed has led researchers to set up camp in their own area and try to come up with an origin theory completely within their field.

'That's not to say there aren't some very good ideas in different theories. I think it's more likely that, instead of just one complex component arising first, several different components providing different functions would have come together to start the process of life.'



Last year, John Sutherland, now at the University of Cambridge, reported the first experimental evidence to back up Matt's hunch.

John's discovery was that lipids, amino acids and nucleotides – most of the fundamental cellular components – can all be made from just hydrogen cyanide, hydrogen sulfide and a few other simple molecules. These compounds were almost certainly very abundant on the early Earth. The conditions for these reactions were also very plausible, needing only ultraviolet light. The process can even be catalysed by copper, similar to the ideas proposed in the iron-sulfur world hypothesis. Describing a complicated diagram of a system of reactions from the paper, 'That's my point in one scheme,' says Matt.

Making life

The picture that emerges suggests that most of the molecular components we see in cells today were available in prebiotic conditions. Specific nucleotide–protein complexes may have been able to auto-catalyse formation of molecules identical to themselves. Lipids would form micelles, encapsulating other bio precursors. Slowly, over millions of years, organised systems of contained reactions may have gained the ability to grow, and maybe self-replicate. So what does Matt think that first organism looked like? What components were present, and what functions were they performing?. 'That's a super difficult question to answer, and, honestly, I don't know. But I think you need compartmentalisation, and lipids seem like the simplest way to get that. And you need something that can be replicated – that's probably polymeric, like a nucleic acid. The question then is, what do you need to sustain replication? You need to keep building the nucleotides and lipids, so you probably need amino acids. So I think most of what we now call biology was there.'

But even if we can determine the molecules present at the beginning of life, we're only a small part of the way there. The presence of biological material doesn't mean something is alive. 'Even if I gave you all the components of a cell, you couldn't just shake it up and have life,' says Matt. 'We still don't have any clue about how you get from just a mixture of the components of life to the level of molecular cooperation you need for the mixture to be alive. 'How can we assemble the compounds into something that functions? That will be the real challenge.' We're only starting out on that journey, but Matt is convinced we'll one day be able to make a living organism from scratch. 'Is there anything more interesting, exciting and fundamental to our understanding of our world than our origins and the potential for that origin to be replicated on other planets? Mastering this, has untold potential for the control of chemistry and materials. It is too big to ignore, so someone will achieve it one day.'

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