A pair of experiments reveal new details regarding the origin of life on Earth

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One of the central questions in biology is how life first evolved from inanimate matter, known as abiogenesis. It has long been hypothesized that the origin of life on Earth involved the evolution of molecules, floating in the "primordial soup" 4 billion years ago, that assembled themselves into structures that self-replicate. Two recently reported research projects bring us closer to an understanding of possible mechanisms by which that took place.

At the most basic level, a living organism is one that can reproduce itself by incorporating raw materials from its environment (i.e., nutrients) and use these materials to make more or less identical copies of itself. In order for the copies to resemble the original, there must be a recorded pattern, a code, which determines the form of the copies.

All life on Earth is based on two complex molecules: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which constitute the code by which the information to construct and reproduce an organism is recorded and implemented. Both are composed of chains of chemicals known as nucleotides. Sets of three nucleotides specify a particular amino acid. The sequence of these nucleotide "triplets" in any given DNA or RNA molecule constitutes a code that can specify a series of amino acids which together compose a particular protein. Proteins are a basic building block of living organisms.

DNA is the famous double helix, the structure of which was first discovered by James Watson and Francis Crick. Its structure consists of two parallel strands of nucleotides entwined helically. RNA exists as a single strand of nucleotides, though it can form double strands and thereby replicate itself.

In addition, not only must living organisms reproduce themselves, but they must have the ability to adapt to a changing environment, in other words, to evolve through succeeding generations, classically known by the Darwinian phrase "descent with modification." Otherwise, if replication were perfect every time, no change would occur, and the pattern would simply be repeated ad infinitum, like the growth of a crystal, and the myriad living organisms that have existed on Earth would never have evolved.

How did these properties originate?

The current dominant theory, known as the "RNA world," formulated by Walter Gilbert in 1986, holds that the first living organisms were based on RNA as their genetic material, with DNA-based organisms evolving later, presumably as an evolutionary development from an RNA ancestor.

In the first of the two recent studies, a Japanese team, based at the University of Tokyo, used RNA sequences that, under specific conditions, spontaneously replicated themselves and underwent modification in subsequent generations (Mizuuchi, Furubayashi, and Ichihashi, "Evolutionary transition from a single RNA replicator to a multiple replicator network," *Nature Communications*, March 18, 2022).

They posed their research question as follows. "An origins-of-life scenario depicts Darwinian evolution from self-replicating molecules, such as RNA, toward complex living systems. How molecular replicators could develop complexity by continuously expanding information and functions is a central issue in prebiotic evolution."

This team conducted a long-term experiment in which they encased RNA molecules obtained from *Escherichia coli* (a common bacteria), in water-in-oil droplets, heating them, and introducing additional nucleotides as raw material. They found that over time, as new copies of the RNA molecules were generated, the original sequences mutated, creating distinct lineages. Notably, the new lineages did not undergo further mutations at the same rate and began to differentiate due to imperfect replication, indicating the potential for different evolutionary trajectories and, in effect, manifesting the potential for different evolutionary "fitness" which would have been subject to natural selection. They also found that different lineages interacted with each other in replication, creating a complex, interdependent system.

The researchers concluded, "Our results provide evidence that Darwinian evolution drives complexification of molecular replicators, paving the way toward the emergence of living systems." Thus, natural chemical processes not only produce molecules that replicate themselves but launch a self-sustaining trajectory to increasing complexity.

One of the team, Ryo Mizuuchi, explained to *OnlySky*, "The simplicity of our molecular replication system, compared with biological organisms, allows us to examine evolutionary phenomena with unprecedented resolution. The evolution of complexity seen in our experiment is just the beginning. Many more events should occur towards the emergence of living systems."

He added, "We found that the single RNA species evolved into a complex replication system: a replicator network comprising five types of RNAs with diverse interactions, supporting the plausibility of a long-envisioned evolutionary transition scenario."

A second experiment was conducted by a different set of researchers, based at the Ludwig-Maximilian University in Munich, Germany (Muller et al, "A prebiotically plausible scenario of an RNA-peptide world," *Nature*, May 11, 2022). This team set out to examine how, prior to the appearance of DNA, the first life forms, based on RNA, could begin to assemble amino acids into proteins. It had been previously observed that RNA strands become increasingly fragile as they lengthen, thus posing the question of how RNA could assemble more than short segments of amino acids, also known as peptides, which are intermediate steps in the construction of proteins.

It has long been known that nucleic acid strands in both RNA and DNA contain segments that code specifically for the assembly of amino acids into proteins and others the function of which was unclear. The research by Muller et al demonstrates that these "non-coding" segments of RNA can bond with amino acids to form structures, some relatively complex, that strengthen the RNA strand and form a "scaffolding" on which longer segments of amino acids can be assembled by the "coding" sections of the RNA.

The German research appears to address earlier criticisms of the RNA-world scenario which contend that RNA alone could not have fulfilled the necessary replicatory and information storage functions necessary to initiate life. RNA by itself does not have what one critic called "computational reflexivity," the capacity to accurately reproduce itself. These critics proposed an RNA-peptide world in which combinations of these two molecules had this property. This is what the German team has found.

In many modern organisms, DNA functions as the primary mechanism by which genetic information is stored in order not only to direct the growth and function of an individual organism but also to transmit the code to produce the next generation. RNA operates in a "supportive" role within a cell, functioning to transfer sections of code to assemble the necessary amino acids to construct specific proteins in intra-cellular structures called ribosomes.

The combined results of these two studies provide key details regarding the initial evolution of life from "non-life." Many questions remain. How did DNA develop? How did RNA become incorporated in a "subordinate" role within cells where DNA functions as the primary information repository?

Nevertheless, the results of these two research projects contribute to the demystification of the origin of life and reinforce our understanding that living things, including humans, do not embody some mysterious "divine spark," as religion would have it, but instead are the product of natural, scientifically understandable laws of the material world. And, furthermore, that if suitable, though not necessarily identical, conditions exist on other planets in the Universe, life is likely to exist elsewhere as well.