Is the Origin of Life Inevitable?

One of the simplest, yet most intriguing questions in astronomy and astrobiology comes from the famed Fermi Paradox which asks, ‘where is everybody?’ The paradox considers that our galaxy and beyond contains near countless stars and likely even more planets. Surely some of these planets host conditions suitable for life to form, but if that is the case then why do we not see the galaxy bustling with life? One proposed solution is dubbed the ‘Great Filter.’[1] This solution states that at some point between ‘pre-life’ and the advancement of life becoming an intelligent ‘Type III’ civilization (see Kardashev Scale[2]), it will experience some event, or ‘wall’ that is extremely difficult or nearly impossible to pass. That begs the question: what is the ‘wall’ and when does it occur in the development of life and civilization? While I will not be determining where/when the filter *is*, I will argue somewhere it is *not*: abiogenesis. Given an environment suitable for the formation of organic compounds, life is likely to form. If suitable conditions are sustained for a substantial amount of time, the formation of life is inevitable.

In the following paragraphs, I will first discuss what organic compounds are and provide evidence that they are common throughout the solar system. Then I will describe how these simple compounds can combine to produce complex structures and thus begin self-replication with the ‘RNA world’ hypothesis. Finally, I will argue that complicated chemical structures such as in the ‘RNA world’ hypothesis is favorable according to physical laws and thus will inevitably form life.

I will first discuss the basis for this argument – that organic compounds are abundant and can be easily produced given the right conditions. Organic compounds are the molecules

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[1] https://waitbutwhy.com/2014/05/fermi-paradox.html

[2] https://en.wikipedia.org/wiki/Kardashev_scale

(carbon-based) life requires to form. Organic compounds ultimately combine to form carbohydrates, lipids, proteins, and nucleic acids[3]. Carbohydrates provide energy for living things; lipids form fats, but more importantly (for the formation of life) they create membranes; proteins are complex chains of relatively simple amino acids and makeup the structure of organisms; and nucleic acids form the blueprints of life in the form of RNA and DNA. Though these are complex structures, the organic compounds from which they are constructed have been found to be created when a source of energy is applied to an early-Earth-like atmosphere. This is the famous Miller-Urey experiment[4]. The early-Earth-like atmosphere used in the experiment contained only a few molecules: methane (CH_4), ammonia (NH_3), water (H_2O), and molecular hydrogen (H_2). These few molecules, however, are abundant throughout the universe. This abundance implies that the possible creation of these important organic compounds, which help to form the building blocks of life, is likely common throughout the solar system and beyond. In fact, organic compounds have been found on comets[5], asteroids[6], and even other planetary bodies[7].

Now that we have established that organic compounds are quite abundant in our solar system (and likely beyond), how might these lifeless structures form life? First, the individual organic compounds called monomers must combine to form more complicated structures called polymers. Polymers can form through a variety of processes which all fall under the umbrella term polymerization. From here, one of the most important steps in the process of creating life

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[3] https://www.cliffsnotes.com/study-guides/biology/biology/the-chemical-basis-of-life/organic-compounds

[4] *Astrobiology.* Charles Cockell. Pg. 201-202

[5] http://www.astronomy.com/news/2017/12/comet-67p

[6] https://www.jpl.nasa.gov/news/news.php?feature=5787

[7] https://www.universetoday.com/143642/the-raw-materials-for-amino-acids-which-are-the-raw-materials-for-life-were-found-in-the-geysers-coming-out-of-enceladus/

must occur: beginning self-replication. However, this is not an easy step and a step that could make life avoidable.

One possible theory as to how polymers became self-replicating is the 'RNA World' hypothesis. This hypothesis states that during Earth's early history, RNA began self-replicating, mutating and evolving, and interacting its environment, ultimately creating more complex structures that functionally give rise to life. RNA, a polymer of nucleic acids, has been shown to fold onto itself (some nucleic acid bases bond with other bases on the same strand) and be capable of catalyzing chemical reactions. These folded, catalyzing RNA strands are called ribozymes. The ability of these ribozymes, in effect, allowed for a kind of chemical Darwinian evolution to begin[8]. However, there is currently debate to whether nucleic acids or proteins (polymers of amino acids) formed first, like a chicken-and-egg debate: "DNA and RNA carry the instructions for making proteins, and proteins extract and copy those instructions as DNA or RNA. Which one could have originally handled both jobs on its own?"[9] The article continues,

> For decades, the favored candidate has been RNA — particularly since the discovery in the 1980s that RNA can also fold up and catalyze reactions, much as proteins do. Later theoretical and experimental evidence further bolstered the "RNA world" hypothesis that life emerged out of RNA that could catalyze the formation of more RNA.
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> But RNA is also incredibly complex and sensitive, and some experts are skeptical that it could have arisen spontaneously under the harsh conditions of the prebiotic world. Moreover, both RNA molecules and proteins must take the form of long, folded chains to do their catalytic work, and the early environment would seemingly have prevented strings of either nucleic acids or amino acids from getting long enough.[9]

Herein lies the issue: If RNA or protein formation is inevitable, life is inevitable. If formation is avoidable, life is avoidable.

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[8] *Astrobiology.* Charles Cockell. Pg. 205-208

[9] https://www.quantamagazine.org/lifes-first-molecule-was-protein-not-rna-new-model-suggests-20171102/

Because the ‘RNA world’ is still considered the leading theory, I will focus on it rather than proteins. So, the question has now shifted from ‘is the origin of life inevitable?’ to ‘is spontaneous synthesis of RNA inevitable?’ Let’s take a step back and instead of looking through the lens of chemistry, let’s look at the situation through the lens of physics. One could argue that the generation of complex structures from molecules is unlikely due to the second law of thermodynamics, which states that the entropy of a system must increase. Organized structures have low entropy, so constructing a complex structure would not increase the entropy of the system – this is true for a closed system. However, an open system, “can keep its entropy low — that is, divide energy unevenly among its atoms — by greatly increasing the entropy of its surroundings.”[10] In our case, an open system is one that does not have a constant energy - for example, a star providing light (and thus energy) to our system. Because of the second law of thermodynamic, the system will still want to tend towards increasing entropy and one way this can be achieved is by sacrificing a small amount of entropy in organizing a complex structure which will ultimately dissipate heat (increase entropy) more effectively than a non-complex structure. According to Jeremy England and the article *A New Physics Theory of Life*[10]:

> England then determined how such systems tend to evolve over time as they increase their [entropy]. “We can show very simply from the formula that the more likely evolutionary outcomes are going to be the ones that absorbed and dissipated more energy from the environment’s external drives on the way to getting there,” he said. The finding makes intuitive sense: Particles tend to dissipate more energy when they resonate with a driving force, or move in the direction it is pushing them, and they are more likely to move in that direction than any other at any given moment.
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> “This means clumps of atoms surrounded by a bath at some temperature, like the atmosphere or the ocean, should tend over time to arrange themselves to resonate better and better with the sources of mechanical, electromagnetic or chemical work in their environments,” England said.

[10] https://www.quantamagazine.org/a-new-thermodynamics-theory-of-the-origin-of-life-20140122/

If creating a complex structure can ultimately increase the entropy of a system, self-replication could even further increase the entropy of the system[10]. This mechanism, backed by statistical physics, shows that not only is it possible for complex structures, such as RNA, to form and self-replicate, but it is likely. Not only does this concept apply to RNA, but we can apply it to lipid bi-layer membranes as well. Lipids tend to naturally form bi-layer vesicles which can enclose RNA and proteins. This primitive cell could take in molecules (such as carbohydrates), drive some chemical process (such as the "production of RNA polymers") and excrete by-products[11]. This sequence represents a simple metabolism that would then begin to place Darwinian pressure on the entire 'cell' instead of individual molecules. Thus, the beginnings of life.

Now, I will provide some counter arguments and attempt to refute them. To begin, if organic compounds inevitably lead to life, as I have argued, then why has life not been found to flourish on the comets, asteroids, and other planetary bodies where those compounds have been found? My answer is that these bodies are missing some key ingredients needed to assist in the formation of life. The first being energy. These bodies are under the influence of our Sun, so they do indeed have a source of energy, however the energy they receive is not sufficient to begin catalytic reactions. Most comets have highly elliptical orbits and rarely ever near the sun. They spend most of their lifetime out among the Kuiper Belt and beyond, or travelling from way out to quickly swing past the Sun and back from which they came. Most asteroids live in the asteroid belt between Mars and Jupiter. This is beyond the Sun's 'habitable zone' which is often defined as the region from a star where H_2O can exist in liquid form. This fact leads me into the other ingredient that these bodies are missing: a good solvent– water. Comets are known to have ice; however, ice is not able to act as a solvent because it is solid. So, without a good solvent, being

[11] *Astrobiology.* Charles Cockell. Pg. 208-210

able to dissipate energy and entropy becomes much more difficult, and thus the formation of complex structures does as well.