Non-Carbon Based Life

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Science is frequently impressed by the adaptability and tenacity of living organisms. Humans, animals and plants are forms of carbon-based life, with proteins, sugars, fats and tissues all incorporating carbon as the primary building block of life. While carbon-based life is common on Earth, scientists have investigated the possibility of alternative forms of life existing, potentially based on similar elements to carbon, such as silicon or germanium.

Carbon has a number of properties that make it a viable building block for life. Carbon has an electron configuration that holds four valence electrons, the electrons in the outer most orbital of an atom, which in carbon is its second orbital [1]. In order to be stable, carbon requires a full outer shell of 8 electrons. Carbon is able to form long chains of molecules with other elements, such as hydrogen, and these hydrocarbons are essential to life on Earth. Carbon also commonly bonds with itself and holds these bonds when immersed in water, a requirement for life on Earth, since water is the liquid medium that has allowed life to develop [1]. Carbon also reacts with oxygen, forming molecules such as carbon dioxide, a product of respiration in many forms of life on Earth. Oxygen requires two additional valence electrons to become stable, and a carbon atom can form double bonds with two oxygen atoms to create a stable molecule. Life also requires energy, and in carbon-based life this is in part made possible through carbohydrates, molecules of carbon, oxygen and hydrogen which store energy that organisms can regulate and consume [2].

In the search for non-carbon based life, silicon has been proposed as one of the most likely alternatives. Silicon is directly below carbon on the periodic table and is similar to carbon in that an atom of silicon also has exactly four valence electrons. While this electron configuration is the primary reason that carbon is prevalent in living organisms, it is not as useful in silicon. Silicon has more difficult forming the essential double bonds that is a common feature of carbon because of its larger size and these bonds are less stable [3]. Silicon also has its four valence electrons in its third orbital which has a maximum electron capacity of 18, meaning that while carbon frequently combines with elements like hydrogen to form a stable molecule with a full outer orbital, the same combination of silicon and hydrogen does not complete its outer orbital. This causes silicon bonds to be approximately half as strong as carbon bonds and makes it a worse candidate for the long chains of molecules that form the basis of carbon-based life [1]. Silicon also does not bond as effectively to other silicon atoms and will break down in liquids like water, the medium essential for life on Earth. Additionally, while carbon and oxygen react to make carbon dioxide, a gas that is readily available to combine with other molecules, silicon reacts with oxygen to produce silicon dioxide, the mineral quartz [1]. As a result of all of these factors, silicon has a minimal role in the development of life here on Earth.

While carbon is a much better building block for life on this planet, scientists have considered extraterrestrial environments where silicon may be able to establish a foothold in the processes of life. Water is not a good medium for silicon based life, however, other liquids like methane are considered to be a potential alternative. Scientists have considered the possibility of silicon-based life on Titan, the largest moon of Saturn, which has a cold enough surface temperature to allow for the formation of liquid methane deposits [4]. Chains of silicon molecules called silanes are stable in liquid methane and this combination could form the building blocks of life in the same way that carbon chains in water do on Earth [4]. This situation is unlikely on Titan, however, as the silicon on Titan is largely buried beneath the ground near the moon's core, far from the liquid methane that runs along its surface.

While substituting silicon for carbon in the chemical processes that allow for life does not look promising, scientists have discovered ways of using silicon in combination with carbon. In 2016, researchers at Caltech found an enzyme of a bacterium that that combines silicon into hydrocarbons as part of its job moving electrons to different proteins [5]. The team "incubated the bacteria with silicon and carbon compounds and selected the organisms that produced the most hydrocarbons incorporating silicon" [5]. At the end of this process, they had created "silicon containing hydrocarbons 2000 times as readily" as the original enzyme, highlighting the potential for evolution to use silicon in the essential hydrocarbons of life.

Even in highly controlled environments, science has had difficult incorporating silicon into the biological processes of life and it is unlikely that silicon composes the dominant building blocks of life anywhere on Earth or in this solar system. The likelihood of other forms of life not based on either silicon or carbon is even slimmer. Both germanium and tin fall in the same column of the periodic table as carbon with four valence electrons in their outermost orbits. These atoms, however, are even larger than silicon and have even weaker bonds because of the greater distance separating the atoms [6]. It is therefore likely that the next lifeforms that humanity discovers will share its foundation of a carbon based biology.

References

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