Alternative biochemistries for life on earth

Though the terrestrial living systems are dominated by Carbon, alternative biochemistries based on elements such as Sulphur, Phosphorous, Silicon and Germanium have also been considered.

Questions are always raised as to whether exobiological life could be based on completely different chemistries, in contrast to the exclusively carbon-dominated terrestrial living systems.

A single carbon atom can bond with up to four atoms at a time (hydrocarbons (Cn H2n+2) are an example). The versatility of its tetravalent bonding capabilities is that which makes carbon the basis for terrestrial organic life.

Again life on earth (in its current forms at least!) depends on its oxygen-rich atmosphere and availability of water. Carbon readily combines with oxygen to form carbon dioxide, utilised by plants to synthesize complex molecules. Oxygen also leads to the formation of ozone, which prevents the harmful UV radiation. In fact, it has been suggested that spectroscopic signatures for life-supporting terrestrial type planets should include the search for ozone, methane and water. So, not only we have the unique bonding properties of carbon but also its favourable synergistic coupling to oxygen and water.

Silicon

Among all the other elements of the periodic table, only silicon has the tetravalent bonding ability and has been seriously considered as an alternative biochemical building block. With our increasing dependence on computing systems and software, silicon-based life of a different sort is surely on the rise.

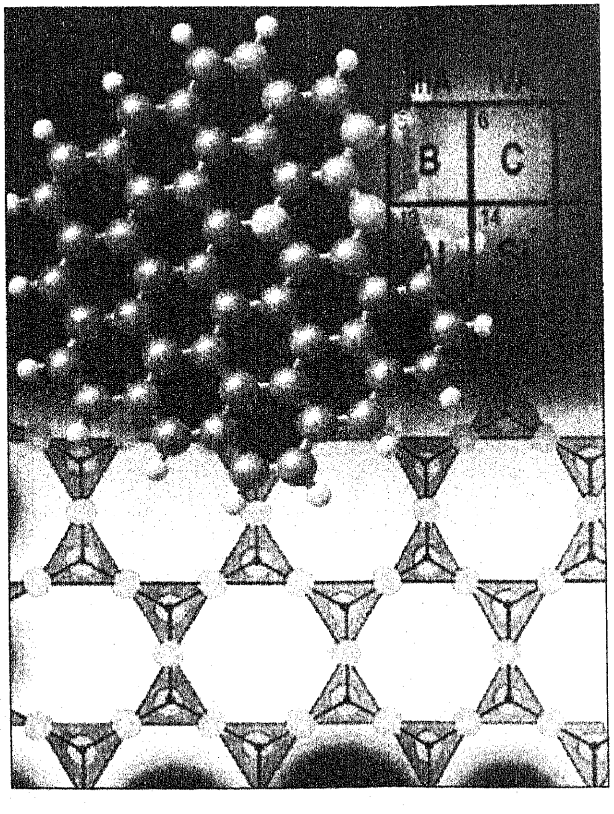
Both carbon and silicon having -sufficiently small atomic numbers enabling the formation of complex molecules. They are solids at ordinary conditions having high melting and boiling points (well above 3000 degrees); and are semi-metallic.

Silicon atoms (having larger atomic number) have however a larger diameter than carbon atoms, which makes their bond energies with other elements correspondingly weaker. C-C bond is stronger than a Si-Si bond. So, carbon is better at combining with lighter elements (like hydrogen) and also bonds more strongly with itself making it more suitable for forming complex molecules. Besides, carbon is three times more abundant than silicon in the universe. Silicon atoms bond more readily with hydrogen and oxygen atoms than among themselves! Again, the ability to form strong double and triple bonds is far less prevalent for silicon atoms. This implies that the formation of ring-based silicon structures and long chain silicon polymers is not so easy as in the case of carbon.

Silicates

Silicon's bonding with oxygen leads to silicates and its bonding with hydrogen leads to silanes. Polymeric molecules need not be made up of long chains of one element only, alternating atoms of two or more elements forming the chain, may also be effective. Most of the silicon on earth has reacted with oxygen atoms to form inert silicate material which forms the bedrock for minerals and rocks. Silicon is also involved in some vital life processes like bone growth and rejuvenation in vertebrates. Silicic acid is an important constituent of skin and nail cells while the presence of silica in the stem walls of plants gives them rigidity, making them less fragile.

Silanes are the analogs of hydrocarbons (formula SinH2n+2). Silane rings are absent, while silanes transform easily to silicates in the presence of oxygen. Very high molecular weight polysilanes and silicone polymers have been synthesised by replacing hydrogen (hydrides) with organic groups but these compounds are stable only at high pressures and low temperatures. Si-O and Si-C bonds are comparable to C-C bonds and can be stable up to temperatures of 500 C. Silicates although inert under terrestrial conditions can form chains, rings and sheets which require temperatures of well over a thousand degrees to react. The above properties would suggest that silicon-based life (at least on Earth) is highly improbable.



Surface temperatures are simply too low for silicone and silicate reactants to be effective. Even the temperatures on planet Mercury's surface are too low! Jupiter's moon, IO with its intense volcanic activity has been suggested as a site. No evidence of silicate life are found in telluric fossils even dating to the earliest epochs, despite suggestions that such life could have arisen then within torrid ambient conditions in volcanic flows.

In a recent book, "Life in the Universe: Expectations and Constraints," by Irving and Schulz-Makuch, it is pointed out that even if silicon-based life on earth emerged early, it would very soon be extinguished by carbon-based life. Silane-based biochemistry can be sustained (if at all) in environments with low oxygen and water contents in combination with low carbon abundance. The moons, Titan and Triton satisfy some of the silane-life criteria (they have suitable dominant solvents like methane, ethane and liquid nitrogen with less water and no oxygen). Again most of the complex molecules discovered in the interstellar medium are all carbon-based, similar to that on Earth.

'No water'

In short, for silicon-based life to be sustained, we need little or no water, little or no atmospheric or lithospheric oxygen (silicon readily combines with oxygen), (a reducing rather than oxidising atmopshere is required), low carbon abundance, suitable solvents for silane-based chemistry, low subzero temperatures and high pressures. For silicate and silicone-based life, as we have seen, high temperatures are required (greater than thousand degrees) with a volcanic type environment.

Again high temperature solvents are problematic. However, it must be noted that some silicate forms, like zeolites have much lower reaction temperatures and can act as semi-permeable membranes required for cell sustenance.

Apart from silicon, boron and nitrogen have also been considered. Boron can form covalent bonds (like boron-nitrogen, borazole, similar to benzene). Boron also reacts with ammonia, which would be an ideal solvent for boron-based chemistry. However, abundance of boron in the universe is very low compared to carbon.

Alternative 'bio' chemistries

Alternative biochemistries based on phosphorous, sulphur and germanium have also been considered. Phosphorous and sulphur can both form hydrides and environments rich in sulphur can produce solvents like hydrogen sulphide (some volcanic and benthic life does utilise H2S). Possible life in the atmosphere of Venus (rich in sulphurous compounds) based on such chemistry, is a planned field of study with space probes like the Venus Express and additional missions to collect atmosphere samples (from Venus).

Germanium too can form polymeric compounds like germylene. However, its large atomic size, metallic nature and low abundance make it even more unlikely for an alternate biochemistry. Again, discussion of habitable zones (around stars) should not perhaps be confined to only presence of water as a liquid, other possible solvents could have potential (in a liquid state) at different distance domains from the star, especially for silane chemistry.

Finally, the observations made by Voyager 2 of liquid nitrogen lakes with floating methane ice on Triton's surface has led to suggestions of exotic life forms.

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Deccan Herald, Tuesday, October 3, 2006, pp.