

Why is C favored over Si?

- C, Si, Ge: Versatility from ability to bind with up to 4 atoms at a time
- Ge: not very abundant in space or on planetary crusts.
- Si is 1000 times as abundant as C in planetary crusts.
- Si-Si bonds have half the strength of C-C bonds; are therefore fragile.
- Si-O bonds are much stronger than Si-Si or C-O bonds and tend to short-circuit the formation of long chains of Si's. [The Horta, Star Trek episode 26, "Devil in the Dark"](#)
- Complex Si-based molecules can't survive long in water.
- Si doesn't normally form double bonds, which limits its range of reactions.
- C is mobile in the environment as CO_2 , but Si is immobile since SiO_2 is a solid (quartz, etc.).
- Observational evidence: Ubiquity of C-based complex molecules in space and in meteorites; there is a lack of complex Si-based molecules.
- Although Si is not favored to form polymers, the strong Si-O bond suggests that SiO units could form the backbones of polymers. SiO polymers are called silicones and can be produced to substitute for many organic materials, for example, cosmetics and lubricants (Mobil One).



Other Possibilities

Boron – Ammonia

- Boron forms covalent bonds like carbon, but with only 3 valence electrons.
- No direct analogues to hydrocarbons.
- Boron bonds with nitrogen like carbon with carbon, forming compounds similar to methane, ethane and benzene.
- These boron-based compounds are more reactive and would operate at lower temperatures where ammonia is a liquid, which could operate as the solvent.
- A big drawback is its scarcity: in the Earth's crust boron has an abundance of 1 part in 100,000.

Important Properties of Solvents for Life

- Abundant
- Chemically simple
- Wide temperature range
- High heat capacity and heat of vaporization
- Good solvent
- Large surface tension

Interesting Properties of Water

- Self-shields against ultraviolet light
- Expands upon freezing

Liquid	Total T Range [†]	Heat Capacity [‡]	Heat of Vaporization*	Surface Tension [♡]	Solvency [♡]
Water	100	1	595	1	1
Ammonia	45	1.23	300	1/2	1/2
M. Alcohol	159	0.6	295	1/3	1/2

[†] of liquid, degrees Celsius

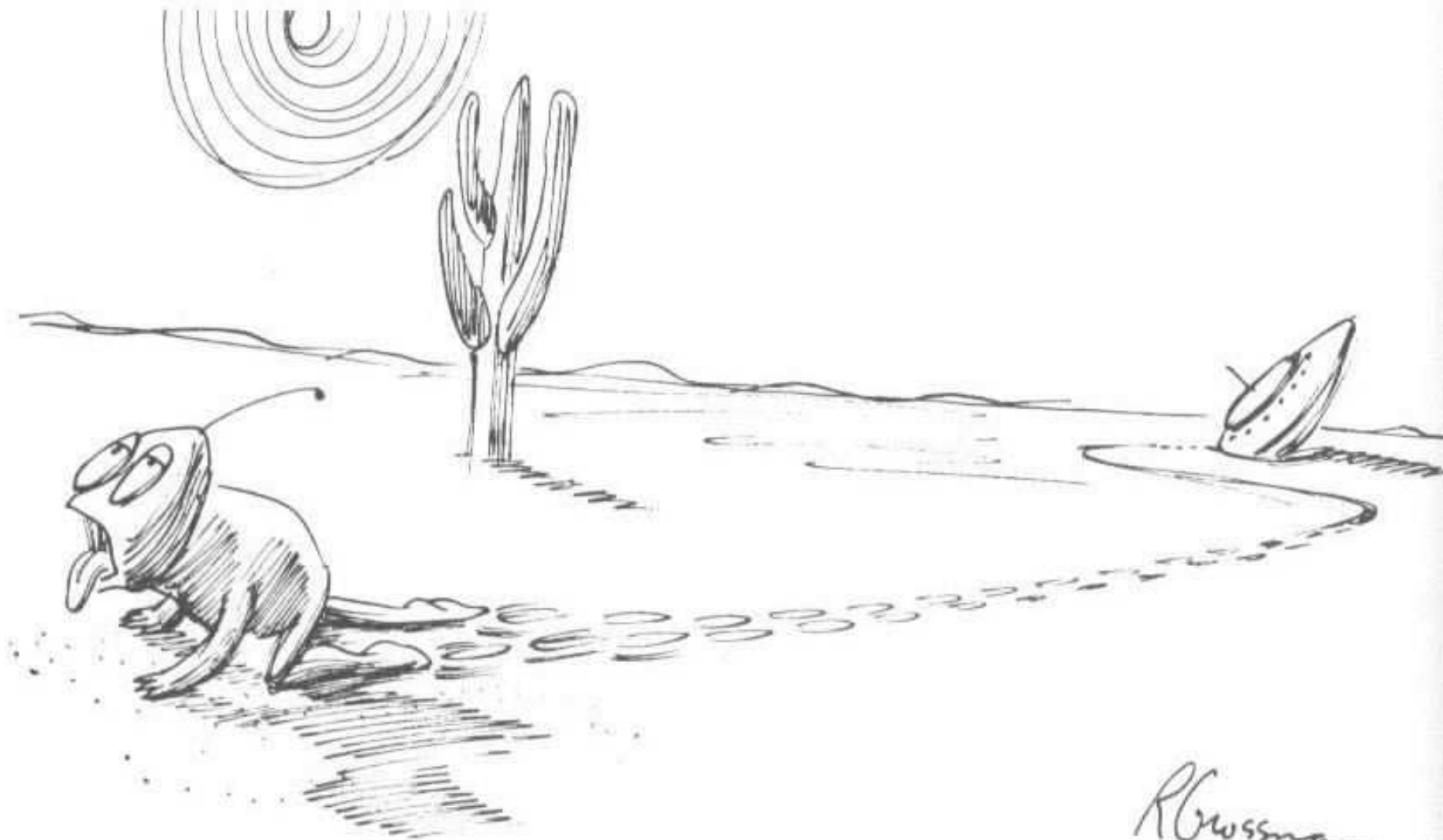
[‡] cal/g/degree Celsius

* cal/g

♡ relative

Ammonia-Based Life

- In 1954, Haldane suggested the replacement of water with ammonia.
- Water has ammonia analogues: $\text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{NH}_2$.
- There exist ammonia-based counterparts to proteins and nucleic acids.
- Amide molecules would substitute for amino acids, and these form polypeptides also.
- Whole systems of organic and inorganic chemistry takes place in ammonia instead of aqueous solutions.
- Ammonia can dissolve most organics as well as or better than water, and can dissolve many elemental metals like Na, Mg and Al, and other elements like I, S, Se and P.
- Although ammonia has a narrow liquidity range at 1 atm, it is much larger at higher pressures.
- Ammonia is a poorer insulator but has a higher heat of fusion and specific heat and is also less viscous.
- In an ammonia system, water would appear to be a strong acid and quite hostile to life.
- Ammonia-based life could use Cs and Rb-chlorides to regulate electrical potentials of cell membranes as opposed to K and Na-salts with water-based life.
- The hydrogen bonds in ammonia are much weaker than those in water, making it difficult to hold prebiotic molecules together.
- The surface tension of ammonia is weaker than in water.



“Ammonia! Ammonia!”

R. Grossman

Drawing by R. Grossman; © 1962.
The New Yorker Magazine, Inc.

Plasma-Based Life?

- Another Star-Trek idea might not be so far-fetched: plasma-based life.
- In 2003 Romanian physicist Sanduloviciu created blobs of plasma that could grow and replicate similarly to biological cells.
- They lacked inherited material, hence were not alive, but these spheres may offer an explanation of how life began.
- Similar to a Miller-Urey experiment, the researchers created electric discharges that caused plasmas to form, specifically argon plasmas.
- Electric sparks spontaneously created spheres (like bubbles forming in water). Each sphere had a boundary made up of two charged layers that trapped gas atoms in between.
- The spheres grew and divided, albeit randomly.
- Even if they aren't alive, they could have been forerunners of protein microspheres or coacervates.

Source: [The Internet Encyclopedia of Science](#)



The Companion, Star Trek

Notes Concerning Alien Lifeforms

- On Earth, life either adapted to “extreme” environments, or it originated in “extreme” environments. Can intelligence evolve in extreme environments, or are benign conditions (land/water/air, needed for toolmaking, astronomy, language) necessary?
- Will alien senses be profoundly different from our own (light, sound, smell, electric (e.g., octupi)...)?
- Is mathematics a universal language?
 $3^2 + 4^2 = 5^2$, $10^2 + 11^2 + 12^2 = 13^2 + 14^2$, $e^{-i} = -\pi$
- Diverse rates and directions of evolution, and extinction of majority of species, show there is no goal-directed route of evolution from origination to intelligence.
- Total system of life has demonstrated an uncanny progression toward complexity and sophistication, even if individual lineages don't.
- Small changes can produce dramatic outcomes, similar to catastrophes in the mathematical sense.
- If humans became extinct, humans would not reappear; odds of finding human-like aliens nil.

Source: The Science of Aliens by Pickover

- Yet *convergent evolution* does occur, representing common solutions to problems or environments (dolphins, salmon, ichthyosaurs; opossums, chameleons, sea horses, binturongs, kinkajous, anteaters, phalangers, monkeys).
- Will convergent evolution lead to *bilateral* symmetry, as opposed to, say, *radial* symmetry (jellyfish, octupi, starfish)? Why do humans have exterior bilateral symmetry, but not internal (heart, liver, stomach, etc.)? Tube-like digestive system violates bilateral symmetry.

Source: The Science of Aliens
by Pickover

Common Octopus



- Nervous system (or analogy) seems essential to promote information capacity beyond chemical limitations of DNA. Brain develops near primary sense organs, and is given protection.
- Will evolution and interaction among individuals lead to a “hive-like” group mind, where the aggregate intelligence vastly exceeds the sum of the individual intelligences (ants, bees, termites, the Borg)?
- Octopi as an example of strange evolution. Its brain encircles its esophagus, and food sometimes gets stuck in it. It has pigment-bearing cells that can change its skin color, pattern and texture (prelude to shapeshifters?). It lacks a skeleton, so is very shape versatile. The Mimic Octopus, not discovered until 1998, has the uncanny ability to mimic several other sea creatures, including sea snakes, lionfish, flatfish, brittle stars, giant crabs, sea shells, stingrays, jellyfish, sea anemones, and mantis shrimp.
- Evolution in response to different gravity, air pressure, chemicals, radioactivity, sunlight, ...
- Alien sex – read the book!

Source: [The Science of Aliens](#) by Pickover

Wonder Octopus





Mimic Octopus



Artificial Life

- The philosophy of artificial life has two positions:
 - Strong artificial life position: “Life is a process which can be abstracted away from any particular medium” – John von Neumann
 - Weak artificial life position: Denies the possibility of creating a living system outside of chemistry. Rather, life processes can be mimicked to understand the underlying mechanics.
- Techniques are mainly:
 - Cellular automata – a model consisting of a regular grid of cells in any number of dimensions. Each cell can be in a finite number of states determined from its neighborhood by a particular set of rules, and updates in time are controlled by another particular set of rules (like a Boolean network).
 - Neural networks – aim to build mathematical models of biological neural systems. These rely on parallel processing as well as implicit instructions based on pattern recognition of sensory inputs from external sources.
- Artificial life has taken a bottom-up approach as opposed to the top-down approach of genetic modification (i.e., stripping) of microorganisms.
- Artificial life has had a controversial history, ranging from claims of being fact-free science (John Maynard Smith) to the discovery of tools that have led to breakthroughs in computational science, art, music and games.
- Artificial intelligence has had a similarly controversial history, but has led to advances like search engines, investing and banking tools, and robotics.