Constrains for the origin of life

Elements of life

Solvents for life

Energy for life

Other limitations
Elements of life

Carbon-based life well-justified:
• self-replicating chemical systems need sufficient complexity
• Carbon is tetravalent and can form complex structures (unlike H, He, Li, O, or F)
• Fourth most common element in the Solar system
Elements of life

Silicon:
- can form multivalent structures
- Earth’s surface – 2nd most abundant element

Star Trek: The Devil in the Dark
Elements of life

Si-O bond far more stable than Si-Si, Si-H or Si-N  
→ oxidation almost irreversible

Energy of C-C bond comparable to C-O, C-N and C-H  
→ easy exchange between elements

Multiple bonds of carbon are stabilized,  
silicon - destabilized
Elements of life

Methane, CH₄
(flammable)
gas at room temperature
(stable)

Silane, SiH₄
(flammable)
gas at room temperature
(extremely unstable)

Silicon is less well suited to support complex chemistry than carbon.

Other atoms are far worse than silicon.
Solvents of life

Life requires a solvent to move molecules around
Solvents of life

Terrestrial organisms based on water
**Solvents of life**

Advantages of water:

- Ice floats → nutrient transport, temperature modulation
- High heat capacity 4.2 J/g°C (3x of rocks or metals), heat of vaporization 41 J/g → both help to moderate Earth’s climate
- Liquidity range – 100°C
- High dielectric constant – water is a very good solvent
- High molecular density 55.5 mol/L – „hydrophobic effect”: H₂O forces dissolved molecules to organize to minimize the entropic cost
- H, O – very abundant in the Universe (1st, 3rd) H₂O – 2nd most abundant after H₂
Solvents of life

Alternative solvents
HF, NH₃, CH₄, H₂

TABLE 1.3
Physical properties of potential biological solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Formula</th>
<th>Liquid range (°C, at atmospheric pressure)</th>
<th>Molar density (mol/L)</th>
<th>Heat capacity (J/g K)</th>
<th>Heat of vaporization (J/g)</th>
<th>Dielectric constant</th>
<th>Density ratio: solid to liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>0 to +100</td>
<td>55.5</td>
<td>4.2</td>
<td>41</td>
<td>80</td>
<td>0.9</td>
</tr>
<tr>
<td>Hydrogen fluoride</td>
<td>HF</td>
<td>−83 to +20</td>
<td>48.0</td>
<td>3.3</td>
<td>0.4</td>
<td>84</td>
<td>1.8</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>−78 to −34</td>
<td>40.0</td>
<td>4.6</td>
<td>23</td>
<td>25</td>
<td>1.2</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>−182 to −161</td>
<td>26.4</td>
<td>2.9</td>
<td>8</td>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>−259 to −253</td>
<td>35.0</td>
<td>0.008</td>
<td>0.5</td>
<td>1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

HF – similar physical properties to water, but fluorine cosmologically rare (100,000 x less than oxygen)
Energy for life

The energy of stars

Life creates order from disorder → need for energy

High energy photons absorbed by plants
→ nutrients absorbed by animals;
both patterns used to run metabolic processes

However, not the only available source of energy
→ Further lecture on extremophiles
Other constrains for the origin of life

Life requires a condensed medium → rocky solid planets with available solvent
not enough support on gas giant planets (Jupiter)

Life requires time to be formed → unstable environment (overheating,
asteroids, supernovae) is detrimental