Life and $f_1$
Recap

\[ N = N_\ast f_s \]
- \( N_\ast = 4 \times 10^{11} \)
- \( f_s = 0.2 \)
- \( f_p = 1.0 \)

\[ N = 8 \times 10^{10} \]
Solar System

• 8 planets
• 3 in or close to habitable zone
• Extrapolating from one example:
  – $f_p = 1$
  – $N_h = 3$
• $N = N^* f_s f_p N_h = 2.4 \times 10^{11}$
Where we are going…

• We’ll return to habitable zones later
• First, what needs to be supported?
What is Life?

And will you know it when you see it?
Properties of Life*

- Produces Order
- Reproduces itself
- Grows and Develops
- Utilizes Energy
- Responds to the Environment
- Adapts and Evolves

*as we know it, on Earth
Definitions of Life

- **Thermodynamic**: Produces order. Temporarily overcomes entropy.
  
  *But are crystals alive?*
Definitions of Life

• **Thermodynamic**: Produces order. Temporarily overcomes entropy. *But are crystals alive?*

• **Metabolic**: Produces energy via chemical reactions. *But is fire alive?*
Definitions of Life

• **Thermodynamic**: Produces order. Temporarily overcomes entropy.  
  *But are crystals alive?*

• **Metabolic**: Produces energy via chemical reactions.  
  *But is fire alive?*

• **Biochemical**: Exhibits specific reactions; uses enzymes.
Definitions of Life

- **Thermodynamic**: Produces order. Temporarily overcomes entropy.  
  *But are crystals alive?*

- **Metabolic**: Produces energy via chemical reactions.  
  *But is fire alive?*

- **Biochemical**: Exhibits specific reactions; uses enzymes.

- **Darwinian**: Self-sustaining and reproducing; capable of evolving.
The Meaning of Life
The Laws of Thermodynamics

• Energy can be transformed, but never created nor destroyed (conservation of energy)

• In a closed system, entropy always increases

• Absolute zero, the complete absence of motion, is unattainable
The Alternative Laws of Thermodynamics

• You can not win
• You can not break even
• You can not get out of the game.
Entropy

Does life, by creating order, violate the second law of thermodynamics?

No.

Entropy must increase in a **closed** system.
   • Earth is not a closed system.
   • A decrease in entropy on Earth is more than compensated by the increase in entropy of the Sun.
Summary of Properties

- Produces Order
- Utilizes Energy
- Reproduces itself
- Grows and Develops
- Responds to the Environment
- Adapts and Evolves

- Thermodynamic
- Metabolic
- Thermodynamic; Darwinian
- Darwinian
- Darwinian
- Darwinian
Evolution

Reproduction with Errors
Earth - a Brief History

4.5 Gya: Earth forms in circumstellar disk

4.4 Gya: Mars-size object collides with the Earth
  • Original atmosphere is stripped
  • Moon forms in debris disk

3.9 Gya: surface is pulverized in the Great Bombardment

3.8 Gya: Oldest rocks; evidence for life
  • C12/C13 isotope ratios

3.5 Gya: first fossils (stromatolites)
Life on Earth - a History

All life on Earth is related:
  • It shares common biochemical mechanisms
  • It shares common DNA sequences

Arose early on: first records about 3.8 Gya -
  about 100 million years after the great bombardment

Arose under adverse conditions

Evolved fast: Essentially modern fossils by 3.5 Gya
Elements of Life

- Oxygen (65.0%)
- Carbon (18.5%)
- Hydrogen (9.5%)
- Nitrogen (3.3%)
- Calcium (1.5%)
- Phosphorus (1.0%)
- Potassium (0.4%)
- Sulfur (0.3%)
- Sodium (0.2%)
- Chlorine (0.2%)
- Magnesium (0.1%)

Trace elements (less than 0.01%)
Tree of Life
Classification of Life on Earth

- Domain
  - Archaea
  - Bacteria
  - Eucarya
- Kingdom
- Phyla
- Class
- Order
- Family
- Genera
- Species

The original Linnaean system began with the Kingdom (Plants, Animals, Fungi, Protists, Bacteria)
Your Classification

• Domain: *Eucarya* (multicellular)
• Kingdom: *Animalia*
• Phylum: *Chordata* (notochord)
  • Subphylum: *Vertebrata* (spinal cord)
• Class: *Mammalia*
  • Subclass: *Theria* (live birth)
    • Infraclass: *Eutheria* (placental)
• Order: *Primatia*
  • Suborder: *Anthropoidea*
    • Infraorder: *Catarrhini* (Old world monkeys)
• Family: *Hominidae* (hominids)
• Genus: *Homo*
• Species: *Sapiens*
It’s a Long Way from Amphioxus
What All Life* Has In Common

• Carbon-based
• Water-soluable
• Organized into cells
• DNA/RNA-based genetic material

* On Earth
Carbon

• Atomic number 6 (6 protons)
• 4th most abundant element
• Isotopes: C\textsuperscript{12}, C\textsuperscript{13}, C\textsuperscript{14}
• Valence +4
• Can form stable
  • Single,
  • double, or
  • triple bonds
• Readily forms long chains
• Forms closed rings
Why not Silicon?

Si also has valence = +4, but:

• Si does not readily form double or triple bonds
  (the nucleus is larger, bonds must bend more)
• Si-Si bonds are half the strength of C-C bonds
• Si-H and Si-O bonds are stronger than Si-Si bonds
  • C-H and C-O bonds are as strong as C-C bonds
• Si-O chains (silicone) are stable and unreactive
• SiO₂ (quartz) is very stable
• Si does not form rings
Water (H$_2$O)

- Abundant
- Easily made, stable
- Liquid over wide temperature range
  - Permits wide habitable zone
- High heat capacity, high heat of vaporization
  - Moderates temperature fluctuations
- Good solvent
  - A polar molecule
- Non-reactive
- High surface tension
- UV self-shielding
- Solid less dense than liquid
  - Ice floats
## Other Solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Temperature Range (°C)</th>
<th>Heat Capacity (Cal/gm/°C)</th>
<th>Heat of Vaporization (Cal/gm)</th>
<th>Relative Surface Tension</th>
<th>Relative Solvency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (H₂O)</td>
<td>100</td>
<td>1</td>
<td>595</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>45</td>
<td>1.2</td>
<td>300</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Methyl Alcohol (CH₃OH)</td>
<td>159</td>
<td>0.6</td>
<td>295</td>
<td>0.33</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Cells

A membrane keeping the cellular mechanisms Inside, and the rest of the work outside.

May or may not contain a nucleus
Extreme Life

- Viruses and Prions
- Extremophiles
  - Thermophiles (heat)
  - Psychrophiles (cold)
  - Halophiles (salt)
- Chemautotrophs (inorganic reactions)
Evolution - A Fact of Life