The nature of life on Earth
Defining Life

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  - e.g., it is debatable if viruses are living or not.
- Fortunately, most life forms on Earth have many properties in common with one another.
- Life elsewhere in the universe may be quite different, but we will start by trying to better understand life on Earth, and the conditions it needs to survive.
What is life (on Earth)?

- A diverse array of living organisms (life forms) can be found in the biosphere on Earth. Properties common to these organisms are a carbon- and water-based cellular form with complex organization and heritable genetic information. Living organisms undergo metabolism, maintain homeostasis, possess a capacity to grow, respond to stimuli, reproduce and, through natural selection, adapt to their environment in successive generations. More complex living organisms can communicate through various means.
Six Key Properties of Life

Most living organisms on Earth share the following properties:

- Order
- Reproduction
- Growth and development
- Energy utilization
- Response to the environment
- Evolutionary adaptation

Could we abbreviate these to metabolism, reproduction, and evolution?
Atoms to molecules

Oxygen, water, methane, glucose

**Organic molecules** contain carbon (and usually also contain hydrogen).

**Compounds** are molecules made from atoms of two or more different elements.

**Molecules** consist of two or more atoms.

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Seeing is believing
The new study has examined fullerene (PAH, C60), which has linked rings of carbon atoms at its core, using an atomic force microscopy or AFM. Their images show the strength and length of the atomic bonds. The bright and dark spots on the images correspond to the higher and lower density of electrons in the particle.
Carbon-based Life

- All life on Earth is carbon-based.
  - carbon plays a key role in the structure of cells.
- Carbon is advantageous because it has four valence electrons available to form bonds with other atoms.
- Other forms of life, such as silicon-based life, are theoretically possible, but not well suited
  - weak bonding makes fragile molecules
  - affinity for oxygen – when C oxidizes then its a gas (waste easy to move), but Si oxides into a solid (quartz)
  - less abundant in Universe, yet on Earth Si is 1000x more abundant than C, and still no Si-based life
Composition of a Human

- Oxygen: 65%
- Carbon: 18%
- Hydrogen: 10%
- Other: 7%
Cells

- All life forms on Earth are made of cells (organic = carbon-based)
  - some organisms are single-celled, while others contain trillions of cells
- A cell contains living matter, and is separated from its surroundings by a cell membrane
- At a basic level, all living cells are similar to one another
- In complex organisms (like us), different cells perform different functions

![Cells](image)
Four Key Components of Cells

- **Carbohydrates**
  - provide energy for cells
  - major component of cell structures

- **Lipids**
  - store energy for cells
  - the major ingredient of cell membranes

- **Proteins**
  - perform many of the cell’s functions
  - enzymes facilitate chemical reactions

- **Nucleic acids**
  - DNA stores genetic instructions
  - RNA carries out these instructions
The building blocks of life (part 2)

The pyrimidines

Uracil

Thymine

Cytosine

The purines

Adenine

Guanine

The sugars

α-d-Glucose

A sugar alcohol

Glycerol

A nitrogenous alcohol

Choline

A fatty acid

Palmitic acid
Chirality = Handedness

- Chiral molecules are those that can arrange themselves in one of two configurations – each being the mirror image of the other.
- Living cells only use left handed amino acid molecules to build proteins.
- The natural mix of chiral molecules is 50/50. Life introduces an imbalance of one over the other.
Microscopic Structure of Cells: Microbes

- **Prokaryotic cell**
  - Bacteria & Archaea
  - No cell nucleus
  - Single-celled organisms

- **Eukaryotic cell**
  - Cell nucleus present
  - Single-celled or multicellular

A cell’s nucleus keeps the genetic material (DNA) separate from the rest of the cell. First form of “complex life”? 

Thursday, October 3, 2013
Microbes rules the Earth!
The single common ancestor

- All life on Earth appears to have followed the same biochemical recipe:
  - Carbon based chemistry
  - Cell based structures
  - 20 (22) amino acids forming the protein chemistry
  - Uniform chirality of chemistry
  - DNA based heredity
  - ATP (or similar) driven cell metabolism **

- If one accepts that the tremendous similarity of (almost) all life on Earth arose from divergent evolution then the above similarities imply the existence of some early, common ancestor to all life on Earth.
Cell Metabolism

- Cells are little chemical factories, where reactions can occur more quickly.
- Raw materials are carbon and energy.
- Every living cell uses ATP (adenosine triphosphate) to store and release energy.
- When ATP releases its energy, it turns into ADP.
- Recycled with input energy.
Sources of Carbon and Energy

Sources of carbon
- organic material (obtained by eating food)
- heterotrophs
- carbon dioxide (from the atmosphere or water)
- autotrophs

Sources of energy
- sunlight (via photosynthesis)
- chemical energy from
  - organic material (contains carbon)
  - inorganic material (no carbon)

<table>
<thead>
<tr>
<th>Metabolic Classification</th>
<th>Carbon Source</th>
<th>Energy Source</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>photoautotroph</td>
<td>carbon dioxide</td>
<td>sunlight</td>
<td>plants, photosynthetic bacteria</td>
</tr>
<tr>
<td>chemoautotroph</td>
<td>carbon dioxide</td>
<td>inorganic chemicals (e.g., iron, sulfur, ammonia)</td>
<td>some bacteria and archaea, especially in extreme environments</td>
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</table>
The Role of Water in Metabolism

- Despite the variety of life forms present on Earth, all these life forms need liquid water to exist.

- Water performs three crucial roles for cells:
  - Contains dissolved organic chemicals within the cell.
  - Transports chemicals and other materials.
  - Plays an important role in chemical reactions within cells, e.g., in ATP reactions.

- In searching for extra-terrestrial life, it makes sense to focus on locations in which liquid water can survive:
  - Not too hot, not too cold.
Extremophiles

- Some life forms on Earth have been found in extreme environments
  - in boiling hot water close to deep sea volcanic vents
  - in hot acidic water near hot springs
  - within rocks in cold dry desert regions
  - deep underground in rocks or subglacial lakes
  - etc.!
- Most are in the archaea domain, and are genetically some of the most primitive organisms known.
Antarctica
Enzyme activity in water/organic solvent mixture (Bragger et al., 2000) (Modified from Deming and Eiken, 2007)

Maximum growth T for eukaryotes (70°C)
Maximum growth T for metazoans (~50°C)

Viable microbes observed at 250°C

Enzyme activity in water/organic solvent mixture (Bragger et al., 2000)

(Modified from Deming and Eiken, 2007)
DNA & Hereditary

- Moved this to next lecture (with Chapter 6)
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- Look for replication of cells.
# Weighing up the pros and cons

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<tbody>
<tr>
<td>liquid water</td>
<td>ionizing radiation</td>
</tr>
<tr>
<td>organic chemicals</td>
<td>extreme temperatures</td>
</tr>
<tr>
<td>energy</td>
<td>vacuum</td>
</tr>
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Abiogenesis -2
Next week
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- Try review questions from Chapter 5
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- Could try Ch5 Q#1, 3-11, 14, 17-23, 29-30, 32-33, 35-36