The Nature of Life on Earth
(Chap. 5 - Bennett & Shostak)

Notes for Chapter 5
HNRS 228 - Astrobiology
Dr. H. Geller
Overview of Chapter 5

- Defining Life (5.1)
  - Its properties, evolution and definition

- Cells: The basic units of life (5.2)
  - Structure, composition, prokaryotes, eukaryotes

- Metabolism: The chemistry of life (5.3)
  - Energy needs and sources; water

- DNA and Heredity (5.4)
  - Structure, replication, genetic code
Overview of Chapter 5

- Life at the Extremes (5.5)
  - Extremophiles and their implications
- Evolution as Science (5.6)
Properties of Living Systems

- Not laws
- From Bennett & Shostak:
  - Order (hierarchy)
  - Reproduction
  - Growth and development
  - Energy use
  - Response to the environment (open systems)
  - Evolution and adaptation
Properties of Living Systems

- From Other Sources
  - Hierarchical organization and emergent properties
  - Regulatory capacity leading to homeostasis
  - Diversity and similarity
  - Medium for life: water (H₂O) as a solvent
  - Information Processing
Properties of Living Systems: Order

- Define “random”
- Define “order” in an abiotic system
- Why is “order” an important property”
- Examples of “order” in living systems
  - Level of a biomolecule
  - Level of the cell
  - Level of the organelle
  - Level of an ecosystem
- Relate to hierarchical
Properties of Living Systems: Reproduction

- Define “reproduction” in abiotic terms
  - E.g., fire, crystals

- Define “reproduction” in biotic terms
  - Why is it important property of living systems?

- Examples in living systems
  - Microbes (fission)
  - Cells (mitosis)
  - Whole organisms
    - Donkey
Properties of Living Systems: Growth and Development

- Define “growth”
- Define “development”
- Why are “growth and development” important properties of living systems
- Examples in living systems
  - Organisms grow
  - Organisms develop
- Examples in abiotic systems
  - Ice crystals
  - Fire
Properties of Living Systems: Energy Use

- **Definitions**
  - Energy capture
    - Autotrophs (photoautotrophs, chemoautotrophs)
    - Heterotrophs (saprovores, carnivores, omnivores, etc.)
  - Energy utilization (1st and 2nd Laws of Thermodynamics)
  - Energy storage
    - Chemical bonds (covalent C-C bonds) and exothermic reactions
    - ATP (adenosine triphosphate) and ADP (adenosine diphosphate)
  - Energy dissipation (2nd Law of Thermodynamics)

- Why is “energy use” an important property of living systems?
Properties of Living Systems: Energy Use

Catabolism

ADP

ATP

Biosynthesis
Metabolic “Class”

ALL ORGANISMS

Chemotrophs
(use chemical compounds as energy source)

Phototrophs
(use light as energy source)

Chemolithotrophs
(use inorganic chemicals)

Chemoorganotrophs
(use organic chemicals)

Chemolithoautotrophs C=CO₂

Mixotrophs C=Organic

Photoautotrophs C=CO₂

Photoheterotrophs C=Organic
Properties of Living Systems: Response to the Environment

Define an “open” versus “closed” system
- Interaction with the environment
- Stimulus followed by a response

Why is “response to the environment” an important property?

Examples in living systems
- Leaf orientation to the sun
- Eyes
- Ears
Properties of Living Systems: Evolution and Adaptation

Define “evolution”

Define “adaptation”

Why is “evolution and adaptation” an important property in living systems?

Examples of evolution in living systems

- Macroscale: origin of species and taxa
- Microscale:
  - microbes resistant to antibiotics
  - moths resistant to air pollution

Examples of adaptation

- Articulation of the joints in animals
- Planar structure of leaves
Properties of Living Systems: Hierarchical Organization

- Define “hierarchical organization”
  - Diagram of atoms to biomolecules to organelles to cells to tissues, etc.

- Define “emergent properties”
  - Emergence of “novel and unanticipated” properties with each step of hierarchy

- Examples in living systems
  - Hierarchy
  - Emergent properties
Properties of Living Systems: Regulatory Capacity

Define “regulatory capacity”
- Relate to open systems

Define “homeostasis”
- Role of feedbacks (positive and negative) and cybernetics

Why is “regulatory capacity and homeostasis” and important property of living systems?

Examples
- Molecular biology: gene regulation
- Biochemistry: enzymes
- Organisms: temperature
- Globe: “Parable of the Daisyworld”
Properties of Living Systems: Regulatory Capacity

- State Variable
- Positive Feedback
- Negative Feedback
- Sensor
- Set Point
Properties of Living Systems: Diversity and Similarity

- Define “diversity”
  - Hallmark of all life (1.5 M known species; 100 M expected)

- Define “similarity”
  - Hallmark of all life

- Why are “diversity and similarity” important properties of living systems?

- Examples of similarity
  - Biochemistry
  - Structure and Morphology
  - DNA and RNA
Properties of Living Systems: Medium for Metabolism

- Define a “medium for metabolism” and why an important property of living systems?

- Role of “water” as medium
  - Physical properties
    - Abundance in universe, state as a function of temperature, freezing properties
  - Chemical properties
    - Bonding, polarity, diffusion, osmosis
Properties of Living Systems: Information

- Define “information” and relate to order
- Why is “information” an important property of living systems?
- Necessary states of “information”
  - Storage
  - Translation
  - Template/Copying
  - Correcting (spell check)
- Examples
  - DNA
  - RNA
Properties of Living Systems: Recap

- Diversity and similarity of structure and function

- What does above suggest?
  - Recurrent theme of similar properties
    - High fitness value
    - Common ancestor
  - Recurrent theme of diverse properties
    - High fitness value
    - Diversity of habitats
    - Creativity and spontaneity of evolution

- What mechanism can account for both similarity and diversity?
Which of the following is not a key property of life?

- A. The maintenance of order in living cells.
- B. The ability to evolve over time.
- C. The ability to violate the second law of thermodynamics.
**iClicker Question**

Natural selection is the name given to

- **A** the occasional mutations that occur in DNA.
- **B** the mechanism by which advantageous traits are preferentially passed on from parents to offspring.
- **C** the idea that organism can develop new characteristics during their lives and then pass these to their offspring.
Which of the following is not a source of energy for at least some forms of life on Earth?

- **A** Inorganic chemical reactions.
- **B** Energy release from plutonium.
- **C** Consumption of pre-existing organic compounds.
Evolution as a Unifying Theme

- Darwin’s Origin of Species (1850)
  - Observations while on the *HMS Beagle*
  - Model: Evolution
    - Individuals vary in their fitness in the environment
    - Struggle for existence and survival of the most fit
    - Origin of species *via* incremental changes in form and function (relate back to observation while on the *Beagle*).

- Link to Mendel and the Particulate Model of Inheritance (1860’s)

- Link to Watson and Crick (1956) and the discovery of DNA

- Examples of evolution in action

- Significance of evolution as a theory in Biology
Structural Features of Living Systems

- Ubiquitous nature of “cells” and its hierarchy
  - Physical, chemical and biological basis for a cell (adaptation)
  - Suggestion of a common progenitor/ancestor
  - Physical dimensions of a cell (maximum size)
- Ubiquitous nature of “organelle”
  - Efficacy of metabolism (random)
  - Diversity of function
  - Diversity of structure
  - Similarity of structure
Structural Features of Living Systems

- Evolution of cell types
  - Prokaryotes
    - Cells, membranes but no nucleus
    - Examples: bacteria
  - Eukaryotes
    - Cells, membrane, and nucleus
    - All higher plants and animals
Biochemical Features of Living Systems

- Carbon-based economy
  - Abundance in the universe
  - Atomic structure (electrons, protons, etc.)
  - Chemical properties (bonding)

- Metabolism
  - Catabolism and biosynthesis
  - Energy capture and utilization
    - ATP and ADP
Biochemical Features of Living Systems

- Biochemicals or biomacromolecules
  - Define polymer
- Carbohydrates (CH$_2$O)
- Lipids (fatty acids + glycerol)
- Proteins (amino acids & polypeptides)
- Nucleic Acids (nucleotides)
- Points to a common ancestor
Biochemical Pathways

carbohydrates → cell wall, glycocalyx

ribose → glucose → glycglycolysis

amino acids → phosphoglycerate

amino acids → phosphoenolpyruvate → pyruvate

transition reaction → acetyl-CoA

acetyl-CoA → oxaloacetate → Krebs cycle

amino acids → Krebs cycle α-ketoglutarate

lipids → fatty acids

cell membrane

nucleic acids

ribose → purines → pyrimidines

cell wall, flagella, pili, capsid → enzymes
Molecular Features of Living Systems

- Genes and genomes
- Replication of DNA
- Transcription, translation, and the genetic code
- Polypeptides and proteins
- Biological catalysis: enzymes
- Gene regulation and genetic engineering
- Points to a common ancestor
Molecular Features of Living Systems (continued)

DNA → Transcription → m-RNA → Translation → t-RNA → Translation/Genetic Code → Polypeptide → Conformation → Functional Protein
Instructional Features of Living Systems: Genetic Code

- Sequence of base pairs (ATCG) on mRNA (DNA) used to “program” sequence of amino acids
- 20 different amino in living systems (60+ total in nature)
- Reading the ‘tea leaves’ of the genetic code helps understand evolution of life
Instructional Features of Living Systems: Genetic Code (cont’d)

遗传密码和“三联体”
- 4种不同的核苷酸（碱基对）
- 20种不同的氨基酸
- 一个核苷酸如何指定一个氨基酸？（N=4）

选项
- 2个字母代码序列（例如，T-A）用于1种氨基酸（N=16）
- 3个字母代码序列（例如，T-A-G）用于1种氨基酸
  （N=64）...远远超过足够，因为只有20种氨基酸

“三联体代码”
- CCG用于丙氨酸
- AGT用于苏氨酸
# Amino Acid Codons

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- Phenylalanine
- Serine
- Tyrosine
- Cysteine
- Leucine
- Stop
- Tryptophan
- Leucine
- Proline
- Histidine
- Arginine
- Leucine
- Proline
- Glutamine
- Arginine
- Leucine
- Proline
- Glutamine
- Arginine
- Isoleucine
- Threonine
- Asparagine
- Serine
- Isoleucine
- Threonine
- Asparagine
- Serine
- Isoleucine
- Threonine
- Lysine
- Arginine
- Methionine
- Threonine
- Lysine
- Arginine
- Valine
- Alanine
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- Aspartate
- Glucine
- Valine
- Alanine
- Glutamate
- Glucine
- Valine
- Alanine
- Glutamate
- Glucine
The codon CAA is translated by your genes as which amino acid?

- A  Leucine
- B  Proline
- C  Glutamine
- D  Histadine
- E  Arginine
The codon CAG is translated by your genes as which amino acid?

- A Leucine
- B Proline
- C Glutamine
- D Histadine
- E Arginine
iClicker Question

The codon GC_ is translated by your genes as alanine?

- A  U
- B  C
- C  A
- D  G
- E  All of the above.
iClicker Question

The codon AC_ is translated by your genes as threonine?

- A  U
- B  C
- C  A
- D  G
- E  All of the above.
Which of the following codons are translated by your genes as the stop signal?

- A  UAA
- B  UAG
- C  UGA
- D  All of the above.
iClicker Question

Which of the following codons are translated by your genes as the start signal?

- A  UAA
- B  UAG
- C  UGA
- D  AUG
- E  All of the above.
Mutations and Evolution

- Mutation at the molecular level
  - Define
  - Causes
    - Environment (examples)
    - Endogenous (e.g., replication)

- Fitness of mutation
  - Negative fitness (extreme is lethal)
  - Positive fitness
  - Neutral fitness

- Role in evolution
Which of the following is not considered a key piece of evidence supporting a common ancestor for all life on Earth?

- A. The fact that all life on Earth is carbon-based.
- B. The fact that all life on Earth uses the molecule ATP to store and release energy.
- C. The fact that life on Earth builds proteins from the same set of left-handed amino acids.
iClicker Question

An organism’s heredity is encoded in

A DNA
B ATP
C Lipids
iClicker Question

An enzyme consists of a chain of

- A carbohydrates.
- B amino acids.
- C nucleic acids.
Which of the following mutations would you expect to have the greatest effect on a living cell?

A A mutation that changes a single base in a region of noncoding DNA.

B A mutation that changes the third letter of one of the three-base “words” in a particular gene.

C A mutation that deletes one base in the middle of a gene.
EXTREMOPHILES
NATURE’S ULTIMATE SURVIVORS

Adapted from
HOUSSEIN A. ZORKOT, ROBERT WILLIAMS, and ALI AHMAD
UNIVERSITY OF MICHIGAN-DEARBORN
What are Extremophiles?

Extremophiles are microorganisms:
- viruses, prokaryotes, or eukaryotes

Extremophiles live under unusual environmental conditions:
- atypical temperature, pH, salinity, pressure, nutrient, oxic, water, and radiation levels
Types of Extremophiles

1) *Psychrophiles*
   Microbes that live in cold environments like sea ice and the arctic and antarctic ice packs.

2) *Thermophiles*
   Microbes that live in very hot environments like deep sea vents and volcanic lakes.

3) *Alkaliphiles*
   Microbes that live in basic environments like soda lakes.

4) *Halophiles*
   Microbes that live in very salty environments like salt lakes and salt mines.

5) *Acidophiles*
   Microbes that live in acidic environments like sulphur springs.
More Types of Extremophiles

- **Barophiles** - survive under high pressure levels, especially in deep sea vents
- **Osmophiles** – survive in high sugar environments
- **Xerophiles** - survive in hot deserts where water is scarce
- **Anaerobes** - survive in habitats lacking oxygen
- **Microaerophiles** - thrive under low-oxygen conditions
- **Endoliths** – dwell in rocks and caves
- **Toxitolerants** - organisms able to withstand high levels of damaging agents. For example, living in water saturated with benzene, or in the water-core of a nuclear reactor
Environmental Requirements

EXTREMOPHILES

Physical Temperature

-20 °C  50 °C  115 °C

Psychrophiles  Mesophiles  Thermophiles  Hyperthermophiles

Chemical pH

-3  0  3  6  9  12

Extreme Acidophiles  Acidophiles  Neutralophiles  Alkalophiles

Eukaryotes
Extremophiles Can Survive:

- 113 to 200 °C
- -15 °C
- pH < 0.0
- pH > 11
- 1200 atmospheres
- 0% oxygen
- 20-40 million years dormancy
- 2 1/2 years in space, etc.
EXTREME PROKARYOTES

Hyperthermophiles

- Members of domains Bacteria and Archaea
- Possibly the earliest organisms
- Early earth was excessively hot, so these organisms would have been able to survive

HYPERTHERMOPHILES at the base of the tree of Life

Eubacteria:
- Aquifex pyrophilus 85°C
- Thermotoga maritima 80°C

Archaebacteria:
- Acidianus infernus 88°C
- Pyrodictium abyssi 105°C
- Pyrococcus furiosus 100°C

DATA FROM STETTER (1994)
Morphology of Hyperthermophiles

- Heat stable proteins that have more hydrophobic interiors
  - prevents unfolding or denaturation at higher temperatures
- Chaperonin proteins
  - maintain folding
- Monolayer membranes of dibiphytanyl tetraethers
  - saturated fatty acids which confer rigidity, prevent degradation in high temperatures
- A variety of DNA-preserving substances that reduce mutations and damage to nucleic acids
  - e.g., reverse DNA gyrase and Sac7d
- Can live without sunlight or organic carbon as food
  - survive on sulfur, hydrogen, and other materials that other organisms cannot metabolize

The red on these rocks is produced by *Sulfolobus solfataricus*, near Naples, Italy
Sample Hyperthermophiles

Frequent habitats include volcanic vents and hot springs, as in the image to the left.

*Pyrococcus abyssi* 1μm  
*Thermus aquaticus* 1μm
Deep Sea Extremophiles

- Deep-sea floor and hydrothermal vents involve the following conditions:
  - low temperatures (2-3°C) – where only psychrophiles are present
  - low nutrient levels – where only oligotrophs present
  - high pressures – which increase at the rate of 1 atm for every 10 meters in depth (as we have learned, increased pressure leads to decreased enzyme-substrate binding)
- Barotolerant microorganisms live at 1000-4000 meters
- Barophilic microorganisms live at depths greater than 4000 meters

A black smoker, i.e. a submarine hot spring, which can reach 518-716°F (270-380°C)
Extremophiles of Hydrothermal Vents

A cross-section of a bacterium isolated from a vent. Often such bacteria are filled with viral particles which are abundant in hydrothermal vents.

A bacterial community from a deep-sea hydrothermal vent near the Azores.

• Natural springs vent warm or hot water on the sea floor near mid-ocean ridges.

• Associated with the spreading of the Earth’s crust. High temperatures and pressures.
Psychrophiles

Some microorganisms thrive in temperatures below the freezing point of water (this location in Antarctica).

Some people believe that psychrophiles live in conditions mirroring those found on Mars – but is this true?
Characteristics of Psychrophiles

- Proteins rich in $\alpha$-helices and polar groups
  - allow for greater flexibility
- “Antifreeze proteins”
  - maintain liquid intracellular conditions by lowering freezing points of other biomolecules
- Membranes that are more fluid
  - contain unsaturated cis-fatty acids which help to prevent freezing
- active transport at lower temperatures
Halophiles

- Divided into classes
  - mild (1-6%NaCl)
  - moderate (6-15%NaCl)
  - extreme (15-30%NaCl)
- Mostly obligate aerobic archaea
- Survive high salt concentrations by
  - interacting more strongly with water such as using more negatively charged amino acids in key structures
  - making many small proteins inside the cell, and these, then, compete for the water
  - accumulating high levels of salt in the cell in order to outweigh the salt outside

The vivid red brine (teeming with halophilic archaea) of Owens Lake contrasts sharply with the gleaming white deposits of soda ash (sodium carbonate). The picturesque Inyo Range can be seen in the distance.
Barophiles

• Survive under levels of pressure that are lethal to most organisms

• Found deep in the Earth, in deep sea, hydrothermal vents, etc.

A sample of barophilic bacteria from the earth’s interior
Xerophiles

- Extremophiles which live in water-scarce habitats, such as deserts
- Produce **desert varnish** as seen in the image to the left
  - A thin coating of Mn, Fe, and clay on the surface of desert rocks, formed by colonies of bacteria living on the rock surface for thousands of years

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SAMPLE PROKARYOTE EXTREMOPHILES

Thermotoga  Aquifex  Halobacterium

Methanosarcina  Thermoplasma  Thermococcus

Thermoproteus  Pyrodictium  Ignicoccus
**Deinococcus radiodurans**

- Possess extreme resistance to up to 4 million rad of radiation, genotoxic chemicals (those that harm DNA), oxidative damage from peroxides/superoxides, high levels of ionizing and ultraviolet radiation, and dehydration

- It has from four to ten DNA molecules compared to only one for most other bacteria

- Contain many DNA repair enzymes, such as RecA, which matches the shattered pieces of DNA and splices them back together. During these repairs, cell-building activities are shut off and the broken DNA pieces are kept in place
Chroococcidiopsis

- A cyanobacteria which can survive in a variety of harsh environments
  - hot springs, hypersaline habitats, hot, arid deserts, and Antarctica
- Possesses a variety of enzymes which assist in such adaptation
Other Prokaryotic Extremophiles

Gallionella ferruginea (iron bacteria), from a cave

Anaerobic bacteria

Current efforts in microbial taxonomy are isolating more and more previously undiscovered extremophile species, in places where life was least expected.
Cyanidium caldararium

Cyanidium is a genus of red algae. This species is acidophilic and thermotolerant. Note that where the stream is cooler to the right, Zygonion dominates.
These algae have successfully adapted to their harsh environment through the development of a number of adaptive features which include pigments to protect against high light, polyols (sugar alcohols, e.g. glycerine), sugars and lipids (oils), mucilage sheaths, motile stages and spore formation.
EXTREME EUKARYOTES

ENDOLITHS

Quartzite (Johnson Canyon, California) with green bands of endolithic algae. The sample is 9.5 cm wide.

- Endoliths (also called hypoliths) are usually algae, but can also be prokaryotic cyanobacteria, that exist within rocks and caves.

- Often are exposed to anoxic (no oxygen) and anhydric (no water) environments.
EXTREME EUKARYOTES
Parasites as extremophiles

- Members of the Phylum Protozoa, which are regarded as the earliest eukaryotes to evolve, are mostly parasites
- Parasitism is often a stressful relationship on both host and parasite, so they are considered extremophiles

*Trypanosoma gambiense*, causes African sleeping sickness

*Balantidium coli*, causes dysentery-like symptoms
EXTREME VIRUSES

- Viruses are currently being isolated from habitats where temperatures exceed 200°F.
- Instead of the usual icosahedral or rod-shaped capsids that known viruses possess, researchers have found viruses with novel propeller-like structures.
- These extreme viruses often live in hyperthermophile prokaryotes such as Sulfolobus.

Virus-like particles isolated from Yellowstone National Park hot springs.
Extremophiles are present among Bacteria, form the majority of Archaea, and also a few among the Eukarya.
Members of Domain Bacteria (such as *Aquifex* and *Thermotoga*) that are closer to the root of the “tree of life” tend to be hyperthermophilic extremophiles.

The Domain Archaea contain a multitude of extremophilic species:

- Phylum Euryarchaeota-consists of methanogens and extreme halophiles
- Phylum Crenarchaeota-consists of thermoacidophiles, which are extremophiles that live in hot, sulfur-rich, and acidic solfatara springs
- Phylum Korarchaeota-new phylum of yet uncultured archaea near the root of the Archaea branch, all are hyperthermophiles

Most extremophilic members of the Domain Eukarya are red and green algae.
What were the first organisms?

- Early Earth largely inhospitable
  - high CO$_2$/H$_2$S/H$_2$ etc, low oxygen, and high temperatures
- Lifeforms that could evolve in such an environment needed to adapt to these extreme conditions
- H$_2$ was present in abundance in the early atmosphere
  - Many hyperthermophiles and archaea are H$_2$ oxidizers
- Extremophiles may represent the earliest forms of life with non-extreme forms evolving after cyanobacteria had accumulated enough O$_2$ in the atmosphere
- Results of rRNA and other molecular techniques have placed hyperthermophilic bacteria and archaea at the roots of the phylogenetic tree of life
Evolutionary Theories

- **Consortia** - symbiotic relationships between microorganisms, allows more than one species to exist in extreme habitats because one species provides nutrients to the others and vice versa.

- **Genetic drift** appears to have played a major role in how extremophiles evolved, with allele frequencies randomly changing in a microbial population. So alleles that conferred adaptation to harsh habitats increased in the population, giving rise to extremophile populations.

- **Geographic isolation** may also be a significant factor in extremophile evolution. Microorganisms that became isolated in more extreme areas may have evolved biochemical and morphological characteristics which enhanced survival as opposed to their relatives in more temperate areas. This involves genetic drift as well.

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**Table: Important Dates**

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<td>4.5 Billion</td>
<td>Origin Of The Earth</td>
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<tr>
<td>3.6 Billion</td>
<td>Prokaryote Bacteria Dominate</td>
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<td>2.5 Billion</td>
<td>Oxygen Accumulates In Atmosphere</td>
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</tr>
</tbody>
</table>

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*Figure 1-1*
Pace of Evolution

- Extremophiles, especially hyperthermophiles, possess slow “evolutionary clocks”
  - They have not evolved much from their ancestors as compared to other organisms
  - Hyperthermophiles today are similar to hyperthermophiles of over 3 billion years ago
- Slower evolution may be the direct result of living in extreme habitats and little competition
- Other extremophiles, such as extreme halophiles and psychrophiles, appear to have undergone faster modes of evolution since they live in more specialized habitats that are not representative of early earth conditions
Mat Consortia

Microbial mats consist of an upper layer of photosynthetic bacteria, with a lower layer of nonphotosynthetic bacteria.

These consortia may explain some of the evolution that has taken place: extremophiles may have relied on other extremophiles and non-extremophiles for nutrients and shelter.

Hence, evolution could have been cooperative.
## Use of Hyperthermophiles

<table>
<thead>
<tr>
<th>Hyperthermophiles (Source)</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA polymerases</td>
<td>DNA amplification by PCR</td>
</tr>
<tr>
<td>Alkaline phosphatase</td>
<td>Diagnostics</td>
</tr>
<tr>
<td>Proteases and lipases</td>
<td>Dairy products</td>
</tr>
<tr>
<td>Lipases, pullulanases and proteases</td>
<td>Detergents</td>
</tr>
<tr>
<td>Proteases</td>
<td>Baking and brewing and amino acid production from keratin</td>
</tr>
<tr>
<td>Amylases, $\alpha$-glucosidase, pullulanase and xylose/glucose isomerases</td>
<td>Baking and brewing and amino acid production from keratin</td>
</tr>
<tr>
<td>Alcohol dehydrogenase</td>
<td>Chemical synthesis</td>
</tr>
<tr>
<td>Xylanases</td>
<td>Paper bleaching</td>
</tr>
<tr>
<td>Lenthionin</td>
<td>Pharmaceutical</td>
</tr>
<tr>
<td>S-layer proteins and lipids</td>
<td>Molecular sieves</td>
</tr>
<tr>
<td>Oil degrading microorganisms</td>
<td>Surfactants for oil recovery</td>
</tr>
<tr>
<td>Sulfur oxidizing microorganisms</td>
<td>Bioleaching, coal &amp; waste gas desulfurization</td>
</tr>
<tr>
<td>Hyperthermophilic consortia</td>
<td>Waste treatment and methane production</td>
</tr>
</tbody>
</table>
# Use of Psychrophiles

<table>
<thead>
<tr>
<th>PSYCHROPHILES (SOURCE)</th>
<th>USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline phosphatase</td>
<td>Molecular biology</td>
</tr>
<tr>
<td>Proteases, lipases, cellulases and amylases</td>
<td>Detergents</td>
</tr>
<tr>
<td>Lipases and proteases</td>
<td>Cheese manufacture and dairy production</td>
</tr>
<tr>
<td>Proteases</td>
<td>Contact-lens cleaning solutions, meat tenderizing</td>
</tr>
<tr>
<td>Polyunsaturated fatty acids</td>
<td>Food additives, dietary supplements</td>
</tr>
<tr>
<td>Various enzymes</td>
<td>Modifying flavors</td>
</tr>
<tr>
<td>b-galactosidase</td>
<td>Lactose hydrolysis in milk products</td>
</tr>
<tr>
<td>Ice nucleating proteins</td>
<td>Artificial snow, ice cream, other freezing applications in the food industry</td>
</tr>
<tr>
<td>Ice minus microorganisms</td>
<td>Frost protectants for sensitive plants</td>
</tr>
<tr>
<td>Various enzymes (e.g. dehydrogenases)</td>
<td>Biotransformations</td>
</tr>
<tr>
<td>Various enzymes (e.g. oxidases)</td>
<td>Bioremediation, environmental biosensors</td>
</tr>
<tr>
<td>Methanogens</td>
<td>Methane production</td>
</tr>
</tbody>
</table>
## Use of Halophiles

<table>
<thead>
<tr>
<th>HALOPHILES (SOURCE)</th>
<th>USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteriorhodopsin</td>
<td>Optical switches and photocurrent generators in bioelectronics</td>
</tr>
<tr>
<td>Polyhydroxyalkanoates</td>
<td>Medical plastics</td>
</tr>
<tr>
<td>Rheological polymers</td>
<td>Oil recovery</td>
</tr>
<tr>
<td>Eukaryotic homologues (e.g. myc oncogene product)</td>
<td>Cancer detection, screening anti-tumor drugs</td>
</tr>
<tr>
<td>Lipids</td>
<td>Liposomes for drug delivery and cosmetic packaging</td>
</tr>
<tr>
<td>Lipids</td>
<td>Heating oil</td>
</tr>
<tr>
<td>Compatible solutes</td>
<td>Protein and cell protectants in variety of industrial uses, e.g. freezing, heating</td>
</tr>
<tr>
<td>Various enzymes, e.g. nuclease, amylase, protease</td>
<td>Various industrial uses, e.g. flavoring agents</td>
</tr>
<tr>
<td>g-linoleic acid, b-carotene and cell extracts, e.g. Spirulina and Dunaliella</td>
<td>Health foods, dietary supplements, food coloring and feedstock</td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Fermenting fish sauces and modifying food textures and flavors</td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Waste transformation and degradation, e.g. hypersaline waste brines contaminated with a wide range of organics</td>
</tr>
<tr>
<td>Membranes</td>
<td>Surfactants for pharmaceuticals</td>
</tr>
</tbody>
</table>
# Use of Alkaliphiles

## ALKALIPHILES (SOURCE)

<table>
<thead>
<tr>
<th>Proteases, cellulases, xylanases, lipases and pullulanases</th>
<th>USES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detergents</td>
<td></td>
</tr>
<tr>
<td>Proteases</td>
<td>Gelatin removal on X-ray film</td>
</tr>
<tr>
<td>Elastases, keratinases</td>
<td>Hide dehairing</td>
</tr>
<tr>
<td>Cyclodextrins</td>
<td>Foodstuffs, chemicals and pharmaceuticals</td>
</tr>
<tr>
<td>Xylanases and proteases</td>
<td>Pulp bleaching</td>
</tr>
<tr>
<td>Pectinases</td>
<td>Fine papers, waste treatment and degumming</td>
</tr>
<tr>
<td>Alkaliphilic halophiles</td>
<td>Oil recovery</td>
</tr>
<tr>
<td>Various microorganisms</td>
<td>Antibiotics</td>
</tr>
</tbody>
</table>

## ACIDOPHILES (SOURCE)

<table>
<thead>
<tr>
<th>Sulfur oxidizing microorganisms</th>
<th>USES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery of metals and desulfurication of coal</td>
<td></td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Organic acids and solvents</td>
</tr>
</tbody>
</table>
**Taq Polymerase**

- Isolated from the hyperthermophile *Thermus aquaticus*
- Much more heat stable
- Used as the DNA polymerase in Polymerase Chain Reaction (PCR) technique which amplifies DNA samples
Alcohol Dehydrogenase

- Alcohol dehydrogenase (ADH), is derived from a member of the archaea called *Sulfolobus solfataricus*
- It can survive to 88°C (190°F) - nearly boiling - and corrosive acid conditions (pH=3.5) approaching the sulfuric acid found in a car battery (pH=2)
- ADH catalyzes the conversion of alcohols and has considerable potential for biotechnology applications due to its stability under these extreme conditions
Bacteriorhodopsin

-Bacteriorhodopsin is a trans-membrane protein found in the cellular membrane of *Halobacterium salinarium*, which functions as a light-driven proton pump.

-Can be used for generation of electricity.
Bioremediation

- Bioremediation is the branch of biotechnology that uses biological processes to overcome environmental problems.

- Bioremediation is often used to degrade xenobiotics introduced into the environment through human error or negligence.

- Part of the cleanup effort after the 1989 Exxon Valdez oil spill included microorganisms induced to grow via nitrogen enrichment of the contaminated soil.
Bioremediation

Microbe Cell

Enzymes

Final Waste – CO2 and Water

Oxygen, Other Nutrients

Food (Contaminate)
Psychrophiles as Bioremediators

- Bioremediation applications with cold-adapted enzymes are being considered for the degradation of diesel oil and polychlorinated biphenyls (PCBs)
  - Health effects associated with exposure to PCBs include
    - acne-like skin conditions in adults
    - neurobehavioral and immunological changes in children
    - cancer in animals
Life in Outer Space?

- Major requirements for life:
  - water
  - energy
  - carbon

- Astrobiologists are looking for signs of life on Mars, Jupiter’s moon Europa, and Saturn’s moon Titan.

- Such life is believed to consist of extremophiles that can withstand the cold and pressure differences of these worlds.
Life in Outer Space?

• Europa is may have an ice crust shielding a 30-mile deep ocean.
  • Reddish cracks (left) are visible in the ice – what are they

• Titan is enveloped with hazy nitrogen (left)
  • Contains organic molecules
  • May provide sustenance for life?

Images courtesy of the Current Science & Technology Center
Life in Outer Space?

- Some discovered meteorites contain amino acids and simple sugars
- Maybe serve to spread life throughout the universe

Image courtesy of the Current Science & Technology Center

- A sample of stratospheric air
  - myriad of bacterial diversity 41 km above the earth’s surface (Lloyd, Harris, & Narlikar, 2001)
CONCLUSIONS

How are extremophiles important to astrobiology?

- reveal much about the earth’s history and origins of life
- possess amazing capabilities to survive in extreme environments
- are beneficial to both humans and the environment
- may exist beyond earth
iClicker Question

People belong to domain

- A  Eukarya
- B  Archaea
- C  Bacteria
Generally speaking, an extremophile is an organism that

A. thrives in conditions that would be lethal to humans and other animals.

B. could potentially survive in space.

C. is extremely small compared to most other life on Earth.
Based upon what you have learned in this chapter, it seems reasonable to think that life could survive in each of the following habitats except for:

- A rock beneath the martian surface.
- B a liquid ocean beneath the icy crust of Jupiter’s moon Europa.
- C within ice that is perpetually frozen in a crater near the Moon’s south pole.