Prokaryotes and the basic needs of organisms

1. The basic needs of organisms
2. Prokaryotic cell structure (and comparison with eukaryotes)
3. Evolutionary history of prokaryotes; importance of cyanobacteria and photosynthesis
4. Diversity and abundance of modern prokaryotes
   - Cyanobacteria
   - Archaeabacteria
   - Bacteria and humans

The three basic requirements of life

1. Energy source
2. Organic (carbon-based) molecules
3. Liquid medium

Water ($H_2O$): A very special molecule

Metabolic relationships to oxygen

- Obligate aerobe—need oxygen
- Facultative aerobes—can do both (use $O_2$ if it is present, or fermentation)
- Obligate anaerobes—cannot have oxygen
- Early prokaryotes were obligate anaerobes. What happened to them as photosynthesis became common?

Prokaryote living arrangements

1. Alone
2. Colonies
3. Transient colonies

Cell membrane plays a critical role. *Fimbriae* and *pili* help them attach and aggregate. Chemical signals act as attractants and repellents.

General characteristics of prokaryotes

- Binary fission
- Budding or fragmentation
- Rapid mutation rate
- Conjugation: prokaryotic ‘sex’—passing genetic material
- Transformation: they can take up free naked DNA from environment (probably rare due to instability of free DNA)
- Transduction: via a virus, passes DNA to another bacteria
Prokaryote characteristics

- Small cells (1-10 um) (though one is 700 um!)
- Unicellular
- Can form colonies
- Cell walls generally made of peptidoglycan rather than cellulose and/or chitin
- Capsule is around the cell wall and is generally composed of polysaccharides or proteins

Figure 6.6: A prokaryotic cell

(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium Bacillus coagulans (TEM)

Figure 27.6: Many prokaryotes are motile, via flagella.

Figure 27.7a: Prokaryotic flagella (A. serpens)

Figure 27.7b: Specialized membranes of prokaryotes. Though they lack membrane-bound organelles, some prokaryotes have specialized membranes that perform functions such as respiration or photosynthesis.

Figure 27.9: An endospore. Many species of bacteria can form a dormant, resistant endospore cells to endure harsh conditions.

What kind of bacteria would have membranes specialized for photosynthesis?

Can withstand boiling water, survive in the dormant state for centuries.
The capsule on this Streptococcus bacterium enables it to adhere to a human tonsil cell.

Bacterial conjugation ... allows exchange of bacterial DNA on plasmids.

Some major episodes in the history of life:

1. Some major episodes in the history of life. One very important one: the evolution of photosynthesis in prokaryotes.
2. One of the most independent organisms on earth: Cyanobacteria (Anabaena). This bacterium is colonial, with some cells specialized for specific functions, such as heterocysts for nitrogen fixation.
3. Contrasting hypotheses for the taxonomic distribution of photosynthesis among prokaryotes. Which hypothesis is most likely?
Prokaryotes

- Domain Bacteria
- Domain Archaea
- Domain Eukarya (Eukaryotes)

Modern prokaryotes:
- Hugely abundant:
  - More in your mouth than humans that have ever lived
  - More current mass than 10x all eukaryotes
- Functionally diverse & important:
  - Many symbiotic with plants or animals
  - Impt for nutrient cycling: many are decomposers
  - Plant and animal diseases
  - Many are important primary producers (cyanobacteria)
  - Many inhabit extreme environments

Bacteria

- Are everywhere
- Play a critical role, both negative and positive
- Are small (1-5 um)
- Cell walls: peptidoglycan: sugar polymers and polypeptides (except Archaea)
- About half can move (mostly with flagella)
- Some exhibit taxis
- Utilize a variety of nutritional modes
- Can form endospores

Billion year old bacteria!

Cyanobacteria: a critical change factor on Earth

Photosynthetic bacteria come in two general groups: Cyanobacteria and Purple/Green Bacteria

Cyanobacteria are Important in global carbon and nitrogen cycles
About 7500 species – only about 200 non symbiotic

Importance

1) First organisms to have 2 photosystems and to produce organic material and give off O₂ as a bi-product.

⇒ Very important to the evolution of the earth’s oxidizing atmosphere.

Cyanobacteria

- Microscopic organisms
  - Found in marine sediments and pelagic zone, freshwater lakes, soils,
  - Live in extreme environments – chemically and temperature.
Cyanobacteria

- Chlorophyll a and Phycobilins: phycocyanin (blue), phycoerythrin (red)
- Storage product glycogen
- Cell wall: amino acids and sugars
- Within the cell are layers of membranes - photosynthetic thylakoids. Look like chloroplasts, and same size ~10 \( \mu \text{m} \). Cyanobacteria probably gave rise to eukaryotic chloroplasts (those without cell walls)
- Very similar in biochemistry and structure to chloroplasts of red algae
- Color due to a mucilaginous sheath to bind cells/filaments together – sheath is pigmented. Cells are independent within sheath

Importance

2) Many – fix or convert atmospheric nitrogen into usable forms through Nitrogen Fixation when other forms are unavailable.

IMPORTANT because atmospheric \( \text{N}_2 \) is unavailable to most living organisms because breaking the triple bond is difficult

\[ \text{N} \equiv \text{N} \]

Forms

- **Unicell** – with mucilaginous envelope
- **Colonies** –
  - **Filaments** – uniserate in a single row
  - OR - multiserate – not TRUE branching when trichomes are > 1 in rows

Features

- **Trichome** – row of cells
- **Filament**
  - Mucilaginous sheath – layer of mucilage outside of the cell wall.

Features

- **Heterocyst** – thick walled cell, hollow looking. Larger than vegetative cells.
  - FUNCTION – provides the anerobic environment for N fixation.

10 microns

Heterocyst

Vegetative cells

Anabaena
Heterocyst
- Larger than vegetative cells
- Hollow looking
- Thick walled – doesn’t allow atmospheric gas to enter.
- Photosynthetically inactive
- No CO₂ fixation or O₂ evolution
- Formation of heterocysts triggered by molybdenum and and low [nitrogen]

Nitrogen
- Nitrogen is a limiting nutrient necessary for the production of amino acids = building blocks of life.

Nitrogen Fixation
- ONLY cyanobacteria and prokaryotic bacteria can FIX nitrogen.
- Of these two only CYANOBACTERIA evolve OXYGEN during photosynthesis
- Important because nitrogenase (enzyme involved in fixing nitrogen) is INACTIVATED by O₂.

Mechanisms to Separate Nitrogenase from Oxygen
- Heterocyst (spatial)
- Fix Nitrogen in the DARK but not LIGHT – found in non-heterocystic cyanobacteria (temporal)

Cyanotoxins in Cyanobacteria
- Neurotoxins – block neuron transmission in muscles (Anabaena, Oscillatoria)
- Hepatotoxins – inhibit protein phosphatase, cause liver bleeding. Found in drinking water. (Anabaena, Oscillatoria, Nostoc)
- Eg. swimmers itch - Lyngbia

Movement
- No flagellae or structures to enhance movement
A) Excrete mucilage – jet propulsion, gliding
B) Helix – fibers send waves of contraction
**Spirulina**

- filamentous
- common in lakes with high pH
- major food for flamingo populations
- commercial food source

**Asexual Reproduction**

- Hormogonia formation -
- Endospore / Akinete formation -
- Fragmentation –
- Exospore

**Hormogonia** – short piece of trichome found in filaments. It detaches from parent filament and glides away.

**Akinete** – thick walled resting spore
**Asexual Reproduction**

**Akinete** – thick walled resting spore

Function – resistant to unfavorable environmental conditions.

Appear as larger cells in the chain and different than heterocyst. Generally lose buoyancy

H  A - akinete

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**Cyanobacteria**

- **Stromatolites**
  - Geol record of 3.5 billion yrs!
  - Form when cyanobacteria bind CaCo3 rich sediments
  - Now they form in shallow pools in hot/dry climates (eg. Australia)
  - Abundant in early earth – played an imp role in elevating free O2 in atmosphere.

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**Habitat – success due to ability tolerate a wide range of conditions**

- Marine – littoral and pelagic
- Fresh Water
- Hot Springs
- Terrestrial – soil flora
Purple and Green Bacteria

- Photosynthetic process and pigments differ from cyanobacteria
- No O2 during photosynthesis (anoxygenic)
- Some use sulfur as electron donors
- Only one photosystem
- Probably gave rise to photosystems I and II in cyanobacteria, algae and plants

Many Archaea are extremophiles

- Halophiles, thermophiles, methanogens
- Key members of oceanic picoplankton (<1 micrometer), outnumbering all other oceanic organisms!

Archaea

- **Halophiles**: great salt lake and dead sea
- **Methanogens** – prokaryotes (archaea) that make natural gas (anaerobic). Cows have them in their gut (help degrade cellulose); cows belch 50 liters of methane per day! Common in sewage treatment plants and in the deep sea
- **Thermophiles** are anaerobes, use sulfur, live at 110 degreesC! Also live in hydrothermal vents in the deep sea.

Symbiotic Relationships

- **Mutualism**
- **Commensalism**
- **Parasitism**

Important mutualism: Legumes and Rhizobia

- Nitrogen is abundant in the atmosphere as N2
- Plants can’t use N2, need NH4+
- Rhizobia living in nodules of legumes convert N2 to NH4+, gut sugars in return