Prokaryotic metabolism and nutrition

- Oxygen requirements:
  - Obligate Aerobes – need oxygen for cellular respiration
  - Facultative anaerobes – use oxygen if is present but can also grow by fermentation in an anaerobic environment
  - Obligate anaerobes are poisoned by oxygen
    - Some obligates live exclusively by fermentation
    - Other obligates perform cellular respiration, however they use substances other than oxygen (nitrate ions, sulfate ions) to accept electrons at the "downhill" end of electron transport chains – anaerobic respiration

Nutrition

  - Species that use light energy are *phototrophs*.
  - Species that obtain energy from chemicals in their environment are *chemotrophs*.
  - Organisms that need only CO_2 as a carbon source are *autotrophs*.
  - Organisms that require at least one organic nutrient as a carbon source are *heterotrophs*.
- These categories of energy source and carbon source can be combined to group prokaryotes according to four major modes of nutrition.
- **Photoautotrophs** are photosynthetic organisms that harness light energy to drive the synthesis of organic compounds from carbon dioxide.
  - Among the photoautotrophic prokaryotes are the cyanobacteria.
  - Among the photosynthetic eukaryotes are plants and algae.
- **Chemoautotrophs** need only CO_2 as a carbon source, but they obtain energy by oxidizing inorganic substances, rather than light.
  - These substances include hydrogen sulfide (H_2S), ammonia (NH_3), and ferrous ions (Fe^{2+}) among others.
  - This nutritional mode is unique to prokaryotes.
- **Photoheterotrophs** use light to generate ATP but obtain their carbon in organic form.
  - This mode is restricted to prokaryotes.
- **Chemoheterotrophs** must consume organic molecules for both energy and carbon.
  - This nutritional mode is found widely in prokaryotes, protists, fungi, animals, and even some parasitic plants.

- The majority of known prokaryotes are chemoheterotrophs.
  - These include **saprobes**, decomposers that absorb nutrients from dead organisms, and **parasites**, which absorb nutrients from the body fluids of living hosts.
  - Some of these organisms (such as *Lactobacillus*) have very precise nutritional requirements, while others (*E. coli*) are less specific in their requirements.
  - With such a diversity of chemoheterotrophs, almost any organic molecule, including petroleum, can serve as food for at least some species.
  - Those few classes of compounds that cannot be broken down by bacteria are said to be nonbiodegradable.
- Accessing nitrogen, an essential component of proteins and nucleic acids, is another facet of nutritional diversity among prokaryotes.
  - Eukaryotes are limited in the forms of nitrogen that they can use.
  - In contrast, diverse prokaryotes can metabolize most nitrogenous compounds.

Significance of Prokaryotes

- Nitrogen Fixation
  - Some chemoautotrophic bacteria convert ammonium (NH_4^+) to nitrite (NO_2^-).
  - Others "denitrify" nitrite or nitrate (NO_3^-) to N_2, returning N_2 gas to the atmosphere.
  - A diverse group of prokaryotes, including cyanobacteria, can use atmospheric N_2 directly.
  - During **nitrogen fixation**, they convert N_2 to NH_4^+, making atmospheric nitrogen available to other organisms for incorporation into organic molecules.
- Nitrogen fixing cyanobacteria are the most self-sufficient of all organisms.
  - They require only light energy, CO_2, N_2, water and some minerals to grow.
- Decomposers recycle elements in the ecosystem.
  - Methanogens convert garbage into methane.
  - Some types of bacteria decompose sewage and oil.

- Prokaryotes often interact with other species of prokaryotes or eukaryotes with complementary metabolisms.
- For example, while the fish provides bioluminescent bacteria under its eye with organic materials, the fish uses its living flashlight to lure prey and to signal potential mates.

  - Legumes (peas, beans, alfalfa, and others) have lumps in their roots which are the homes of mutualistic prokaryotes (*Rhizobium*) that fix nitrogen that is used by the host.
    - The plant provides sugars and other organic nutrients to the prokaryote.

Pathogenic prokaryotes cause many human diseases

- Exposure to pathogenic prokaryotes is a certainty.
  - Most of the time our defenses combat the growth of these pathogens.
  - Occasionally, the parasite invades the host, resists internal defenses long enough to begin growing, and then harms the host.
- Pathogenic prokaryotes cause about half of all human disease, including pneumonia caused by *Haemophilus influenzae* bacteria.
- Some pathogens are **opportunistic**.
  - These are normal residents of the host, but only cause illness when the host's defenses are weakened.
- Some pathogens produce symptoms of disease by invading the tissues of the host.
  - The actinomycete that causes tuberculosis is an example of this source of symptoms.
- More commonly, pathogens cause illness by producing poisons, called exotoxins and endotoxins.
- **Exotoxins** are proteins secreted by prokaryotes.
- Exotoxins can produce disease symptoms even if the prokaryote is not present.
  - *Clostridium botulinum*, which grows anaerobically in improperly canned foods, produces an exotoxin that causes botulism.
  - An exotoxin produced by *Vibrio cholerae* causes cholera, a serious disease characterized by severe diarrhea.
  - Even strains of *E. coli* can be a source of exotoxins, causing traveler's diarrhea.
- **Endotoxins** are components of the outer membranes of some gram-negative bacteria.
  - The endotoxin produced by *Salmonella typhi* causes typhoid fever.
  - Other *Salmonella* species, including some that are common in poultry, cause food poisoning.
- Since the discovery that "germs" cause disease, improved sanitation and improved treatments have reduced mortality and extended life expectancy in developed countries.
  - More than half of our antibiotics (such as streptomycin and tetracycline) come from the soil bacteria *Streptomyces*.

Humans use prokaryotes in research and technology

- Humans have learned to exploit the diverse metabolic capabilities of prokaryotes, for scientific research and for practical purposes.
  - Much of what we know about metabolism and molecular biology has been learned using prokaryotes, especially *E. coli*, as simple model systems.
  - Prokaryotes are now used to solve some environmental problems.
- The application of organisms to remove pollutants from air, water, and soil is **bioremediation**.
  - The most familiar example is the use of prokaryote decomposers to treat human sewage.
  - Anaerobic bacteria decompose the organic matter into sludge solid matter in sewage), while aerobic microbes do the same to liquid wastes.
  - Soil bacteria, called pseudomonads, have been developed to decompose petroleum products at the site of oil spills or to decompose pesticides.
- Humans also use bacteria as metabolic "factories" for commercial products.
  - The chemical industry produces acetone, butanol, and other products from bacteria.
  - The pharmaceutical industry cultures bacteria to produce vitamins and antibiotics.
  - The food industry used bacteria to convert milk to yogurt and various kinds of cheese.
- The development of DNA technology has allowed genetic engineers to modify prokaryotes to achieve specific research and commercial outcomes.