CHAPTER 21 VIRUSES, BACTERIA AND ARCHAEA

Chapter Outline

21.0 The Viruses

A. Viruses are not organisms; they
   1. are noncellular;
   2. cannot metabolize;
   3. cannot respond to stimuli;
   4. multiply only within living cells by parasitizing the synthetic machinery of the infected cell; and
   5. evolve as a result of mutation and natural selection
   6. All viruses are infectious.
   7. In 1884, Pasteur suspected something smaller than bacteria caused rabies; he chose Latin term for "poison."
   8. In 1892, Russian biologist Dimitri Ivanowsky, working with tobacco mosaic virus, confirmed Pasteur's hypothesis that an infectious agent smaller than a bacterium existed.
   9. With the invention of the electron microscope, these infectious agents could be seen for the first time.

B. Viral Structure
   1. A virus is similar in size to a large protein, generally smaller than 200 nm in diameter.
   2. Many viruses can be purified and crystallized, and the crystals stored for long periods of time.
   3. Viral crystals become infectious when the viral particles they contain invade host cells.
   4. All viruses have at least two parts:
      a. An outer **capsid** is composed of protein subunits.
      b. An inner core contains either DNA (deoxyribonucleic acid) or RNA (ribonucleic acid), but not both.
         1) The viral genome at most has several hundred genes; a human cell contains thousands of genes.
         2) The viral envelope is usually partly host plasma membrane with viral glycoprotein spikes.
         3) Viral particles have proteins, especially enzymes (e.g., polymerases), to produce viral DNA or RNA.
   5. The classification of viruses is based on
      a. their type of nucleic acid, including whether it is single-stranded or double-stranded;
      b. their size and shape; and
      c. the presence or absence of an outer envelope.

C. Parasitic Nature
   1. Viruses are **obligate intracellular parasites** that cannot multiply outside a living cell.
      a. Animal viruses in laboratories are raised in live chick embryos or in cell tissue culture.
      b. Viruses infect all sorts of cells, from bacteria to human cells, but are very specific.
         1) Tobacco mosaic virus only infects certain plants.
         2) The rabies virus infects only mammals.
         3) The AIDS virus, HIV, infects only certain human blood cells.
         4) Hepatitis virus invades only liver tissues.
         5) Polio virus only reproduces in spinal nerve cells.
   2. Virus Evolution
      a. Viruses are likely to have originated from the very cells that they infect.
      b. Therefore, nucleic acids originated from the host cell genome.
      c. Therefore, viruses evolved after cells came into existence; new viruses are probably evolving now.
   3. Viruses often mutate; therefore, it is correct to say that they evolve.
      a. Those that mutate are troublesome; a vaccine effective today may not be effective tomorrow.
      b. Influenza (flu) viruses mutate regularly.

D. Viral Reproduction
   1. Viruses gain entry into and are specific to a particular host cell because portions of the capsid (or spikes of the envelope) adhere to specific receptor sites on host cell surface.

2. Viral nucleic acid then enters a cell, where viral genome codes for production of protein units in the capsid.
3. A virus may have genes for a few special enzymes needed for the virus to reproduce and exit from a host cell.
4. Virus relies on host cell enzymes, ribosomes, transfer RNA (tRNA), and ATP for its own replication.
5. A virus takes over the metabolic machinery of the host cell when it reproduces.

E. Replication of Bacteriophages
   1. **Bacteriophages** (phages) are viruses that parasitize a bacterial cell.
   2. **Lytic cycle** is a bacteriophage "life" cycle of five stages where a virus takes over operation of the bacterium immediately upon entering it and then destroys the bacterium.
      a. During **attachment**, portions of the capsid bind with receptors on the bacterial cell wall.
      b. During **penetration**, a viral enzyme digests part of cell wall; the viral DNA is injected into a bacterial cell.
      c. **Biosynthesis** involves synthesis of viral components and begins after the virus brings about inactivation of host genes not necessary to viral replication.
      d. During **maturation,** viral DNA and capsids are assembled to produce several hundred viral particles and lysozyme, coded by the virus, is produced.
      e. When lysozyme disrupts the cell wall, **release** of the viral particles occurs and the bacterial cell dies.
   3. **Lysogenic cycle** is a cycle where the virus incorporates its DNA into the bacterium but only later does it produce phage.
      a. Following attachment and penetration, viral DNA becomes integrated into bacterial DNA with no destruction of host DNA.
      b. At this point the phage is **latent** and the viral DNA is called a **prophage.**
      c. Prophage is replicated along with host DNA; all subsequent cells (lysogenic cells) carry a copy.
      d. Certain environmental factors (e.g., ultraviolet radiation) induce prophage to enter the biosynthesis stage of the lytic cycle, followed by maturation and release.

F. Reproduction of Animal Viruses
   1. Animal viruses replicate similarly to bacteriophages but there are modifications.
      a. If the virus has an envelope, glycoprotein spikes allow it to adhere to plasma membrane receptors.
      b. The virus genome covered by the capsid penetrates the host cell.
      c. Once inside, the virus is uncoated as the envelope and capsid are removed.
      d. Free of its covering, the viral genome (DNA or RNA) proceeds with biosynthesis.
      e. Newly assembled viral particles are released by budding.
      f. Components of viral envelopes (i.e., lipids, proteins, and carbohydrates) are obtained from the plasma or nuclear membrane of the host cell as the viruses leave.
   2. **Retrovirus** is an RNA animal virus with a DNA stage.
      a. Retroviruses contain **reverse transcriptase** that carries out reverse transcription producing cDNA.
      b. Viral cDNA is integrated into host DNA and is replicated as host DNA replicates.
      c. Viral DNA is transcribed; new viruses are produced by biosynthesis, maturation and release by budding.

G. Viral Infections
   1. Viruses cause infectious diseases in plants and animals, including humans.
   2. Some animal viruses are specific to human cells: papillomavirus, herpes virus, hepatitis virus, and adenoviruses, which can cause specific cancers.
   3. Retroviruses include the AIDS viruses (e.g., HIV) and also cause certain forms of cancer.
   4. Some viruses are cancer-producing because they bring with them **oncogenes,** normal genes transformed so that they can cause the cell to undergo repeated cell divisions.
   5. In humans, viral diseases are controlled by preventing transmission, administering vaccines, and only recently by the administration of antiviral drugs.
   6. Antibiotics do not cure viral infections because viruses use host cell enzymes, not their own enzymes; interfering with the enzyme kills the host cell.

7. Over a thousand plant viruses cause diseases; virus infections are difficult to distinguish from nutrient deficiencies and plants are propagated to stay free of virus infection.
8. **Viroids** are naked strands of RNA, a dozen of which cause crop diseases.
9. Prions are newly discovered disease agents that vary from viruses and bacteria.
    a. Prions are proteins with a wrongly shaped tertiary structure that cause other proteins to distort.
    b. Creutzfeldt-Jakob disease in humans and scrapie and mad cow disease (BSE) in cattle are due to prions.

21.2 The Prokaryotes

A. Prokaryotes include the bacteria and archaea.
    1. Bacteria were discovered in the seventeenth century when Dutch naturalist Antonie van Leeuwenhoek examined scrapings from his teeth.
    2. The organisms Leeuwenhoek observed were thought to arise spontaneously from inanimate matter.
    3. Around 1850, Pasteur devised an experiment showing that the bacteria present in air contaminated the media.
    4. A single spoonful of soil contains 10^{10} prokaryotes; these are the most numerous life forms.

B. Structure of Prokaryotes
    1. Prokaryotes range in size from 1–10 μm in length and from 0.7–1.5 μm in width.
    2. "Prokaryote" means "before a nucleus" and their cells lack a eukaryotic nucleus.
    3. Prokaryotic fossils date back to 3.5 billion years ago.
    4. Fossils indicate prokaryotes were alone on earth for 2 billion years; they evolved very diverse metabolic capabilities.
    5. Prokaryotes adapted to most environments because they differ in the many ways they acquire and utilize energy.
    6. Outside the plasma membrane of most cells is a rigid cell wall that keeps the cell from bursting or collapsing due to osmotic changes.
        a. The cell wall is surrounded by an organized capsule called a glycocalyx and/or by a loose gelatinous sheath called a slime layer.
        b. In parasitic forms, these outer coverings protect the cell from host defenses.
    7. Some prokaryotes move using flagella.
        a. The **flagellum** is a filament composed of three strands of the protein flagellin wound in a helix and inserted into a hook that is anchored by a basal body.
        b. The flagellum is capable of 360^{o} rotation which causes the cell to spin and move forward.
    8. Many prokaryotes adhere to surfaces by means of fimbriae.
        a. **Fimbriae** are short hairlike filaments extending from the surface.
        b. The fimbriae of *Neisseria gonorrhoeae* allow it to attach to host cells and cause gonorrhea.
    9. Prokaryotic cells lack the membranous organelles of eukaryotic cells.
    10. Various metabolic pathways are located on the plasma membrane.
    11. A **nucleoid** is a dense area in prokaryotes where the chromosome is located; it is a single circular strand of DNA.
    12. **Plasmids** are accessory rings of DNA found in some prokaryotes; they can be extracted and used as vectors to carry foreign DNA into bacteria during genetic engineering procedures.
    13. Protein synthesis in prokaryotic cells is carried out by thousands of ribosomes, which are smaller than eukaryotic ribosomes.

C. Reproduction in Prokaryotes
    1. Binary fission is a splitting of a parent cell into two daughter cells; it is asexual reproduction in prokaryotes.
        a. A single circular chromosome replicates; the two copies separate as the cell enlarges.
        b. Newly formed plasma membrane and cell wall separate the cell into two cells.
        c. Mitosis, which involves formation of a spindle apparatus, does not occur in prokaryotes.
    2. Sources of Genetic Variation
        a. Because prokaryotes have a short generation time, mutations are generated and distributed through a population more rapidly.
        b. Prokaryotes are haploid; mutations are therefore immediately subjected to natural selection.

c. In bacteria, genetic recombination can occur in three ways.
    1) **Conjugation** occurs when a bacterium passes DNA to a second bacterium through a tube (**sex pilus**) that temporarily joins two cells; this occurs only between bacteria in the same or closely related species.
    2) **Transformation** involves bacteria taking up free pieces of DNA secreted by live bacteria or released by dead bacteria.
    3) In **transduction**, the bacteriophage transfers portions of bacterial DNA from one cell to another.
d. Plasmids can carry genes for resistance to antibiotics and transfer them between bacteria by any of these processes.

D. Endospore Formation
1. Some bacteria form resistant **endospores** in response to unfavorable environmental conditions.
2. Some cytoplasm and the chromosome dehydrate and are encased by three heavy, protective spore coats.
3. The rest of the bacterial cell deteriorates and the endospore is released.
4. Endospores survive in the harshest of environments: desert heat and dehydration, boiling temperatures, polar ice, and extreme ultraviolet radiation.
5. Endospores also survive very long periods of time; anthrax spores 1,300 years old can cause disease.
6. When environmental conditions are again suitable, the endospore absorbs water and grows out of spore coat.
7. In a few hours, newly emerged cells become typical bacteria capable of reproducing by binary fission.
8. Endospore formation is not reproduction but it is a means of survival and dispersal to new locations.

E. Prokaryotic Nutrition
1. Bacteria differ in their need for, and tolerance of, oxygen (O_2).
    a. **Obligate anaerobes** are unable to grow in the presence of O_2; this includes anaerobic bacteria that cause botulism, gas gangrene, and tetanus.
    b. **Facultative anaerobes** are able to grow in either the presence or absence of gaseous O_2.
    c. Aerobic organisms (including animals and most prokaryotes) require a constant supply of O_2 to carry out cellular respiration.
2. Autotrophic Prokaryotes
    a. **Photoautotrophs** are photosynthetic and use light energy to assemble the organic molecules they require.
        1) Primitive photosynthesizing bacteria (e.g., green sulfur bacteria and purple sulfur bacteria) use only photosystem I that contains **bacteriochlorophyll;** they do not give off O_2 because hydrogen sulfide (H_2S) is used as an electron and H^+ donor instead of H_2O.
        2) Advanced photosynthesizing bacteria (e.g., cyanobacteria) use both photosystem I and II that contain the same types of chlorophylls found in plants; they do give off O_2 because H_2O is used as an electron and H^+ donor.
    b. **Chemoautotrophs** make organic molecules by using energy derived from the oxidation of inorganic compounds in the environment.
        1) Deep ocean hydrothermal vents provide H_2S to form of chemosynthetic bacteria.
        2) The methanogens are chemosynthetic bacteria that produce methane (CH_4) from hydrogen gas and CO_2; ATP synthesis and CO_2 reduction are linked to this reaction and methanogens can decompose animal wastes to produce electricity as an ecological friendly energy source.
        3) Nitrifying bacteria oxidize ammonia (NH_3) to nitrites (NO_2) and nitrites to nitrates (NO_3).
3. Heterotrophic Prokaryotes
    a. Most free-living bacteria are **chemoheterotrophs** that take in pre-formed organic nutrients.
    b. As **aerobic saprotrophs**, there is probably no natural organic molecule that cannot be broken down by some prokaryotic species.
    c. **Decomposers** are critical in recycling materials in the ecosystem; they decomposing dead organic matter and make it available to photosynthesizers.
4. Commercial Uses
    a. Prokaryotes produce chemicals including ethyl alcohol, acetic acid, butyl alcohol, and acetones.
    b. Prokaryotic action produces butter, cheese, sauerkraut, rubber, cotton, silk, coffee and cocoa.
    c. Antibiotics are produced by some bacteria.

6. Some chemoheterotrophs are **symbiotic**, forming intimate, long-term relationships with members of other species; includes mutualistic, commensalistic, and parasitic relationships.
    a. Mutualistic nitrogen-fixing *Rhizobium* bacteria live in nodules on roots of soybean, clover, and alfalfa where they reduce N_2 to ammonia for their host; bacteria use some of a plant's photosynthetically produced organic molecules.
    b. Mutualistic bacteria that live in the intestines of humans benefit from undigested material and release vitamins K and B_{12}, which we use to produce blood components.
    c. In the stomachs of cows and goats, mutualistic prokaryotes digest cellulose.
    d. Commensalistic bacteria live in or on organisms of other species and cause them no harm.
    e. Parasitic bacteria are responsible for a wide variety of infectious plant, animal and human diseases.

21.3 The Bacteria

A. Gram Stain and Shape
    1. The Gram stain procedure (developed in the late 1880s by Hans Christian Gram) differentiates bacteria.
        a. Gram-positive bacteria stain purple, whereas Gram-negative bacteria stain pink.
        b. This difference is dependent on the thick or thin (respectively) peptidoglycan cell wall.
    2. Bacteria and archaea have three basic shapes.
        a. A **spirillum** is spiral-shaped.
        b. A **bacillus** is an elongated or rod-shaped bacteria.
        c. **Coccus** bacteria are spherical.
        d. Cocci and bacilli tend to form clusters and chains of a length typical of the particular species.

B. Types of Bacteria
    1. Earlier classification of bacteria was based on metabolism, nutrition, etc.
    2. Work by Carl Woese since 1980 has revised bacterial taxonomy based on similarity of 16S rRNA.
    3. Twelve groups are now recognized based on bacterial 16S ribosomal RNA sequences.

C. Cyanobacteria
    1. **Cyanobacteria** are Gram-negative bacteria with a number of unusual traits.
    2. They photosynthesize in same manner as plants; are responsible for introducing O_2 into the primitive atmosphere.
    3. They were formerly mistaken for eukaryotes and classified with algae.
    4. They have pigments that mask chlorophyll; they are not only blue-green but also red, yellow, brown, or black.
    5. They are relatively large (1–50 μm in width).
    6. They can be unicellular, colonial, or filamentous.
    7. Some move by gliding or oscillating.
    8. Some possess heterocysts, thick-walled cells without a nucleoid, where nitrogen fixation occurs.
    9. Cyanobacteria are common in fresh water, soil, on moist surfaces, and in harsh habitats (e.g., hot springs).
    10. Some species are symbiotic with other organisms (e.g., liverworts, ferns, and corals).
    11. **Lichens** are a symbiotic relationship where the cyanobacteria provide organic nutrients to the fungus and the fungus protects and supplies inorganic nutrients.
    12. Cyanobacteria were probably the first colonizers of land during evolution.
    13. Cyanobacteria "bloom" when nitrates and phosphates are released as wastes into water; when they die off, decomposing bacteria use up the oxygen and cause fish kills.

21.4 The Archaea

A. Relationship to Domain Bacteria and Domain Eukarya
    1. **Archaea** are prokaryotes with molecular characteristics that distinguish them from bacteria and eukaryotes; their rRNA sequence is different from rRNA in bacteria.
    2. Because archaea and some bacteria are both found in extreme environments (hot springs, thermal vents, salt basins), they may have diverged from a common ancestor.
    3. Later, the eukarya split from the archaea; archaea and eukarya share some ribosomal proteins not found in bacteria; initiate transcription in the same manner, and have similar types of tRNAs.

B. Structure and Function
    1. Archaea have unusual lipids in their plasma membranes that allow them to function at high temperatures: glycerol linked to hydrocarbons rather than fatty acids.
    2. Cell walls of archaea do not contain the peptidoglycan found in bacterial cell walls.
    3. Only some methanogens have the ability to form methane.
    4. Most are chemoautotrophs; none are photosynthetic; this suggests chemoautotrophy evolved first.
    5. Some are mutualistic or commensalistic but none are parasitic—none are known to cause disease.

C. Types of Archaea
    1. Methanogens live under anaerobic environments (e.g., marshes) where they produce methane.
        a. Methane is produced from hydrogen gas and carbon dioxide and is coupled to formation of ATP.
        b. Methane released to the atmosphere contributes to the greenhouse effect.
        c. About 65% of methane found in our atmosphere is produced by methanogenic archaea.
    2. Halophiles require high salt concentrations (e.g., Great Salt Lake).
        a. Their proteins have unique chloride pumps that use halorhodopsin to synthesize ATP in presence of light.
        b. Usually they require 12–15% salt concentrations; ocean is only 3.5% salt.
    3. Thermoacidophiles live under hot, acidic environments (e.g., geysers).
        a. They survive best at temperatures above 80^{o}C; some survive above boiling!
        b. Metabolism of sulfides forms acidic sulfates; these bacteria grow best at pH of 1 to 2.