CHAPTER 16 – *PROKARYOTES AND VIRUSES*

- What is a prokaryote?
  - An organism that does not have a true nucleus and also does not have other membrane-bound organelles.

- Earth is roughly 4.6 billion years old.
- First life on Earth = 3.5 billion years ago (bya)
  - Scientists found what they believe to be Earth's first life in ancient fossils called **stromatolites**
    - Stromatolites are fossils made of thin layers of sediment/soil pressed together
    - Inside these stromatolites, scientists found photosynthetic prokaryotes.

- Photosynthetic prokaryotes – simplest organisms that can produce their own food.
  - Because photosynthesis is such a complex process, it is unlikely that photosynthetic prokaryotes were the *first* forms of life on Earth.
    - Most likely, life in an even simpler form existed about 3.9 bya when Earth was cool enough for liquid water to exist.

- **How did life begin?**
  - Earth's atmosphere used to consist of ↑ CO_2, ↑Nitrogen gas, but no O_2 (oxygen).
  - In the 1950s, a scientist named Miller confirmed the hypothesis of Oparin
    - Oparin's hypothesis stated that Earth's gases combined during lightning events to form simple amino acids, sugars, lipids, ATP, and the nitrogen bases/nucleotides that make up DNA/RNA.
    - Basically, Miller's work gave support to the idea that all of life's major organic molecules/building blocks were formed from chemical and physical processes.
    - Recall: An organic molecule is a carbon – containing molecule. The four major groups of organic molecules found in organisms are: proteins, carbohydrates, lipids, and nucleic acids. A *monomer* is a basic building block that combines with other like monomers to make a more complex organic compound called a *polymer*.

Monomer	**Polymer**
Amino acid	Polypeptide (Protein)
Monosaccharide	Polysaccharide (Sugar)
Fatty acid	Lipid
Nucleotide	Nucleic Acid (DNA, RNA)

    - How did polymers form without enzymes or cells?
      - It is thought that polymers were able to form within hot clay; in this hot clay, monomers became concentrated and were in such close proximity to each other that they began to bond together to form polymers.

- Recall: DNA → RNA → Protein
  - How did earliest life forms copy this hereditary information so it could be passed on to offspring?

        - It is thought that the first genes were actually short RNA strands that could replicate without enzymes.
            - This theory is what your book calls the "RNA World" – a period of time when RNA served both to store genetic information and to direct protein synthesis/production.

- How did proteins eventually become encased in a membrane to form a cell?
    - Polypeptides came together to form little bubbles called microspheres.
    - Lipids then attached to these microspheres to form a selectively-permeable membrane very similar to today's cell membrane.
        - This little molecular package/microsphere is a "pre-cell"; in other words, it is not living but has some characteristics of living cells. This pre cell still needs DNA to be considered living.
            - A microsphere is like a remote without the battery – it has most of the parts it needs to work (proteins, lipids), but not the main source to direct its functions (DNA).

- **Four stage sequence for how life developed on Earth:**
    - 1) Small organic molecules/monomers formed from gases in Earth's atmosphere.
    - 2) Small monomers joined together to form polymers (proteins, RNA, etc.).
    - 3) RNA was able to copy itself and provide a means of inheritance.
    - 4) Organic molecules eventually became packaged into membranes.

- **Where did life begin?**
    - Scientists once believed that life began in water and moist clay. However, the Earth may still have been too hot 3.5 bya for life to have formed in clay.
    - Now, scientists think life began in deep sea vents; they believe this in part because many prokaryotes still live in deep sea vents and these modern prokaryotes look very similar to their ancient ancestors.

- **Diversity of Prokaryotes**
    - Recall: The 3 domain system of classification:

ARCHAEA	**BACTERIA**	**EUKARYA**
- Prokaryotes that tend to live in extreme environments (extremophiles)	- Prokaryotes that differ from archaea by the information contained in their DNA and RNA and their proteins. - (Bacterial polymerases used in DNA/RNA replication are very small and simple, while arachaea's polymerases are very similar to eukarya.)	- Includes all eukaryotes: - Protists - Fungi - Plants - Animals
Thermophiles live in hot water	Introns are absent in bacteria but present in archaea and eukarya	
Halophiles live in *very* salty water	Antibiotics that kill bacteria do not affect archaea	
Anaerobes – can live without oxygen	The cell wall structure that bacteria has is not found in archaea or eukarya	

- **Structure and Function of Bacteria**
  - Bacteria are grouped by three major characteristics:
    - 1) CELL SHAPE: 3 basic shapes:
      - Spherical, called **cocci**: Staphylococcus and Streptococcus are examples of spherical or circular shaped bacteria
      - Rod, called **bacilli**: E. coli is an example of a rod shaped bacterium.
      - Spiral, called **spirochetes**: The bacteria that cause Lyme's disease and syphilis are spirochetes.
    - 2) CELL WALL STRUCTURE
      - The bacterial cell wall is very different from the cell wall found in some eukaryotes (in plants, fungi, protists).
      - Two types of bacterial cell wall:
        - One is made mainly of peptidoglycan. (Think about it: "peptido" looks like peptide, which is a protein and "glycan" looks like glucose, which is sugar, so a peptidoglycan cell wall is made of protein and sugar.)
        - The other type is made of some peptidoglycan but also has an additional outer membrane.
      - You can distinguish between the two types of cell walls by using a lab technique called Gram staining, where the bacteria are exposed to pink and purple dyes and then viewed under a microscope:
        - If the bacteria appear **P**urple, they are gram **P**ositive. Gram positive bacteria have the second type of cell wall with the additional outer membrane that holds the purple dye.
        - If the bacteria appear pi**N**k, they are gram **N**egative.
        - Why is gram staining important?
          - A gram-negative bacterial infection is treated with a completely different kind of antibiotic vs. a gram-positive bacterial infection. (So when a patient's blood or throat culture is taken and gram stained, a doctor can determine what kind of antibiotic treatment to give.)
    - 3) MOTILITY (MOVEMENT)
      - Different bacteria move in different ways:
        - Use a flagellum (tail) that is different in structure than a eukaryotic flagellum
        - Use pili (short, foot-like projections) to help with "crawling"
        - Secrete slime threads that allow for gliding motion

- **PROKARYOTIC REPRODUCTION**
  - Main form of reproduction is asexual, by **binary fission** (the prokaryotic cell multiplies its genetic material and then splits in two).
  - Though binary fission usually produces EXACT copies of the parent cell, mutation can occur in the genes during copying and so a mutated offspring cell can be formed. Mutation can actually be helpful in a bacterial cell, because that mutation may help the bacterium fight off an antibiotic. (More on this later.)

- Prokaryotic reproduction can be VERY fast – each cell can copy itself every 20 minutes.
- How do prokaryotes ever produce offspring that are genetically different from the parents if they do not reproduce sexually?
  - Prokaryotes can mix their DNA with the DNA of another prokaryote in one of three ways:
    - **Transformation:** Free floating DNA released from a dead bacterium can be taken up by another bacterium.
    - **Conjugation**: A "mating bridge" forms between two bacteria and they swap DNA.
    - **Transduction**: A virus called a bacteriophage infects a bacterium and inserts its viral DNA into the bacterial DNA.

- **Endospore formation:**
  - An endospore is a form a bacterium can take on when it is exposed to harsh conditions – allows for survival.
    - Bacillus anthracis (bacterium that causes anthrax) commonly undergoes endospore formation.

- **Modes of Nutrition:**
  - How do prokaryotes obtain energy?
    - Whether a cell is prokaryotic or eukaryotic, it needs two things to make energy:
      - An energy source (light, inorganic molecules, etc.)
      - A carbon source (to use for making monomers, polymers, etc.)

Autotrophic (make own food by obtaining carbon atoms directly from CO2)	**Heterotrophic** (eat already existing food; obtain carbon atoms from that food)
Photoautotrophs – use light for energy and CO2 as carbon source - **Both prokaryotes and eukaryotes can be photoautotrophs (for eukaryotes, plants, fungi, protists)	***Photoheterotrophs*** – use light for energy to make ATP but get carbon from an already existing food source - **ONLY prokaryotes are photoheterotrophs.
Chemoautotrophs – use inorganic (non-carbon containing) molecules for energy and CO2 as their carbon source. - **ONLY prokaryotes are chemoautotrophs.	***Chemoheterotrophs*** – Use already existing organic molecules (food) for both energy and carbon source. - **Some prokaryotes, protists, fungi, and ALL animals are chemoheterotrophs.

- **Cyanobacteria:**
  - Photoautotrophic type of bacteria
  - Generates O2 as waste during photosynthesis
  - As cyanobacteria evolved, oxygen was released into the atmosphere. (Remember that Earth's atmosphere did not contain oxygen at first.)
    - This new oxygen was toxic to other early organisms – oxygen split the bonds of organic molecules within cells and killed them.
      - Because of this, only anaerobic organisms thrived.
      - However, some other cells were mutants – they had genes that allowed them to survive in the presence of oxygen and use that

oxygen to get energy from food by a process called *cellular respiration*.
    - Because aerobic cellular respiration ended up being a much more efficient way to produce energy (vs. anaerobic respiration), aerobic organisms eventually dominated Earth.

- **Major Functions of Prokaryotes:**
    - 1) CHEMICAL RECYCLING
        - Bacteria can decompose waste and dead organisms and release CO2 into the atmosphere.
        - Bacteria living in the soil can change atmospheric Nitrogen gas into a form of nitrogen that plants can use – plants take up this usable nitrogen in the soil and use it to make necessary proteins.
    - 2) HUMAN USES
        - Bioremediation: use prokaryotes to remove pollutants from atmosphere (use bacteria to decompose sewage, clean up oil spills and old mining sites, etc.)
        - In pharmaceutical research – study bacteria to develop effective antibiotics.

- **How Bacteria Cause Disease:**
    - Any organism/agent that can cause disease is a **Pathogen.**
    - We "catch" bacterial infections in multiple ways if our immune systems are weakened (by stress, poor diet, etc.):
        - Inhalation
        - Hand-to-hand contact
        - Sexual transmission
        - Bite of an animal
        - Poorly prepared or stored food
    - Modes of bacterial disease generation:
        - 1) Bacteria can invade tissues and directly destroy cells (The tuberculosis bacterium gets trapped inside white blood cells but is able to destroy those cells directly.)
        - 2) Bacteria can produce toxins/poisons to kill cells – two types of toxins:
            - Exotoxins – poisonous proteins released by a bacterium that can kill our cells (Staphylococcus bacteria do this).
                - (Exo means outside – the exotoxin is released outside the bacterium.)
            - Endotoxin – poisonous protein that sits on the bacterial cell wall – our immune systems generate a response to that protein that actually causes problems like shock (rapid drop in blood pressure). Salmonella bacteria have endotoxins.
                - (Endo means inside – the endotoxin stays on the bacterium and is NOT released outside the bacterium.)

- **Our defenses against bacterial diseases:**
    - Primary defense – physical barriers
        - Skin, mucous layer of mouth, nose, gut all help block bacteria from entering body.
    - Secondary defense – chemical and cellular defenses of the immune system (white blood cells, antibodies, etc.)
    - Antibiotics – damage the bacterial cell wall.
        - Since we don't have cell walls, we do not have to worry that these antibiotics will attack our own cells.
        - With overuse of antibiotics, multi-drug resistance is becoming a problem.
            - Let's say you have 100 bacterial cells in your body causing an infection. You take an antibiotic designed to kill these cells. However, 1 of these bacterial cells is mutated and is able to survive the attack brought on by the antibiotic.
            - This 1 bacterial cell will multiply and when you get sick again from that bacteria, the antibiotic you used before will not help.
            - A good example of this is MRSA – Methicillin Resistant Staph aureus. Staph can be a nasty infection if it enters the body through a cut, etc. It can cause tissue/muscle infection and abscesses. Most Staph can no longer be treated with a simple penicillin-based drug called methicillin. For years, staph was treated with methicillin. Even though the methicillin killed off most of the staph, any mutant staph that was able to survive the methicillin attack multiplied and caused new infection.

- **What is a virus?**
    - A package of DNA or RNA wrapped in a protein coat that must use a host cell's machinery to reproduce itself.
    - Why is a virus not technically considered "living"?
        - Because viruses are not made of cells.
        - Because viruses cannot reproduce on their own.

    - Viral Structure:
        - DNA or RNA surrounded by a protein coat called a capsid.
        - Some viruses have an additional fat layer outside the protein coat.
    - Viral Reproduction:
        - **Lytic Cycle:**
            - "Lyse" means to break; this is the cycle where a virus will break open a host cell.
            - First, the virus attaches to the host cell and injects its DNA or RNA into the host cell. However, the viral DNA/RNA does NOT stick itself into the DNA of the host cell; instead, this viral DNA/RNA is just floating in the cell.
            - The host cell's enzymes make copies of the viral DNA/RNA and proteins.
            - The viral DNA/RNA/proteins assemble themselves into multiple viruses.
            - The host cell bursts open and releases the virus onto more host cells.

        - Once the host cell bursts, it's dead.
    - **Lysogenic Cycle:**
        - The virus injects its genes DIRECTLY into the host DNA; the viral genetic material is actually part of the host DNA now.
        - Every time the host reproduces, both the host and the viral genetic material is copied.
        - This is known as a "dormant" phase – the virus is hiding/resting in the host cell but not causing active death of the host cell. Herpes virus and HIV can have long lysogenic cycles in which they are not actively causing disease.
        - A lytic cycle can occur if the viral DNA or RNA separates from the host cell's DNA.

- **How do viruses cause disease?**
    - Host cells are killed when viruses burst open the host cell during the lytic cycle.
    - How can we treat viral infections if the virus is hiding within our own cells?
        - This is the big problem with viruses. Antibiotics do NOT work on viruses because of this (also because viruses do not have a cell wall, and most antibiotics are designed to attack a bacterial cell wall).

- **HIV as an example of a virus:**
    - Human Immondeficiency Virus – can cause AIDS (Acquired Immune Deficiency Syndrome)
        - HIV attacks T cells – a type of white blood cell that normally helps fight disease. As a person's T cell number drops due to HIV infection, that person will begin to be infected with many dangerous pathogens, including viral, bacterial, and fungal. Once a person's T cell count is extremely low and he/she has developed a serious infection (some types of pneumonia, brain infections, etc.), he/she is considered to have "full-blown" AIDS.
        - HIV is an RNA virus and is also known as a retrovirus, because it reverses the usual DNA → RNA flow in a host cell.
        - HIV uses one of its enzymes called "reverse transcriptase" to make HIV DNA from HIV RNA. Once the HIV DNA is made, it will enter the host cell's DNA and begin a lysogenic cycle.
        - When a lytic cycle begins, T cells begin to die off and full blown AIDS may develop.

- **Our defenses against viruses:**
    - Vaccines – basically, vaccines work by injecting small parts of pathogens into our bodies. The parts are small enough that they do not cause disease but they do stimulate the immune system to make antibodies against the pathogen. If a vaccinated person is ever exposed to the real pathogen, he/she will be able to fight it off because he has made antibodies against it.
    - The first vaccine created in the late 1700s was against the smallpox virus; developed by Jenner.
    - Salk and Sabin are more modern scientists who developed vaccines against polio.
    - Why are vaccines not always successful?
        - Because some bacteria and viruses rapidly mutate. If you are injected with a vaccine containing one kind of virus known to cause the flu, that vaccine may not protect you in next year's flu season, when a new strain of virus has taken over.
    - There are some anti-viral drugs that interfere with viral DNA/RNA synthesis or, in the case of HIV infection, block reverse transcriptase.