Chapter 4

4.1 Cellular Level of Organization

1. Detailed study of the cell began in the 1830s; some of the scientists contributing to the understanding of cell structure and function were Robert Brown, Matthais Schleiden, Theodor Schwann, and Rudolph Virchow.
2. The **cell theory** states that all organisms are composed of **cells**, that cells are the structural and functional unit of organisms, and that cells come only from preexisting cells.

A. Cell Size

1. Cells range in size from one millimeter down to one micrometer.
2. Cells need a surface area of plasma membrane large enough to adequately exchange materials.
3. The **surface-area-to-volume ratio** requires that cells be small.
   a. As cells get larger in volume, surface area relative to volume decreases.
   b. Size limits how large the actively metabolizing cells can become.
   c. Cells needing greater surface area utilize membrane modifications such as folding, microvilli, etc.

B. Microscopy Today (*Science Focus* Box)

1. **Compound light microscopes** use light rays focused by glass lenses.
2. **Transmission electron microscopes** (TEM) use electrons passing through specimen and focused by electromagnetic lenses.
3. **Scanning electron microscopes** (SEM) use electrons scanned across metal-coated specimen; secondary electrons given off by metal are collected by a detector.
4. **Magnification** is a function of wavelength; the shorter wavelengths of electrons allow greater magnification than the longer wavelengths of light rays.
5. **Resolution** is the minimum distance between two objects at which they can still be seen as separate objects.
6. **Contrast** is the difference in the shading of an object compared to its background.
7. **Phase contrast and differential interface contrast microscopy** uses fluorescent antibodies to reveal proteins in cells.
8. **Confocal microscopy** uses laser beam to focus on a shallow plane within the cell; this forms a series of optical sections from which a computer creates a three dimensional image.
9. **Video-enhanced contrast microscopy** accentuates the light and dark regions and may use a computer to contrast regions with false colors.
10. **Bright-field, phase contrast, differential interference**, and **darkfield** are different types of light microscopes.

4.2 Prokaryotic Cells

1. Prokaryotic cells lack a nucleus and are smaller and simpler than eukaryotic cells (which have a nucleus).
2. Prokaryotic cells are placed in two taxonomic domains: Bacteria and Archaea. Organisms in these two domains are structurally similar but biochemically different.

A. The Structure of Prokaryotes

1. Prokaryotes are extremely small; average size is 1–1.5 µm wide and 2–6 µm long .
2. Prokaryotes occur in three basic shapes: spherical **coccus**, rod-shaped **bacillus**, and spiral **spirillum** (if rigid) or **spirochete** (if flexible).

3. Cell Envelope
    a. In bacteria, the cell envelope includes the **plasma membrane**, the **cell wall**, and the **glycocalyx**. The plasma membrane is a lipid bilayer with imbedded and peripheral proteins; it regulates the movement of substances into and out of the cell.
    b. The plasma membrane can form internal pouches called **mesosomes**, which increase the internal surface area of the membrane for enzyme attachment.
    c. The cell wall maintains the shape of the cell and is strengthened by **peptidoglycan**.
    d. The glycocalyx is a layer of polysaccharides on the outside of the cell wall; it is called a **capsule** if organized and not easily removed, or a **slime layer** if it is not well-organized and is easily removed.
4. Cytoplasm
    a. The **cytoplasm** is a semifluid solution containing water, inorganic and organic molecules, and enzymes.
    b. The **nucleoid** is a region that contains the single, circular DNA molecule.
    c. **Plasmids** are small accessory (extrachromosomal) rings of DNA; they are not part of the bacterial genetic material.
    d. **Ribosomes** are particles with two RNA- and protein-containing subunits that synthesize proteins.
    e. **Inclusion bodies** in the cytoplasm are granules of stored substances.
    f. **Cyanobacteria** (also called **blue-green bacteria**) are bacteria that photosynthesize; they lack chloroplasts but have **thylakoids** containing chlorophyll and other pigments.
5. Appendages
    a. Motile bacteria usually have **flagella;** the filament, hook, and basal body work to rotate the flagellum like a propeller to move through fluid medium.
    b. **Fimbriae** are small, bristle like fibers that attach to an appropriate surface.
    c. **Conjugation pili** are tubes used by bacteria to pass DNA from cell to cell.

4.3 Introducing Eukaryotic Cells

A. Origin of the Eukaryotic cell

1. According to the **endosymbiotic theory**, energy-related organelles, such as mitochondria and chloroplast, arose when a eukaryotic cell engulfed prokaryotic cells.
1. Eukaryotic cells are members of the domain Eukarya, which includes the protists, fungi, plants, and animals.
2. A membrane-bounded **nucleus** houses DNA; the nucleus may have originated as an invagination of the plasma membrane.
3. Eukaryotic cells are much larger than prokaryotic cells, and therefore have less surface area per volume.

B. Structure of Eukaryotic Cells

1. Some eukaryotic cells (e.g., plant cells) have a **cell wall** containing cellulose; **plasmodesmata** are channels in a cell wall that allow cytoplasmic strands to extend between adjacent cells.
2. Eukaryotic cells are compartmentalized; they contain small structures called **organelles** that perform specific functions.

3. The **nucleu**s communicates with **ribosomes** in the cytoplasm.
4. The organelles of the endomembrane system communicate with one another; each organelle contains its own set of enzymes and produces its own products, which move from one organelle to another by transport vesicles.
5. The energy-related **mitochondria** (plant and animal cells) and **chloroplasts** (plant cells) do not communicate with other organelles; they contain their own DNA and are self-sufficient.
6. The **cytoskeleton** is a lattice of protein fibers that maintains the shape of the cell and assists in movement of the organelles.

C. Cell Fractionation and Differential Centrifugation (*Science Focus* Box)
1. **Cell fractionation** allows the researcher to isolate and individually study the organelles of a cell.
2. **Differential centrifugation** separates the cellular components by size and density.
3. Using these two techniques, researchers can obtain pure preparations of any cell component.

4.4 The Nucleus and Ribosomes

A. Nucleus
1. The nucleus has a diameter of about 5 µm.
2. **Chromatin** is a threadlike material that coils into chromosomes just before cell division occurs; contains DNA, protein, and some RNA.
3. **Nucleoplasm** is the semifluid medium of the nucleus.
4. **Chromosomes** are rodlike structures formed during cell division; composed of coiled or folded chromatin.
5. The **nucleolus** is a dark region of chromatin inside the nucleus; it is the site where ribosomal RNA (rRNA) joins with proteins to form ribosomes.
6. The nucleus is separated from the cytoplasm by the **nuclear envelope,** which contains **nuclear pores** to permit passage of substances (e.g., ribosomal subunits, messenger RNA, proteins, etc.) in and out of the nucleus

B. Ribosomes
1. **Ribosomes** are the site of protein synthesis in the cell. In eukaryotic cells, ribosomes may occur freely or in groups called **polyribosomes**.
2. Ribosomes receive messenger RNA (mRNA) from the nucleus, which instructs the ribosomes of the correct sequence of amino acids in a protein to be synthesized.

4.5 The Endomembrane System

A. The **endomembrane system** is a series of intracellular membranes that compartmentalize the cell.
1. It consists of the nuclear envelope, the membranes of the endoplasmic reticulum, the Golgi apparatus, and several types of vesicles.

B. **Endoplasmic Reticulum**
1. The endoplasmic reticulum (ER) is a system of membrane channels and saccules (flattened vesicles) continuous with the outer membrane of the nuclear envelope.
2. **Rough ER** is studded with ribosomes on the cytoplasm side; it is the site where proteins are synthesized and enter the ER interior for processing and modification.
3. **Smooth ER** is continuous with rough ER but lacks ribosomes; it is a site of various synthetic processes, detoxification, and storage; smooth ER forms **transport vesicles.**

C. **The Golgi Apparatus**

1. It is named for Camillo Golgi, who discovered it in 1898.
2. The Golgi apparatus consists of a stack of slightly curved saccules.
3. The Golgi apparatus receives protein-filled vesicles that bud from the rough ER and lipid-filled vesicles from the smooth ER.
4. Enzymes within the Golgi apparatus modify the carbohydrates that were placed on proteins in the ER; proteins and lipids are sorted and packaged.
5. Vesicles formed from the membrane of the outer face of the Golgi apparatus move to different locations in a cell; at the plasma membrane they discharge their contents as **secretions**, a process called *exocytosis* because substances exit the cell.

D. Lysosomes

1. Lysosomes are membrane-bounded vesicles produced by the Golgi apparatus.
2. Lysosomes contain powerful digestive enzymes and are highly acidic.
3. Macromolecules enter a cell by vesicle formation; lysosomes fuse with vesicles and digest the contents of the vesicle.
4. White blood cells that engulf bacteria use lysosomes to digest the bacteria.
5. *Autodigestion* occurs when lysosomes digest parts of cells.
6. Lysosomes participate in **apoptosis,** or programmed cell death, a normal part of development.

E. Endomembrane System Summary

1. Proteins produced in rough ER and lipids from smooth ER are carried in vesicles to the Golgi apparatus.
2. The Golgi apparatus modifies these products and then sorts and packages them into vesicles that go to various cell destinations.
3. Secretory vesicles carry products to the membrane where exocytosis produces secretions.
4. Lysosomes fuse with incoming vesicles and digest macromolecules.

4.6 Other Vesicles and Vacuoles

A. **Peroxisomes** are membrane-bounded vesicles that contain specific enzymes.

1. Peroxisome action results in production of hydrogen peroxide.
2. Hydrogen peroxide (H_2O_2) is broken down to water and oxygen by **catalase.**
3. Peroxisomes in the liver produce bile salts from cholesterol and also break down fats.
4. Peroxisomes also occur in germinating seeds where they convert oils into sugars used as nutrients by the growing plant.

B. Vacuoles

1. **Vacuoles** are membranous sacs and are larger than vesicles.
2. Contractile vacuoles in some protists rid the cell of excess water.
3. Digestive vacuoles digest nutrients.
4. Vacuoles generally store substances, e.g., plant vacuoles contain water, sugars, salts, pigments, and toxic molecules
5. The **central vacuole** of a plant cell maintains turgor pressure within the cell, stores nutrients and wastes, and degrades organelles as the cell ages.

4.7 The Energy-Related Organelles

A. **Chloroplasts** are membranous organelles (a type of **plastid**) that serve as the site of photosynthesis.

1. Photosynthesis is represented by the equation:

$$\text{solar energy} + \text{carbon dioxide} + \text{water} \rightarrow \text{carbohydrate} + \text{oxygen}$$

2. Only plants, algae, and certain bacteria are capable of conducting photosynthesis.
3. The chloroplast is bound by a double membrane organized into flattened disc-like sacs called **thylakoids** formed from a third membrane; a stack of thylakoids is a **granum**.
4. Chlorophyll and other pigments capture solar energy, and the enzymes which synthesize carbohydrates are located in the chloroplasts.
5. Chloroplasts have both their own DNA and ribosomes, supporting the *endosymbiotic hypothesis*.
6. Other types of plastids, which differ in color, form, and function from chloroplasts, include **chromoplasts** and **leucoplasts.**

B. Mitochondria are surrounded by a double membrane: the inner membrane surrounds the **matrix** and is convoluted to form **cristae.**
1. Mitochondria are smaller than chloroplasts, and often vary their shape.
2. Mitochondria also can be fixed in one location or form long, moving chains.
3. Mitochondria contain ribosomes and their own DNA.
4. The matrix of the mitochondria is concentrated with enzymes that break down carbohydrates.
5. ATP production occurs on the cristae.
6. More than forty different diseases involving mitochondria have been described.

4.8 The Cytoskeleton

A. The **cytoskeleton** is a network of connected filaments and tubules; it extends from the nucleus to the plasma membrane in eukaryotes.
1. Electron microscopy reveals an organized cytosol.
2. Immunofluorescence microscopy identifies protein fibers.
3. Elements of the cytoskeleton include: actin filaments, intermediate filaments, and microtubules.

B. **Actin Filaments**
1. Actin filaments are long, thin fibers (about 7 nm in diameter) that occur in bundles or meshlike networks.
2. The actin filament consists of two chains of globular actin monomers twisted to form a helix.
3. Actin filaments play a structural role, forming a dense complex web just under the plasma membrane; this accounts for the formation of **pseudopods** in amoeboid movement.
4. Actin filaments in microvilli of intestinal cells likely shorten or extend cell into intestine.
5. In plant cells, they form tracks along which chloroplasts circulate.

6. Actin filaments move by interacting with **myosin**; myosin combines with and splits ATP, binding to actin and changing configuration to pull actin filament forward.
7. Similar action accounts for pinching off cells during cell division.

C. **Intermediate Filaments**
1. Intermediate filaments are 8–11 nm in diameter, between actin filaments and microtubules in size.
2. They are rope-like assemblies of fibrous polypeptides.
3. Some support the nuclear envelope; others support plasma membrane and form cell-to-cell junctions.

D. **Microtubules**
1. Microtubules are small hollow cylinders (25 nm in diameter and from 0.2–25 μm in length).
2. Microtubules are composed of a globular protein **tubulin** that occurs as α tubulin and β tubulin.
3. Assembly brings these two together as dimers and the dimers arrange themselves in rows.
4. Regulation of microtubule assembly is under control of a microtubule organizing center (MTOC): the main MTOC is called a **centrosome**.
5. Microtubules radiate from the MTOC, helping maintain the shape of cells and acting as tracks along which organelles move.
6. Similar to actin-myosin, the motor molecules *kinesin* and *dynein* are associated with microtubules.
7. Different kinds of kinesin proteins specialize to move one kind of vesicle or cell organelle.
8. Cytoplasmic dynein is similar to the molecule dynein found in flagella.

E. **Centrioles**
1. **Centrioles** are short cylinders with a ring pattern (9 + 0) of microtubule triplets.
2. In animal cells and most protists, centrosome contains two centrioles lying at right angles to each other.
3. Plant and fungal cells have the equivalent of a centrosome, but they do not contain centrioles.
4. Centrioles serve as **basal bodies** for cilia and flagella.

F. **Cilia and Flagella**
1. **Cilia** are short, usually numerous hairlike projections that can move in an undulating fashion (e.g., *Paramecium*; lining of human upper respiratory tract).
2. **Flagella** are longer, usually fewer, projections that move in whip-like fashion (e.g., sperm cells).
3. Both have similar construction, but differ from prokaryotic flagella.
   a. Membrane-bounded cylinders enclose a matrix containing a cylinder of nine pairs of microtubules encircling two single microtubules (9 + 2 pattern of microtubules).
   b. Cilia and flagella move when the microtubules slide past one another.

c. Cilia and flagella have a basal body at base with the same arrangement of microtubule triples as centrioles.
d. Cilia and flagella grow by the addition of tubulin dimers to their tips.