Cell Structure & Biology Unit

Comprehensive Study Guide

Detailed notes covering Prokaryotes, Eukaryotes, Cell Membrane, Endomembrane System, Organelles, Genetics, and Tuberculosis Case Study.

1. The Cell & Types of Cells

Definition: The cell is the organism's basic unit of structure and function. It's responsible for carrying out the essential processes needed for life, such as metabolism, energy production, and protein synthesis.

Prokaryotic Cells

The name "prokaryote" comes from Ancient Greek and consists of two parts: **Pro**, which means "before," and **Karyon**, which refers to the nucleus. This describes prokaryotic cells, which are small and simple cells (all of them are unicellular) that don't have a membrane-bound nucleus. Instead, their DNA is located in an area called the nucleoid.

- **Size:** Smaller than eukaryotic cells.
- **Cell Membrane:** Have a cell membrane, but they don't contain sterols (except *Mycoplasma* bacteria, which contain sterols like cholesterol).
- **DNA:** Usually a single circular chromosome located in the nucleoid.
- **Ribosomes:** Have 70S ribosomes, which are smaller and simpler than those in eukaryotic cells.
- **Organelles:** Only have non-membranous organelles, such as ribosomes.
- **Examples:** Bacteria and Archaea.

Eukaryotic Cells

The name "eukaryote" comes from **Eu** ("true" or "well") and **Karyon** (nucleus). Eukaryotic cells have their DNA enclosed in a membrane-bound nucleus, and they are more complex than prokaryotic cells (most of them are multicellular).

- **Size:** Larger than prokaryotic cells.
- **Cell Membrane:** Contains various lipids, such as sterols (cholesterol is the main sterol in animal cell membranes).
- **DNA:** Multiple linear chromosomes located in the double-membrane-bounded nucleus.
- **Ribosomes:** 80S ribosomes in their cytoplasm, but mitochondria and chloroplasts contain smaller 70S ribosomes.
- **Organelles:** Both membranous and non-membranous organelles, such as endoplasmic reticulum, Golgi apparatus, and ribosomes.
- **Examples:** Animal cells, plant cells, fungi, and protists.

> **Important Notes:**
> • The smallest cell is *Mycoplasma* (type of bacteria), which is 0.1-1 µm.
> • Bacteria, archaea, protists, and plant cells have a cell wall, but animal cells do not.
> • Some protists have cell walls, while others do not.

Points of comparison	Prokaryotes	Eukaryotes
Cell Membrane	Present but doesn't contain sterols, except mycoplasma bacteria.	Present and generally contains sterols.
Genetic Material	Circular DNA is in a non-membrane bounded area called the nucleoid in the cytoplasm.	Linear DNA is in the double membrane bounded nucleus.
Ribosomes	Present (70S).	Present (80S) in the cytoplasm.
Organelles	Only have non membranous organelles (as ribosomes).	Have non-membranous and membranous organelles (as chloroplasts).
Examples	Bacteria and Archaea.	Animal cells, plant cells, fungi, and protists.

2. Cell Membrane (Plasma Membrane)

The cell membrane is also known as the plasma membrane; it's thin, flexible, and looks like the skin that separates the outside from the inside of the cell.

Structure of the Cell Membrane

It consists of a simple phospholipid bilayer with some proteins embedded in it. Each phospholipid consists of two parts:

- **Hydrophilic head:** Attracted to water (outer and inner surfaces).
- **Hydrophobic tails:** Repel water because they are mainly composed of fatty acid chains.

The cell membrane contains different components that include: **1. Proteins**, **2. Carbohydrates**, and **3. Cholesterol**.

Functions of the Cell Membrane

- **Selective Permeability:** Protects the cell and regulates the movement of molecules across the cell.
- **Homeostasis:** The process of maintaining the internal balance of the cell.
- **Protection:** Forms a boundary between the cell and the external environment.
- **Transport:** Helps transport specific substances across the membrane.

3. Endomembrane System

Definition: The endomembrane system is a network of membranes in eukaryotic cells that regulates protein traffic and performs metabolic functions. It is an active processing system in which both the membranes themselves and the materials they carry are modified and refined as they travel from one organelle to the next.

Structure (Components)

- **Nuclear envelope:** Surrounds the nucleus.
- **Endoplasmic reticulum (ER):** Rough and smooth.
- **Golgi apparatus:** Packaging and sorting center.
- **Lysosomes:** Digestive organelles.
- **Vesicles:** Transport sacs.
- **Vacuoles:** Storage spaces.
- **Plasma membrane:** Cell boundary.

How It Works – The Protein Production Line

- DNA in the nucleus holds the instructions for making proteins, transcribed into mRNA inside the nucleus.
- The mRNA exits the nucleus through nuclear pores and travels to the rough ER.
- Ribosomes on the rough ER read the mRNA and translate it into a polypeptide chain. The protein enters the ER lumen, where it folds into its correct shape, carbohydrates may be added, and it is packaged into a transport vesicle that buds off the ER.
- The vesicle travels to the Golgi apparatus and fuses with the cis face. Inside the Golgi, the protein is modified, sorted, and repackaged into new vesicles.
- Vesicles leave from the trans face and go to their final destinations: lysosomes (for digestion), plasma membrane (to become part of the membrane or secreted outside), or other organelles inside the cell.

How Membranes Are Related

The membranes of this system are related in two main ways:

- **Direct physical continuity:** Some membranes are physically connected to each other (the nuclear envelope is connected to the ER).
- **Transfer by vesicles:** Membrane segments are transferred as tiny vesicles that bud off one organelle and fuse with another. Different compartments allow specialized environments so multiple chemical reactions can happen simultaneously without interference.

> **Important Note:**
> • Despite these relationships, the various membranes are not identical in structure and function. Their thickness, molecular composition, and types of chemical reactions carried out in a given membrane are not fixed.
> • Mitochondria and chloroplasts are NOT part of the endomembrane system; they are separate organelles.

4. The Endoplasmic Reticulum (ER)

Definition: "Endoplasmic reticulum" comes from the Latin word "reticulum," which means "little net."

Structure: The ER consists of a network of membranous tubules and sacs called **cisternae** ("cisterna" means reservoir for liquid). The ER membrane separates the internal compartment (ER lumen or cisternal space) from the cytosol.

Rough ER

- **Structure:** Called "rough" because ribosomes are embedded on its outer surface, making it appear rough under the electron microscope. It is connected to the smooth ER and the nuclear envelope.
- **Function:** Protein synthesis, protein folding, glycoprotein formation, membrane factory production (making membrane proteins and phospholipids), and vesicle budding.

Smooth ER

- **Structure:** Called "smooth" because its outer surface has no ribosomes. Made of tubules rather than flattened sacs, connected to the rough ER.
- **Function:** Lipid synthesis (oils, phospholipids, steroids/sex hormones), detoxification (breaking down drugs and toxins in liver cells like alcohol and barbiturates), calcium storage (stores Ca2+ ions to trigger muscle contraction), and carbohydrate metabolism.

5. Mitochondria (The Powerhouse of the Cell)

Definition: Mitochondria are the organelles where cellular respiration occurs and most ATP is generated. They are the "energy factories" of the cell, converting food into usable energy (ATP).

Structure (Double-Membrane Organelle)

- **Outer Membrane:** Smooth and surrounds the entire organelle, acting as a protective boundary.
- **Inner Membrane:** Highly folded into structures called **cristae**, which increase surface area for ATP production and contain proteins for the electron transport chain.
- **Two Compartments:** Intermembrane space and the **matrix** (inside the inner membrane, containing enzymes, DNA, and ribosomes).

Properties & Mitochondrial DNA

- Found in almost all eukaryotic cells (especially high-energy cells like muscle cells).
- **Mitochondrial DNA:** Mitochondria have their own circular DNA and ribosomes, independent of nuclear DNA. This provides strong evidence for the **endosymbiotic theory**.

6. Chloroplasts (The Photosynthetic Organelle)

Definition: A chloroplast is a photosynthetic organelle that converts the energy of sunlight into chemical energy stored in sugar molecules.

Structure

- **Envelope:** Double membrane (outer and inner) separated by an intermembrane space.

- **Thylakoids:** Flattened, interconnected sacs inside the chloroplast containing chlorophyll and photosystems. Often stacked like poker chips into **grana** (singular: granum).
- **Stroma:** Fluid surrounding the thylakoids; contains chloroplast DNA, ribosomes, enzymes, and other molecules needed for photosynthesis.

Function: Main site of photosynthesis in plants and algae, using light energy to convert carbon dioxide and water into carbohydrates and oxygen. Chloroplasts are dynamic organelles that can change shape and position inside cells.

7. The Nucleus & Genetic Material

The Nucleus: Acts as the control center of the cell, averaging about 5 µm in diameter. It stores hereditary information (DNA) and controls most functions of a eukaryotic cell.

Nuclear Envelope & Pores

- **Nuclear Envelope:** Double membrane made of two lipid bilayers separated by a 20-40 nm space, separating the nucleus from the cytoplasm.
- **Nuclear Pores:** Small channels (~100 nm in diameter) lined with a **pore complex** that controls the entry and exit of proteins, RNAs, and macromolecules.
- **Nucleoplasm:** Gel-like fluid inside the nucleus suspending chromatin and the nucleolus.

Genetic Material & The Nucleolus

- **Chromatin:** Complex of DNA and proteins (histones) that make up chromosomes. DNA is wrapped around histones so long molecules can fit inside the nucleus. Appears as a scattered, fuzzy mass.
- **Chromosomes:** Discrete units carrying genetic information (human body has 46 chromosomes, sex cells have 23).
- **The Nucleolus:** Prominent structure inside the nondividing nucleus. Acts as the cell's ribosome workshop where rRNA is synthesized from DNA genes and combined with imported cytoplasmic proteins to form ribosomal subunits.

8. Ribosomes & Gene Expression

Gene Expression: The process by which information in DNA is used to make a protein (Flow: DNA → mRNA → Protein).

Ribosomes (Protein Factories)

- Made of ribosomal RNA (rRNA) and proteins, consisting of a large subunit and a small subunit.
- **Free Ribosomes:** Found in the cytosol; make proteins that function within the cytosol (e.g., enzymes for sugar breakdown).
- **Bound Ribosomes:** Attached to the rough ER or nuclear envelope; make proteins destined to become part of membranes, get packaged into organelles (like lysosomes), or be secreted outside the cell.

9. Plant vs. Animal Cells

Structure	Plant Cell	Animal Cell
Cell Membrane	Present	Present
Cell Wall	Present (made of cellulose)	Absent
Nucleus	Present	Present
Chloroplasts	Present	Absent
Vacuoles	Large central vacuole	Small vacuoles
Centrosome/Centrioles	Absent	Present

10. Case Study: Tuberculosis (TB)

Overview: Tuberculosis (TB) is an infectious disease caused mainly by the bacterium *Mycobacterium tuberculosis*. It primarily affects the lungs (pulmonary TB), but can also spread to the brain, kidneys, bones, and spine. Transmitted via airborne droplets from coughs/sneezes.

Structure of the Bacterial Cell

As a prokaryotic cell, *M. tuberculosis* is small and simple:

- **Cell Membrane:** Controls substance movement and maintains internal conditions.
- **Cell Wall:** Particularly unusual and unique—it is lipid-rich and contains **mycolic acids** (peptidoglycan + arabinogalactan + outer mycolic acid layer), giving it a waxy structure with reduced permeability, greater protection, and increased survival.
- **DNA/Nucleoid:** Circular DNA molecule located in the nucleoid without a nuclear membrane. Ribosomes are 70S and non-membranous.

Pathogenesis & Immune Response

- **Macrophages:** Immune cells that engulf bacteria via phagocytosis. *M. tuberculosis* can interfere with intracellular killing, allowing it to survive inside macrophages.
- **Granulomas:** The immune system accumulates cells around infected areas to form granulomas, helping contain the bacteria.
- **Latent vs. Active TB:** In latent TB, bacteria remain alive but growth is controlled with no symptoms or transmission risk. Active TB symptoms include persistent cough, fever, night sweats, weight loss, fatigue, chest pain, and coughing up blood.

Prevention, Treatment & Risks

- **BCG Vaccine:** Live attenuated vaccine derived from *Mycobacterium bovis*; protects children against severe childhood TB (like TB meningitis and disseminated TB).
- **Treatment:** Treated with multiple anti-tuberculosis antibiotics lasting several months (including **Isoniazid (INH), Rifampin (RIF), Pyrazinamide (PZA), and Ethambutol (EMB)**) to prevent drug resistance.
- **HIV/AIDS Complication:** HIV weakens the immune system, making it harder to control *M. tuberculosis* and increasing the risk of rapid, severe disease progression.