Cell Structure and Function

1. Cell Theory

- Proposed by Schleiden and Schwann in 1839, later modified by Rudolf Virchow.
- States that:
    - All living organisms are composed of cells.
    - The cell is the basic unit of structure and function in living organisms.
    - All cells arise from pre-existing cells (Omnis cellula e cellula).
- Modern additions include:
    - Cells contain genetic material passed to daughter cells.
    - Cells perform all life processes.

2. Types of Cells

- **Prokaryotic Cells**
    - Lack a true nucleus (nucleoid region present).
    - No membrane-bound organelles.
    - Example: Bacteria and Archaea.
- **Eukaryotic Cells**
    - Have a well-defined nucleus.
    - Contain membrane-bound organelles (Mitochondria, ER, Golgi, etc.).
    - Example: Plants, Animals, Fungi, and Protists.

3. Cell Membrane

- **Structure**:
    1. Composed of a phospholipid bilayer with embedded proteins.
    2. Follows the Fluid Mosaic Model (proposed by Singer and Nicolson).
- **Functions**:
    1. Selective permeability – regulates entry and exit of substances.
    2. Provides structural support.
    3. Helps in cell signaling and communication.

4. Cell Wall (in Plant Cells, Fungi, and Bacteria)

- **Structure**:
    1. Plants: Made of cellulose.
    2. Fungi: Composed of chitin.
    3. Bacteria: Composed of peptidoglycan.
- **Functions**:
    1. Provides rigidity and shape.
    2. Protects against mechanical and osmotic stress.
    3. Helps in cell-to-cell interaction.

5. Cytoplasm

- **Structure**:
    1. A semi-fluid matrix filling the cell, containing cytosol and organelles.
- **Functions**:
    1. Site for metabolic activities.
    2. Provides medium for organelle movement.
    3. Stores molecules needed for cellular processes.

6. Nucleus

- **Structure**:
    1. Enclosed by a double membrane (nuclear envelope) with pores.
    2. Contains chromatin (DNA + proteins) and nucleolus.
- **Functions**:
    1. Controls cellular activities through gene expression.
    2. Stores genetic information.
    3. Nucleolus is responsible for ribosome synthesis.

7. Endoplasmic Reticulum (ER)

- **Types**:
    1. **Rough ER (RER)**: Ribosome-studded, involved in protein synthesis.
    2. **Smooth ER (SER)**: Lacks ribosomes, involved in lipid synthesis and detoxification.
- **Functions**:
    1. RER: Protein synthesis and transport.
    2. SER: Lipid metabolism and detoxification.
    3. Forms transport vesicles for intracellular transport.

8. Golgi Apparatus

- **Structure**:
    1. Stacks of flattened, membrane-bound sacs.
- **Functions**:
    1. Modifies, sorts, and packages proteins and lipids.
    2. Forms lysosomes.
    3. Secretes cell products via vesicles.

9. Mitochondria

- **Structure**:
    1. Double membrane organelle with an inner folded membrane (cristae) and matrix.
    2. Contains its own DNA and ribosomes.
- **Functions**:
    1. Site of aerobic respiration (ATP synthesis).
    2. Provides energy for cellular functions.
    3. Regulates cell metabolism and apoptosis.

10. Lysosomes

- **Structure**:
    1. Membrane-bound vesicles containing hydrolytic enzymes.
- **Functions**:
    1. Digests cellular waste and foreign particles.
    2. Involved in autophagy (self-digestion) and apoptosis.
    3. Helps in defense against pathogens.

11. Peroxisomes

- **Structure**:
    1. Single-membrane vesicles containing oxidative enzymes.
- **Functions**:
    1. Breakdown of hydrogen peroxide (H2O2) using catalase.
    2. Lipid metabolism.
    3. Detoxification of harmful substances.

12. Ribosomes

- **Structure**:
    1. Composed of rRNA and proteins; can be free-floating or attached to the RER.
- **Functions**:
    1. Site of protein synthesis.
    2. Helps in translation of mRNA.
    3. Found in both prokaryotes and eukaryotes (70S in prokaryotes, 80S in eukaryotes).

13. Cytoskeleton

- **Components**:
    1. Microfilaments (actin), Intermediate filaments, Microtubules.
- **Functions**:
    1. Maintains cell shape.
    2. Aids in intracellular transport.
    3. Involved in cell movement (cilia, flagella, pseudopodia).

14. Cilia and Flagella

- **Structure**:
    1. Composed of microtubules in a 9+2 arrangement.
- **Functions**:
    1. Helps in cell locomotion.
    2. Cilia aid in movement of substances over the cell surface.
    3. Flagella help in sperm movement.

15. Centrosome and Centrioles

- **Structure**:
    1. Centrosome consists of two centrioles arranged perpendicular to each other.
- **Functions**:
    1. Forms spindle fibers during cell division.
    2. Organizes microtubules in the cytoskeleton.
    3. Aids in chromosome movement during mitosis.

16. Plastids (Only in Plant Cells)

- **Types**:
    1. **Chloroplasts**: Contain chlorophyll, site of photosynthesis.
    2. **Chromoplasts**: Contain pigments other than green (carotenoids, xanthophylls).
    3. **Leucoplasts**: Store starch (amyloplasts), proteins (proteinoplasts), or lipids (elaioplasts).
- **Functions**:
    1. Photosynthesis in chloroplasts.
    2. Storage of food in leucoplasts.
    3. Provides pigmentation in flowers and fruits.

17. Vacuoles

- **Structure**:
    1. Membrane-bound sacs, larger in plant cells.
- **Functions**:
    1. Stores water, nutrients, and waste products.
    2. Provides turgidity to plant cells.
    3. Helps in detoxification.

Cell Cycle and Cell Division

Introduction

The cell cycle is a series of events that cells go through as they grow and divide. It consists of **interphase** (G1, S, G2 phases) and **mitotic phase** (mitosis and cytokinesis).

Phases of the Cell Cycle

1️⃣ Interphase

Interphase is the longest phase of the cell cycle and consists of three stages:

- **G1 Phase (Gap 1)**: Cell grows and carries out normal metabolic activities.

- **S Phase (Synthesis)**: DNA replication occurs, doubling the genetic material.
- **G2 Phase (Gap 2)**: The cell prepares for division by synthesizing proteins and organelles.

Mitosis and Meiosis: A Detailed Overview

Mitosis

Mitosis is a type of cell division that ensures the formation of two genetically identical daughter cells. It consists of the following stages:

Prophase

- Chromatin condenses into visible chromosomes, each consisting of two sister chromatids.
- The nuclear envelope begins to break down.
- The mitotic spindle starts forming as centrioles move to opposite poles of the cell.

Metaphase

- Chromosomes align along the metaphase plate at the cell's equator.
- Spindle fibers attach to the kinetochores of each chromosome.

Anaphase

- Sister chromatids separate at the centromere and are pulled toward opposite poles of the cell.
- Ensures that each daughter cell receives an identical set of chromosomes.

Telophase

- Separated chromosomes decondense into chromatin.
- A new nuclear envelope forms around each set of chromosomes.
- Spindle fibers disappear, completing nuclear division.

Cytokinesis

- Follows mitosis, resulting in the physical separation of the cytoplasm into two daughter cells.

- In animal cells, a cleavage furrow forms, while in plant cells, a cell plate develops, leading to complete division.

Meiosis

Meiosis is a specialized type of cell division that reduces chromosome numbers by half, producing four haploid cells. It occurs in two successive stages: **Meiosis I and Meiosis II.**

Meiosis I

Meiosis I is the reductional division where homologous chromosomes separate.

Prophase I

Prophase I is the longest and most complex stage, divided into five sub-stages:

1. **Leptotene** – Chromosomes condense and become visible under a microscope.

2. **Zygotene** – Homologous chromosomes begin pairing (synapsis) to form bivalents or tetrads.

3. **Pachytene** – Crossing over occurs between non-sister chromatids, increasing genetic variation.

4. **Diplotene** – Synaptonemal complex dissolves, and homologous chromosomes start separating but remain attached at chiasmata.

5. **Diakinesis** – Chiasmata terminalize, spindle fibers form, and the nuclear membrane breaks down.

Metaphase I

- Homologous chromosome pairs align at the metaphase plate.

- Spindle fibers attach to kinetochores.

Anaphase I

- Homologous chromosomes separate and move toward opposite poles.

- Unlike mitosis, sister chromatids remain attached at the centromere.

Telophase I and Cytokinesis

- A nuclear membrane may reappear around separated chromosomes.
- Cytokinesis follows, forming two haploid cells.

Meiosis II

Meiosis II is similar to mitosis but separates sister chromatids instead of homologous chromosomes.

Prophase II

- Chromosomes re-condense, and spindle fibers reform.
- The nuclear membrane dissolves if it had reformed.

Metaphase II

- Chromosomes align at the metaphase plate.
- Spindle fibers attach to kinetochores.

Anaphase II

- Sister chromatids separate and are pulled toward opposite poles of the cell.

Telophase II and Cytokinesis

- A new nuclear membrane forms around each set of chromatids.
- Cytokinesis follows, resulting in four genetically unique haploid daughter cells.

Significance of Meiosis

- Ensures genetic diversity through recombination and independent assortment.
- Maintains chromosome numbers across generations in sexually reproducing organisms.
- Crucial for evolution and species survival.