CHAPTER

1

Cell Biology

INTRODUCTION

Cell biology is a branch of biology that deals with the study of cell structure, function, and behaviour. Cells are the basic membrane-bound units of life and contain all the essential molecules required for living organisms. They function as the structural, functional, and biological units of life. Each cell is surrounded by a plasma membrane that selectively regulates the movement of substances into and out of the cell.

Inside the cell, various specialized structures known as organelles carry out specific functions necessary for survival, growth, and reproduction. The nucleus stores genetic material and controls cellular activities, mitochondria produce energy in the form of ATP, and chloroplasts in plant cells are responsible for photosynthesis.

All living organisms are composed of cells and may exist as unicellular or multicellular forms. Cells vary in complexity, ranging from simple prokaryotic cells without membrane-bound organelles to complex eukaryotic cells containing many specialized organelles. Cell biology also examines dynamic processes such as metabolism, growth, division, and differentiation. The cell cycle ensures proper growth and accurate transmission of genetic material during cell division.

Understanding cells is essential to understanding life, as cells form tissues, organs, and entire organisms through regulated genetic and biochemical processes. Progress in cell biology has contributed greatly to advancements in medicine, biotechnology, and genetics, emphasizing its scientific and practical importance.

METHODS OF SCIENCE

The methods of science are systematic approaches used to study natural phenomena, gain new knowledge, and improve existing understanding. The scientific method is central to this process, providing an organized and logical framework that ensures results are objective, reliable, and reproducible.

Key Steps in the Scientific Method

1. **Observation and questioning:** Scientific inquiry begins with careful observation, followed by the formulation of a clear and testable question.
2. **Background research:** Existing information and previous studies are reviewed to understand current knowledge and refine the research question.

3. **Formulation of hypothesis:** A hypothesis is a testable and falsifiable explanation or prediction based on observations.
4. **Experimentation:** Controlled experiments are designed to test the hypothesis, with variables carefully managed and appropriate controls included.
5. **Data collection and analysis:** Experimental data are collected and analyzed using logical and statistical methods to determine whether the hypothesis is supported.
6. **Communication and replication:** Results are shared through reports, publications, or presentations, allowing other scientists to review and replicate the findings.
7. **Retesting and theory development:** Repeated testing and consistent evidence may lead to the development of a scientific theory.

Importance of the Scientific Method

The scientific method ensures research is systematic, unbiased, and evidence-based. It forms the foundation of scientific progress across all disciplines by allowing discoveries to be tested, verified, and expanded.

LIVING ORGANISMS: CELLS AND CELL THEORY

Cells form the foundation of all living organisms and can reproduce independently. Each cell contains cytoplasm, enclosed by a cell membrane. The cytoplasm consists of biomolecules such as proteins, lipids, and nucleic acids, along with organelles that carry out specific functions. The scientific study of cells and their organelles is known as cell biology.

Organisms may be unicellular or multicellular. Mycoplasma represents the smallest known cells. Cells provide shape, support, and energy to organisms, and their size and shape vary according to function, similar to how different building materials serve specific purposes. The human body contains a wide variety of cells with diverse structures.

Cells represent the simplest level of biological organization. Their number varies among organisms, and each cell contains genetic material that controls growth, development, and reproduction. Specialized organelles perform distinct functions necessary for life.

The discovery of cells is credited to Robert Hooke (1665). While examining a thin slice of cork under a microscope, he observed tiny, box-like compartments resembling small rooms in a monastery and named them "cells." Because of the limited magnifying power of his microscope, Hooke could not see their internal structures and thought they were non-living.

Later, Antonie van Leeuwenhoek used a more powerful microscope and observed living cells exhibiting movement (motility). He called these microscopic organisms animalcules, confirming that cells are living entities.

In 1833, Scottish botanist Robert Brown identified and described the nucleus in orchid cells, providing key insight into cell structure.

The cell theory was formulated by Theodor Schwann, Matthias Schleiden, and Rudolf Virchow, which states:

- All living organisms are composed of cells.
- The cell is the basic unit of life.
- All cells arise from pre-existing cells.

A modern version of cell theory further includes:
- Energy flow occurs within cells.
- Genetic information is transmitted from one cell to another.
- All cells share a similar basic chemical composition.

Characteristics of Cells

- Cells provide structural support and help maintain the shape of an organism.
- The cell interior is organized into membrane-bound organelles with specific functions.
- The nucleus contains genetic material essential for growth and reproduction.
- Cytoplasm suspends the nucleus and other organelles within the cell.
- Mitochondria, with a double membrane, produce energy required for cellular activities.
- Lysosomes break down waste materials and unwanted substances.
- The endoplasmic reticulum is involved in synthesis, modification, transport, and internal organization of cellular materials.

Types of Cells

Cells function like factories, where different units and workers perform specific tasks to achieve a common goal. In living organisms, different types of cells carry out different functions. Based on structural organization, cells are classified into two main groups:
1. Prokaryotic cells
2. Eukaryotic cells

Prokaryotic Cells

- Prokaryotic cells lack a true nucleus. In organisms such as bacteria, the genetic material is located in a region called the nucleoid, which is not enclosed by a membrane.
- All prokaryotes are unicellular organisms. Examples include archaea, bacteria, and cyanobacteria.
- These cells are very small, typically ranging from about 0.1 to 0.5 μm in diameter. Their genetic material may consist of DNA or RNA.
- Prokaryotes primarily reproduce by binary fission, a form of asexual reproduction. They may also undergo conjugation, which allows the exchange of genetic material but is not considered true sexual reproduction.

Eukaryotic Cells

- Eukaryotic cells possess a well-defined nucleus surrounded by a nuclear membrane.
- These cells are generally larger in size, typically ranging from 10 to 100 μm in diameter.
- This group includes animals, plants, fungi, and protozoa.
- The plasma membrane regulates the movement of substances into and out of the cell and facilitates communication between cells.
- Eukaryotic organisms are capable of both sexual and asexual reproduction.
- Structural differences exist between plant and animal cells. For example, plant cells contain chloroplasts, a large central vacuole, and plastids, whereas animal cells lack these structures.

CELL ORGANELLES: STRUCTURE AND FUNCTION

Cells consist of several components, each performing specific functions essential for survival. The major components include the cell wall, cell membrane, cytoplasm, nucleus, and various organelles.

Cell Membrane

- The cell membrane protects the cell and regulates the movement of substances entering and leaving the cell. It forms a boundary that separates the cell from its external environment and is present in all cells **(Fig. 1.1)**.
- It forms the outer covering of the cell and encloses internal structures such as the cytoplasm and nucleus. The cell membrane is also known as the plasma membrane.
- It is a selectively permeable membrane containing tiny pores that allow only specific substances to pass through. It also prevents leakage and protects the cell contents from physical damage.
- The membrane acts as a barrier between adjacent cells and between the cell and its surrounding environment.
- In plant cells, which are generally stationary, an additional protective layer called the cell wall provides extra strength and protection.

Cell Wall

- The cell wall is a prominent structure found in plant cells and is mainly composed of cellulose, hemicellulose, and pectin.
- It is present only in plant cells and forms the outermost boundary, protecting the plasma membrane and all internal cell components.
- The cell wall is tough and rigid, completely surrounding the cell membrane.
- It provides a definite shape to the cell, offers mechanical support, and protects the cell from physical damage.

Cytoplasm

- Cytoplasm is a thick, jelly-like substance present within the cell membrane.
- Most of the vital biochemical reactions of the cell occur in the cytoplasm.

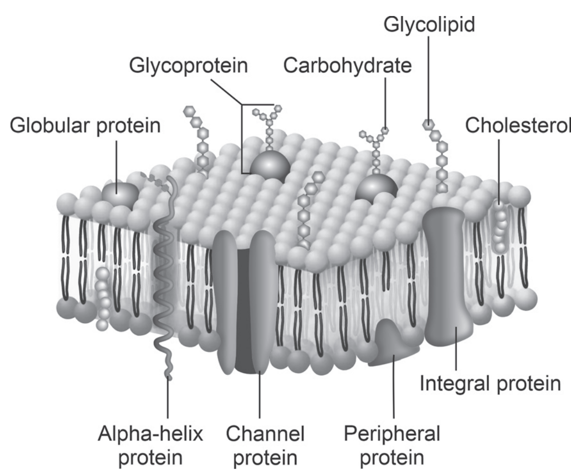

Fig. 1.1: Cell membrane (*see* Color Plate 1)

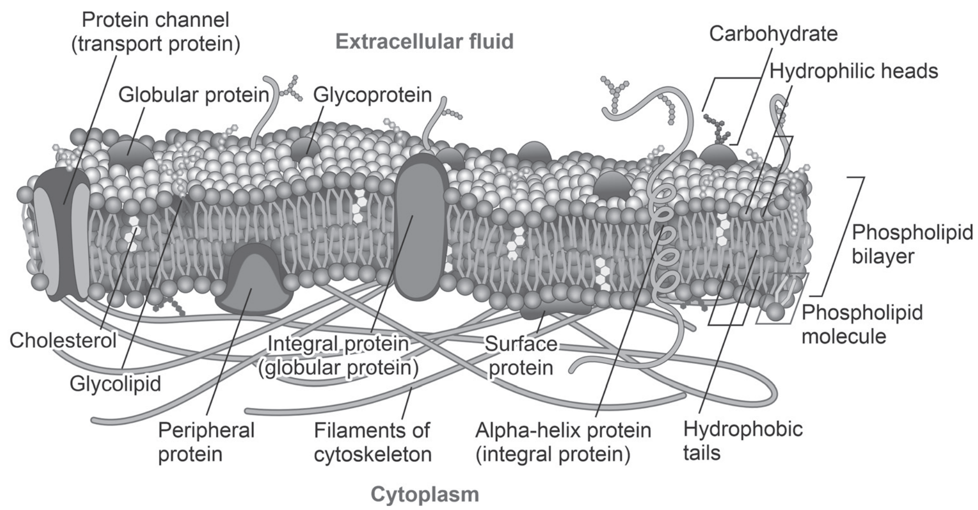

Fig. 1.2: Cytoplasm (*see* Color Plate 1)

- Cell organelles such as the endoplasmic reticulum, mitochondria, vacuoles, and ribosomes are embedded within the cytoplasm **(Fig. 1.2)**.

Nucleus

- The nucleus contains the cell's genetic material, known as DNA.
- It controls cellular activities by regulating processes such as growth, development, cell division, and programmed cell death.
- The nucleus is surrounded by a protective double-layered membrane called the nuclear envelope, which separates the DNA from the rest of the cell contents.
- The nucleus protects genetic information and plays a vital role as a key regulatory structure in plant cells.

Cell Organelles

Cells contain various organelles that perform specific functions necessary to carry out life processes. The different cell organelles and their principal functions are listed below **(Table 1.1)**.

Table 1.1: Cell organelles and their functions

Cell organelles	*Function*
Nucleolus	Site of ribosome synthesis; involved in controlling cellular activities and cell reproduction
Nuclear membrane	Protects the nucleus by forming a boundary between the nucleus and the cytoplasm
Chromosomes	Carry genetic information and determine inherited characteristics; each human cell contains 23 pairs of chromosomes
Endoplasmic reticulum	Transports substances within the cell; involved in carbohydrate metabolism and the synthesis of lipids, steroids, and proteins

(Contd...)

Table 1.1: Cell organelles and their functions *(Contd...)*

Cell organelles	*Function*
Golgi bodies	Modify, package, and transport materials within the cell; often referred to as the cell's post office
Ribosomes	Responsible for protein synthesis
Mitochondria	Known as the powerhouse of the cell; produce ATP, the energy currency of the cell
Lysosomes	Digest foreign particles and worn-out organelles; aid in cell renewal and are known as the cell's suicide bags
Chloroplasts	Sites of photosynthesis; contain the pigment chlorophyll
Vacuoles	Store food, water, and waste materials within the cell

FUNCTIONS OF A CELL

Cells perform vital activities necessary for the survival, growth, and proper functioning of living organisms. The important functions of cells are described below.

Provides Structure and Support

All living organisms are composed of cells, which form the structural foundation of the body. The cell membrane and the cell wall in plant cells help maintain shape and provide strength to the organism. For example, the skin is made up of numerous cells that give it structure. In plants, xylem cells contribute to mechanical support and help the plant remain upright.

Enables Growth Through Mitosis

Growth in living organisms occurs through mitosis, a process in which a single parent cell divides to form two identical daughter cells. Continuous cell division increases the total number of cells, leading to growth and development of the organism.

Helps in Transporting Substances

Cells absorb essential nutrients required for metabolic activities and eliminate waste products formed during these processes. Transport across the cell membrane occurs by two main mechanisms:

- **Passive transport:** Small molecules such as oxygen, carbon dioxide, and ethanol move across the membrane from a region of higher concentration to lower concentration without the use of energy.
- **Active transport:** Larger or charged molecules are transported across the membrane against the concentration gradient using energy, usually in the form of ATP.

Energy Generation

Cells require energy to perform various life activities. In plant cells, energy is produced through photosynthesis, whereas in animal cells, energy is released through cellular respiration.

Supports Reproduction

Cells enable reproduction by undergoing cell division through mitosis and meiosis.

- Mitosis produces two genetically identical daughter cells and is associated with growth, repair, and asexual reproduction.

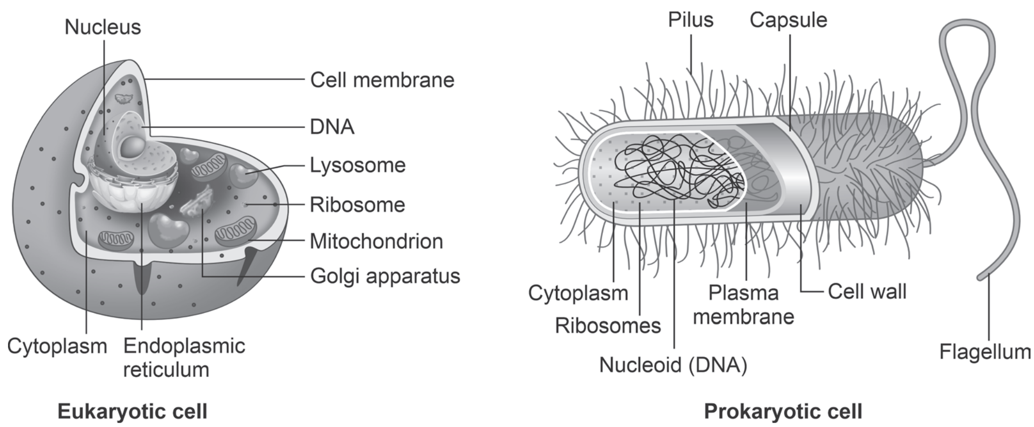

Fig. 1.3: Eukaryotic and prokaryotic cell structure (*see* Color Plate 1)

- Meiosis produces genetically different daughter cells and plays a crucial role in sexual reproduction.

The structural differences between prokaryotic and eukaryotic cells are illustrated in **Fig. 1.3.**

ANIMAL CELL STRUCTURE

Animal cells are eukaryotic cells with a well-defined nucleus and membrane-bound organelles. The detailed structure of an animal cell is shown in **Fig. 1.4.**

Functions of the Cell Membrane in Animal Cells

The cell membrane performs several important functions:

1. Allows the entry of liquid nutrients into the cell through vesicles formed during pinocytosis.
2. Protects the protoplasm by acting as a selectively permeable barrier between the cell and its external environment.
3. Encloses and safeguards internal organelles, maintaining cellular integrity.

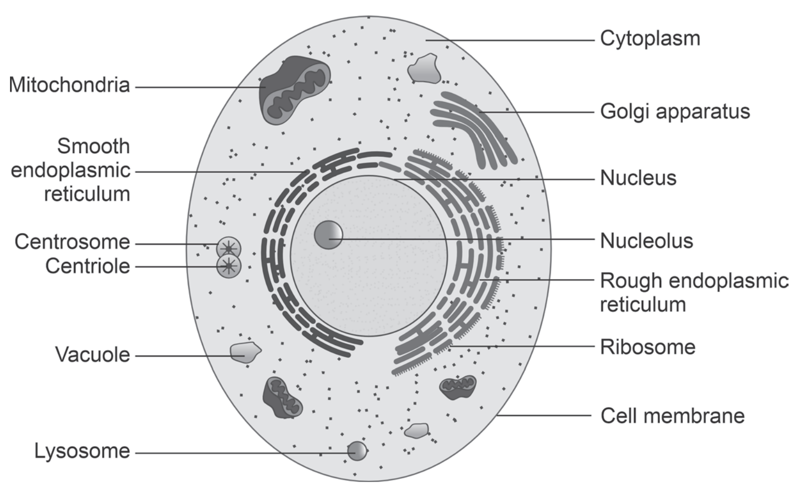

Fig. 1.4: Animal cell structure (*see* Color Plate 2)

Protoplasm

Protoplasm is the living, jelly-like substance inside the cell and represents its living component. It consists of two main parts:

1. Nucleus
2. Cytoplasm

Nucleus

The nucleus is the largest organelle in eukaryotic cells, usually spherical or oval, containing chromatin, the genetic material. It regulates vital cellular activities such as growth, metabolism, and reproduction.

Structure of the Nucleus

1. **Nuclear membrane:** A double-layered membrane with nuclear pores regulating substance movement between the nucleus and cytoplasm.
2. **Nucleoplasm:** Dense, semi-fluid substance supporting chromatin and nucleolus.
3. **Nucleolus:** A rounded structure that plays a key role in ribosome formation.
4. **Nuclear reticulum (chromatin network):** Thread-like structures in the nucleoplasm that condense into chromosomes during cell division.

Functions of the Nucleus

- Acts as the control centre of the cell.
- Participates in chromosome formation during cell division.
- Nucleolus synthesizes ribosomes.
- Plays a role in protein synthesis and RNA formation.
- Chromosomes assist in DNA replication and inheritance.

Cytoplasm

Cytoplasm is the living, semi-liquid portion of protoplasm outside the nucleus, composed of approximately 75% water and 25% dissolved substances. It consists of:

- **Cytosol (hyaloplasm):** Fluid portion
  - **Ectoplasm:** Clear outer layer
  - **Endoplasm:** Dense, granular inner region
- **Cell organelles:** Structures suspended in the cytosol

Cell organelles in cytoplasm

1. Mitochondria
2. Centrosomes
3. Golgi apparatus
4. Ribosomes
5. Endoplasmic reticulum
6. Lysosomes
7. Vacuoles

1. Mitochondria

Rod- or spiral-shaped organelles enclosed by a double membrane.

Functions

1. Carry out cellular respiration and control Krebs cycle reactions.

2. Produce ATP, the energy currency of the cell.
3. Release energy for cellular activities ("powerhouse of the cell").
4. Assist in heme synthesis, beta-oxidation of fatty acids, and store calcium ions.

2. Centrosome

A small, star-shaped organelle near the nucleus, essential for cell division.

Structure

- Two centrioles arranged at right angles (diplosome)
- Pericentriolar material
- Centrosphere (cytoplasm around centrioles)
- Astral rays formed by microtubules

Functions

- Forms spindle fibres during cell division
- Assists in chromosome movement and separation
- Involved in cilia and flagella formation

3. Golgi apparatus

Single membrane-bound organelle near the nucleus, involved in modification, packaging, and secretion of cellular substances.

Properties

- Round or cylindrical shape
- Composed of cisternae and vesicles
- Located near the endoplasmic reticulum

Functions

- Secretes enzymes, hormones, and mucus
- Forms acrosome in mature sperm
- Temporary storage for cellular products
- Transports proteins and other substances to lysosomes, cell membrane, or outside

4. Ribosomes

Small, spherical, non-membranous organelles found attached to the rough ER or freely in the cytoplasm.

Properties

- Composed of rRNA and proteins
- 80S type in eukaryotes
- Single ribosome = monosome; multiple = polysomes

Function

- Primary site of protein synthesis ("protein factories of the cell")

5. Endoplasmic reticulum (ER)

A network of membranes involved in intracellular transport and synthesis.

Structure

- Cisternae: Flattened sac-like structures
- Vesicles: Small sacs
- Tubules: Branched tube-like structures

Types

- Rough ER (RER): With ribosomes; folds and transports proteins
- Smooth ER (SER): Without ribosomes; synthesizes lipids, steroids, and hormones

Functions

- Supports formation and function of other organelles
- Increases surface area for biochemical reactions
- Compartmentalizes the cytoplasm, isolating chemical reactions

6. Lysosomes

Spherical, single membrane-bound organelles containing digestive enzymes.

Functions

- Digest unwanted or damaged cellular components
- Can rupture to destroy damaged cells ("suicide sacs")

7. Vacuoles

Small or absent in animal cells; smaller than plant vacuoles.

Functions

- Temporary storage of food
- Waste removal in some cells.

DIFFERENCES BETWEEN PLANT AND ANIMAL CELLS

The structural and functional differences between plant and animal cells are summarized in **Table 1.2,** highlighting features such as cell shape, presence of cell wall, vacuoles, and plastids. The overall organization of these cells, including their membrane-bound organelles, is illustrated in **Fig. 1.5**, showing that plant cells are generally larger than animal cells.

Table 1.2: Comparison of plant *vs* animal cells

Feature	*Plant cell*	*Animal cell*
Cell shape	Square or rectangular	Irregular or round
Cell wall	Present	Absent
Plasma membrane	Present	Present
Endoplasmic reticulum	Present	Present
Nucleus	Present; usually at one side	Present; usually at centre
Lysosomes	Rare	Present
Golgi apparatus	Present	Present
Cytoplasm	Present	Present
Ribosomes	Present	Present
Plastids	Present	Absent
Vacuoles	Few large or central	Small, numerous
Cilia	Absent	Present in most cells
Mitochondria	Present but fewer	Present, numerous
Mode of nutrition	Autotrophic	Heterotrophic

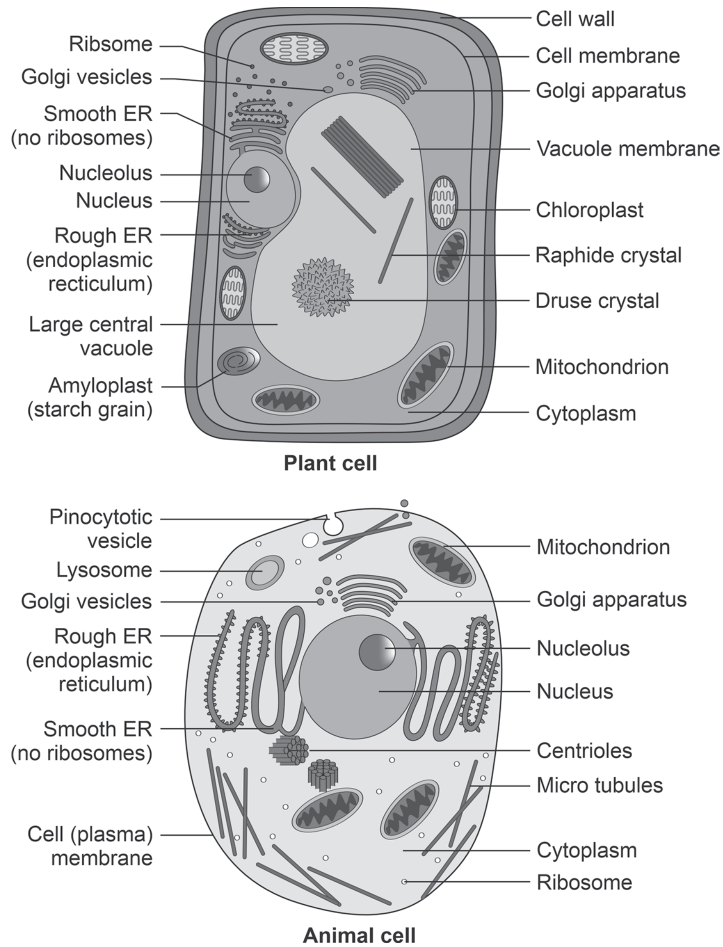

Fig. 1.5: Structure of plant and animal cells (*see* Color Plate 2)

Both plant and animal cells contain membrane-bound organelles such as the nucleus, mitochondria, Golgi apparatus, ER, and lysosomes. Plant cells are generally larger (10–100 µm) than animal cells (10–30 µm).

CELL DIVISION

Cell division/cell reproduction/cell cycle is the process by which a single parent cell divides to form two or more daughter cells. This process is essential for growth, repair, and reproduction in all living organisms **(Figs 1.6 and 1.7)**.

Cell Cycle

The cell cycle is a sequence of events from the formation of a cell to its division. It consists of the following phases:

1. **Interphase**
   - The period before cell division.
   - The cell grows and replicates its DNA in preparation for division.

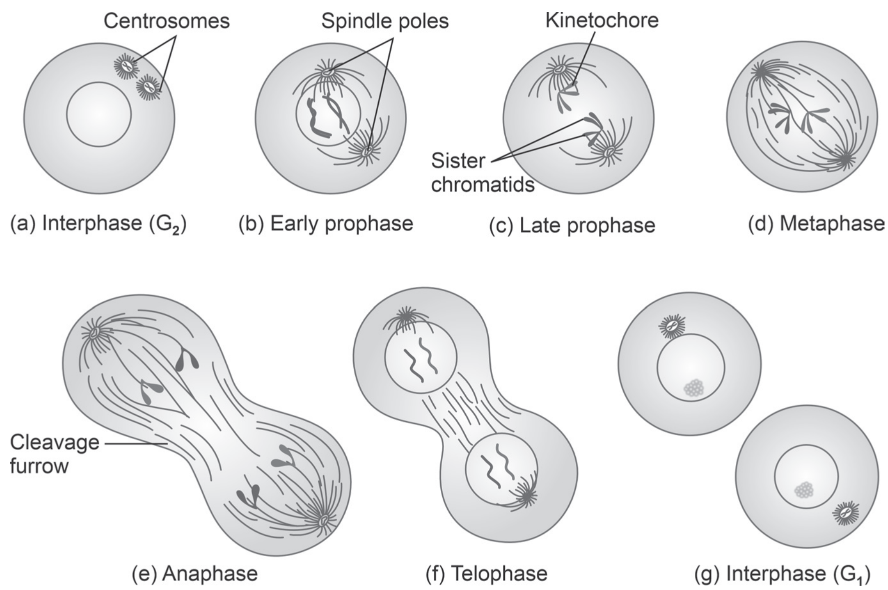

Fig. 1.6: Steps of cell division (*see* Color Plate 3)

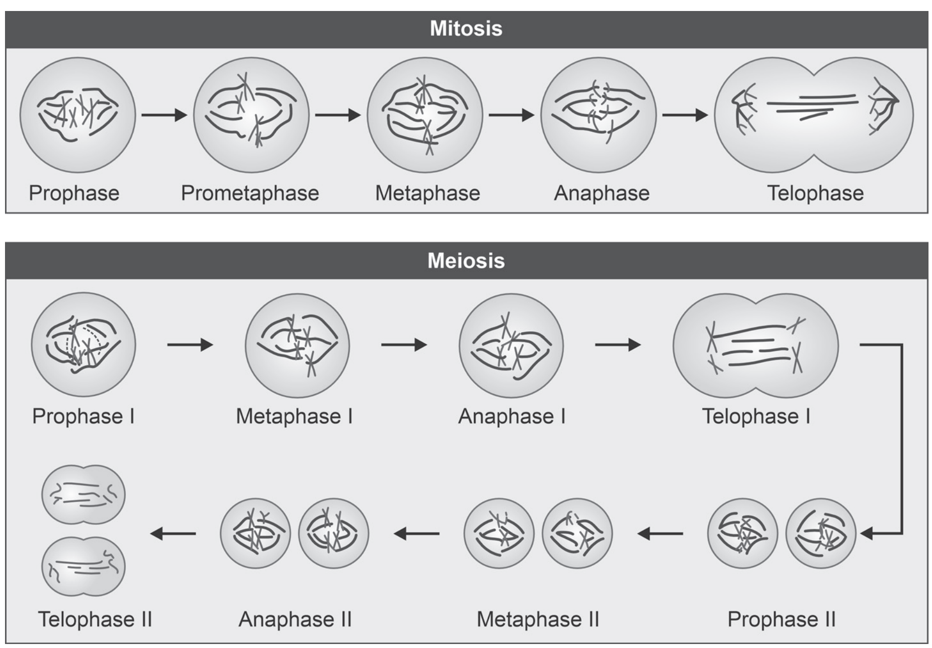

Fig. 1.7: Cell division during mitosis and meiosis (*see* Color Plate 3)

2. **Mitosis**
   - A type of cell division that produces two genetically identical daughter cells**.**
   - Responsible for growth and repair in somatic cells.
3. **Meiosis**
   - A type of cell division that produces gametes (sperm and egg cells) with half the chromosome number of the parent cell.
   - Essential for sexual reproduction.

Stages of Mitosis

1. **Prophase**
   - Chromosomes condense.
   - Nuclear envelope breaks down.
   - Spindle apparatus forms.
2. **Metaphase**
   - Chromosomes align at the centre of the cell (metaphase plate).
3. **Anaphase**
   - Sister chromatids separate and move toward opposite poles of the cell.
4. **Telophase**
   - Nuclear envelopes reform around the separated chromosomes.
   - Cytoplasm divides (cytokinesis), producing two daughter cells.

MEIOSIS

Purpose

Meiosis is a type of cell division that produces gametes (sperm and egg cells) with half the number of chromosomes, ensuring the correct chromosome number in offspring during sexual reproduction.

Key Features of Meiosis

- **Two divisions:** Meiosis I and meiosis II, each with stages similar to mitosis.
- **Chromosome reduction:** The chromosome number is halved in meiosis I and maintained in meiosis II, producing four haploid (n) cells from a diploid (2n) parent cell.
- **Genetic variation:** Homologous chromosomes exchange genetic material during crossing over in prophase I, increasing genetic diversity.
- **Formation of gametes:** The primary function is to produce gametes essential for sexual reproduction.

Stages of Meiosis

Meiosis I

1. **Prophase I:** Chromosomes condense; homologous chromosomes pair and exchange genetic material (crossing over).
2. **Metaphase I:** Homologous chromosome pairs align at the cell centre.
3. **Anaphase I:** Homologous chromosomes separate and move toward opposite poles.
4. **Telophase I:** The cell divides, forming two haploid daughter cells with half the chromosome number.

Meiosis II

1. **Prophase II:** Chromosomes condense; the nuclear envelope breaks down.
2. **Metaphase II:** Sister chromatids align at the cell centre
3. **Anaphase II:** Sister chromatids separate and move to opposite poles.
4. **Telophase II:** The cell divides, resulting in four haploid daughter cells.

Significance of Cell Reproduction

1. **Growth and development:** Cell division allows organisms to grow from a single cell to a multicellular organism.
2. **Repair and renewal:** Damaged or old cells are replaced by new ones.
3. **Reproduction:** Cell division ensures the transmission of genetic information to the next generation.

Key Terms

- **Haploid (n):** A cell with a single set of chromosomes (e.g. sperm or egg cells).
- **Diploid (2n):** A cell with two sets of chromosomes (e.g. most human body cells, 2n = 46).
- **Gene:** Fundamental unit of heredity.
- **Allele:** One of two or more alternative forms of a gene located at the same position on a chromosome.
- **Inheritance:** Individuals inherit two alleles for each gene, one from each parent.
- **Homozygous:** Two identical alleles for a gene.
- **Heterozygous:** Two different alleles for a gene.
- **Dominant allele:** Expressed even if only one copy is present.
- **Recessive allele:** Expressed only when two copies are present.

ASEXUAL *VS* SEXUAL REPRODUCTION

Asexual Reproduction

- **Single parent:** Requires only one parent.
- **Genetic similarity:** Offspring are genetically identical to the parent and to each other; essentially clones.
- **Mitosis:** Cell division occurs through mitosis, producing two identical daughter cells.

Sexual Reproduction

- **Two parents:** Requires two parents, usually a male and a female.
- **Genetic diversity:** Offspring are genetically unique, inheriting traits from both parents.
- **Meiosis:** Cell division produces haploid gametes (sperm and egg).
- **Fertilization:** Gametes fuse to form a diploid zygote, which develops into a new individual.

METABOLISM AND HOMEOSTASIS

Metabolism is the sum of all chemical reactions within a living organism that sustain life **(Fig. 1.8)**. These reactions convert food into energy, build and repair tissues, and eliminate waste. Metabolism includes:

- **Chemical reactions**
  - **Catabolism:** Breaks down molecules to release energy.
  - **Anabolism:** Builds complex molecules from simple ones, using energy **(Figs 1.9 and 1.10)**.
- **Energy conversion:** Transforms chemical energy in food into usable energy for cellular processes.

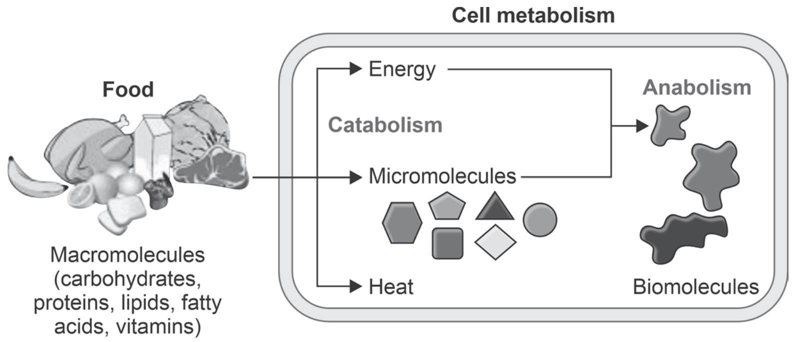

Fig. 1.8: Cell metabolism (*see* Color Plate 4)

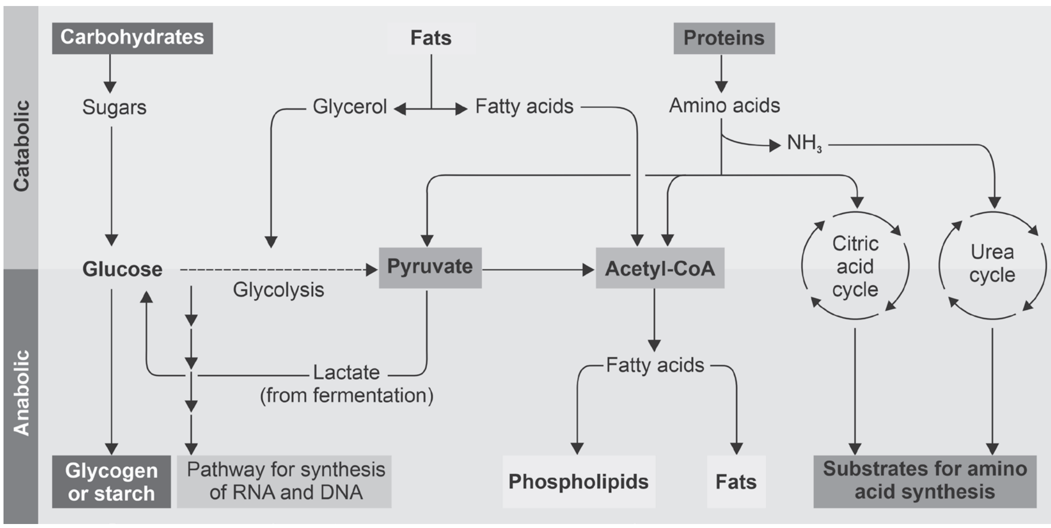

Fig. 1.9: Catabolic and anabolic pathways (*see* Color Plate 4)

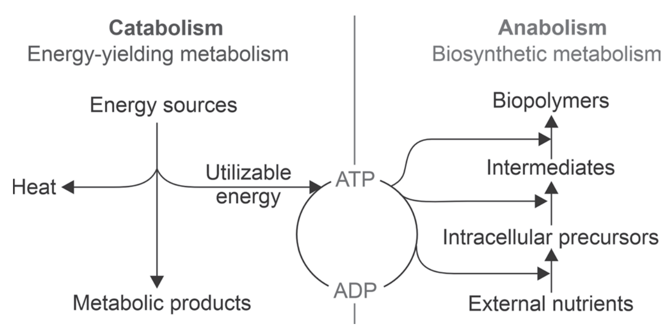

Fig. 1.10: Mechanism of catabolism and anabolism

- **Building and repair:** Synthesizes proteins, lipids, nucleic acids, and some carbohydrates.
- **Waste elimination:** Removes byproducts of cellular processes.
- **Homeostasis:** Maintains a stable internal environment so enzymes can function efficiently.

- **Metabolic rate:** The speed of metabolic reactions, which varies with age, activity, and health.
- **Hematopoiesis:** Formation of blood cellular components, occurring during embryonic development and throughout adulthood.

LEVELS OF CELLULAR ORGANIZATION IN MULTICELLULAR ORGANISMS

In multicellular organisms, biological structures are organized hierarchically, from microscopic components to the entire organism. This tiered arrangement ensures specialization, coordination, and efficient functioning. The primary levels include:

1. **Organelles:** Distinct structures within a cell, such as the nucleus, mitochondria, and lysosomes, performing specific tasks necessary for survival and activity.
2. **Cells:** The basic building blocks of life, each type (e.g. blood cells, nerve cells) is specialized for certain functions.
3. **Tissues:** Groups of similar cells working together to achieve a common purpose. For example:
   - **Muscle tissue**—facilitates contraction
   - **Nervous tissue**—transmits signals
4. **Organs:** Formed from multiple tissue types cooperating to perform complex functions. Example: The heart contains muscle tissue (contraction), connective tissue (support), and nervous tissue (regulation).
5. **Organ systems:** Groups of organs working together to carry out broad physiological tasks. Examples:
   - **Digestive system**—processes food and absorbs nutrients
   - **Respiratory system**—enables gas exchange
6. **Organism:** The complete living entity composed of interconnected organ systems, such as humans, plants, fungi, and animals.

Significance: This hierarchical organization enables division of labour, specialization, and coordination of functions, which are essential for complex life.

CELLULAR COMMUNICATION AND SIGNALLING MECHANISMS

Cells continuously exchange information with their environment and other cells to maintain balance, coordinate functions, and respond to internal and external stimuli. This process is known as cellular communication or cell signalling.

Core Concepts

1. **Signal conduction:** Transmission of signals between cells or within a cell.
2. **Signal transduction:** Conversion of received signals into specific cellular responses via biochemical pathways.

Forms of Cell Signalling

- **Autocrine:** A cell signals itself by releasing molecules that bind to its own receptors (e.g. tumour cells).
- **Paracrine:** Signals affect nearby cells in the local environment (e.g. inflammation).
- **Endocrine:** Hormones travel through the bloodstream to reach distant target cells.

- **Direct contact/gap junctions:** Molecules or ions pass directly between adjacent cells for rapid responses (e.g. cardiac muscle cells).
- **Synaptic:** Neurotransmitters transmit signals across synapses between neurons or from neurons to other cell types.

Phases of Cell Signalling

1. **Signal generation and release:** Cells secrete ligands such as hormones or neurotransmitters.
2. **Signal reception:** Target cells detect signals via receptors on the membrane or inside the cell.
3. **Signal transduction:** Ligand binding activates intracellular cascades (second messengers like cAMP, Ca^{2+}, phosphorylation pathways) to amplify and propagate the signal.
4. **Cellular response:** The cell executes a specific action, such as gene expression, secretion, division, contraction, or apoptosis.

Key Signalling Pathways

- **G-protein coupled receptors (GPCRs):** Activate enzyme cascades and second messengers; involved in vision, taste, and growth.
- **Tyrosine kinase receptors:** Dimerize and autophosphorylate upon ligand binding, activating intracellular proteins that regulate growth and differentiation.
- **Ligand-gated ion channels:** Open in response to ligands, allowing ion flow and rapid electrical responses in neurons.
- **Intracellular/nuclear receptors:** Bind lipid-soluble signals (e.g. steroids) to directly influence DNA transcription.

Signal Amplification and Termination

Amplification: Once a receptor is activated, the signal is commonly intensified through enzyme cascades and the generation of second messengers, allowing a small initial signal to produce a significant cellular reaction.

Termination: Cells strictly control signalling; feedback systems, breakdown of signal molecules, and receptor desensitization are essential for ceasing a response at the appropriate moment.

Physiological and Clinical Relevance

Cell signalling is crucial for orchestrating various processes such as cell growth, metabolism, inflammation, immune response, and tissue repair. Abnormal signalling can cause diseases, including cancer (e.g. an overactive Ras pathway), diabetes, and autoimmune disorders. Numerous contemporary treatments, including targeted cancer therapies, aim to specifically modify or inhibit signalling pathways.

Cellular communication and signalling ensure that living organisms can adjust, survive, and function as cohesive systems in ever-changing environments.

MEMBRANE TRANSPORT MECHANISMS

Membrane transport pertains to the movement of substances—such as ions, nutrients, and gases—across the selectively permeable cell membrane. This movement is crucial for sustaining cellular homeostasis, obtaining nutrients, disposing of waste, and facilitating cell signalling. The lipid bilayer of the membrane and the embedded transport proteins dictate which substances can enter or exit the cell.

Passive Transport

Passive transport operates without the need for cellular energy (ATP) and involves the movement of molecules from areas of higher concentration to lower concentration—adhering to their concentration gradient. The primary mechanisms of passive transport include:

- **Simple diffusion:** Small, nonpolar molecules like oxygen and carbon dioxide pass directly through the lipid bilayer. This process occurs spontaneously, driven by the natural kinetic energy of the molecules.
- **Facilitated diffusion:** Larger molecules, polar substances, or ions are unable to traverse the lipid bilayer freely. Instead, they are assisted by specific integral membrane proteins, such as channels or carriers.

  Example: Glucose and ions cross the membrane through designated transport proteins.
- **Osmosis:** This is the movement of water molecules through a selectively permeable membrane from areas of higher water concentration to lower water concentration. Osmosis plays a critical role in regulating cell volume and internal pressure.

Active Transport

Active transport necessitates energy, typically sourced from ATP, to move molecules against their concentration gradient—from areas of lower to higher concentration. This process is facilitated by specialized membrane proteins known as pumps.

- **Primary active transport:** This method directly utilizes ATP to propel the movement of molecules.

  Example: The sodium-potassium pump (Na^+/K^+-ATPase), essential for nerve and muscle function, exports sodium ions while importing potassium ions.
- **Secondary active transport (co-transport):** This approach leverages the energy from an established gradient (usually created by primary active transport) to facilitate the transfer of other substances.
  – **Symporters:** Transport two molecules in the same direction.
  – **Antiporters:** Move two molecules in opposite directions.

Bulk Transport (Vesicular Transport)

Large molecules, particles, or fluids are transported across the cell membrane through the formation and movement of vesicles, which requires energy:

- **Endocytosis:** The cell membrane envelops external material, creating a vesicle that carries substances into the cell. This process includes phagocytosis ("cell eating") and pinocytosis ("cell drinking").
- **Exocytosis:** Vesicles merge with the cell membrane to discharge their contents outside the cell, vital for secretion of hormones, neurotransmitters, and waste.

Regulation and Selectivity

- **Selective permeability:** The cell membrane permits some substances to pass more freely than others, ensuring internal cellular balance.

- **Transport proteins:** The specificity of integral proteins dictates which substances can cross and the speed of their transit.
- **Cell signalling:** Signalling pathways can modulate transport by changing the number or activity of transport proteins on the membrane.

Membrane transport guarantees that cells can take in essential nutrients, eliminate waste, transmit signals, and maintain a stable internal environment—an essential aspect of life in all living organisms.

IMPORTANT QUESTIONS—2 MARKS

Q1. What is a cell?

Answer: A cell is defined as the fundamental, structural, and functional unit of all living organisms. Cells are the basic unit of life and range in size from 0.0001 mm to nearly 150 mm across.

Q2. State the characteristics of cells.

Answer

- Cells provide the necessary structural support to an organism.
- The genetic information required for reproduction is present within the nucleus.
- Structurally, the cell contains organelles suspended in the cytoplasm.
- Mitochondria are responsible for fulfilling the cell's energy requirements.
- Lysosomes digest metabolic wastes and foreign particles within the cell.
- The endoplasmic reticulum synthesizes specific molecules, processes them, and directs them to their appropriate locations.

Q3. Highlight the cell structure and its components.

Answer: The cell structure comprises several components that perform specific functions essential for carrying out life processes. The components of the cell include:

- Cell membrane
- Cell wall
- Cell organelles
- Nucleolus
- Nuclear membrane
- Endoplasmic reticulum
- Golgi bodies
- Ribosome
- Mitochondria
- Lysosomes
- Chloroplast
- Vacuoles

Q4. State the types of cells.

Answer: Cells are primarily classified into two types:

- Prokaryotic cells
- Eukaryotic cells

Q5. State and elaborate the cell theory with examples.

Answer: Cell theory was proposed by German scientists Matthias Schleiden, Theodor Schwann, and Rudolf Virchow. It explains the basic structure and functioning of living organisms. According to the cell theory:

1. All living organisms are made up of one or more cells.
2. The cell is the basic structural and functional unit of life.
3. All new cells arise from pre-existing cells.

Examples:

- Amoeba is a unicellular organism in which a single cell performs all vital life processes such as respiration, digestion, and reproduction.
- In humans, the body is composed of millions of specialized cells like nerve cells, muscle cells, and blood cells, each performing specific functions necessary for the survival of the organism.

Q6. Recall the contribution of Robert Hooke to the discovery of cells.

Answer: Robert Hooke was the first scientist to observe, discovered and name cells in 1665. He examined a thin slice of cork using a simple microscope and noticed small, box-like compartments, which he called "cells" (from the Latin word *cellula*, meaning small rooms).

The cells observed by Robert Hooke were dead cells, as cork consists of dead plant tissue. Although he did not propose the complete cell theory, his discovery laid the foundation for the development of modern cell theory by Matthias Schleiden and Theodor Schwann.

Example: The honeycomb-like structure observed in cork under a microscope represents the cell walls of plant cells seen by Robert Hooke.

Q7. What is the function of mitochondria in the cells?

Answer: Mitochondria are known as the powerhouse of the cell. Their primary function is to produce the energy currency of the cell, ATP, and regulate cellular metabolism.

Q8. What are the functions of the cell?

Answer: The essential functions of the cell include:

- Providing support and structure to the body.
- Facilitating growth through mitosis.
- Assisting in reproduction.
- Supplying energy and allowing the transport of substances.

Q9. What is the function of Golgi bodies?

Answer: Golgi bodies pack and sort proteins for secretion, create lysosomes, and transport lipids throughout the cell.

Q10. Name the cell organelle that contains hydrolytic enzymes capable of breaking down organic matter.

Answer: Lysosomes

Q11. Which cellular structure regulates the entry and exit of molecules to and from the cell?

Answer: Cell membrane—a selectively permeable structure that controls molecule movement into and out of the cell.

Q12. Define lysosomes.

Answer: Lysosomes are referred to as "suicidal bags" as they contain digestive enzymes within a membrane. They digest worn-out organelles, food particles, and foreign bodies in the cell. In plants, vacuoles perform a similar role.

Q13. Differentiate between prokaryotic and eukaryotic cells.

Answer: Refer to **Table 1.3**.

Table 1.3: Differences between prokaryotic and eukaryotic cells

Feature	***Prokaryotes***	***Eukaryotes***
Type of cell	Always unicellular	Unicellular and multicellular
Cell size	0.2–2.0 μm	10–100 μm
Cell wall	Usually present; chemically complex	When present, chemically simple
Nucleus	Absent; nucleoid region present	Present
Ribosomes	Small, spherical	Larger, linear
DNA arrangement	Circular	Linear
Mitochondria	Absent	Present
Cytoplasm	Present, organelles absent	Present, organelles present
Endoplasmic reticulum	Absent	Present
Plasmids	Present	Rare
Lysosome	Absent	Present
Cell division	Binary fission	Mitosis
Flagella	Small	Large
Reproduction	Asexual	Asexual and sexual
Example	Bacteria, archaea	Plant and animal cells

Q14. What is a ribosome?

Answer: The ribosome is a multi-component cell organelle consisting of RNA and protein and is the site of protein synthesis. Ribosomes are present in both prokaryotic and eukaryotic cells, with eukaryotic ribosomes being larger.

Q15. List the similarities and unique features of animal and plant cells.

Answer: Similarities:

- Both have a nucleus and a selectively permeable plasma membrane.
- Both contain membrane-bound organelles like mitochondria, endoplasmic reticulum, and Golgi apparatus.

- Both have vacuoles (though their size and function differ).
- Mitochondria provide energy in both cell types.

Unique features of plant cells

- Cell wall made of cellulose provides rigidity and structural support.
- Chloroplasts carry out photosynthesis.
- Large central vacuole maintains turgor pressure and stores water and nutrients.
- Generally fixed, rectangular shape due to the cell wall.

Unique features of animal cells

- No cell wall, so shape is flexible.
- Centrioles are present and play a role in cell division.
- Small vacuoles if present, mainly for storage.
- Often irregular or round in shape.

Q16. List the functions of chloroplasts.

Answer: Chloroplasts are plastids found in plant cells containing chlorophyll. They synthesize food via photosynthesis.

Q17. What is a nucleus?

Answer: The nucleus (plural: nuclei) is the most integral component of the cell. Derived from a Latin word meaning "kernel of a nut," it is a double-membraned eukaryotic organelle that contains genetic material and other instructions required for cellular processes **(Fig. 1.11)**. It is exclusively found in eukaryotic cells and is one of the largest organelles.

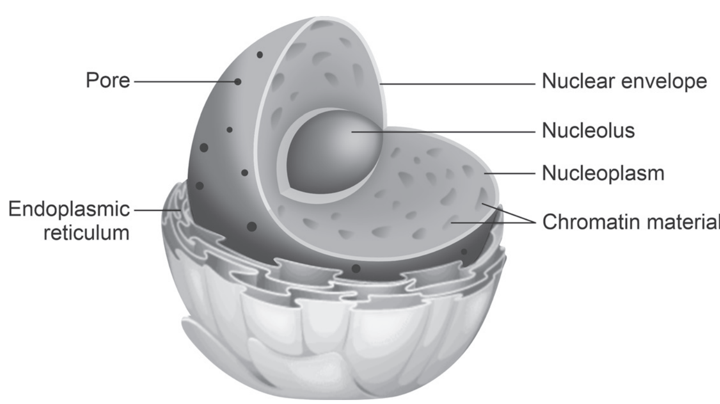

Fig. 1.11: Nucleus (*see* Color Plate 4)

Q18. Outline the structure of the nucleus.

Answer

- Encircled by a double-membraned nuclear membrane/envelope.
- Contains a nucleolus occupying ~25% of the nucleus volume.
- Chromatin, thread-like dense structures containing DNA and proteins, is present.
- The nuclear matrix, a network of fibres and filaments, provides mechanical strength similar to the cytoskeleton.

Q19. Highlight the functions of the nucleus.

Answer

- Stores the cell's hereditary material (DNA).
- Coordinates key cellular activities, including protein synthesis, cell division, and growth.

Q20. What is an animal cell?

Answer: An animal cell is a type of cell found in animal tissues, characterized by the absence of a cell wall, with organelles enclosed within the cell membrane.

Q21. Name the cell organelle that contains genetic material.

Answer: Nucleus

Q22. Which cell organelle generates energy for cellular activities?

Answer: Mitochondria

Q23. Name the double-layered membrane that envelops the nucleus.

Answer: Nuclear envelope

Q24. What is the role of lysosomes?

Answer: Lysosomes assist in digestion, excretion, and cell renewal.

Q25. State the various types of animal cells.

Answer

- Skin cells
- Muscle cells
- Blood cells
- Nerve cells
- Fat cells

Q26. Explain how an animal cell differs from a plant cell.

Answer: An animal cell is usually irregular and round due to the absence of a cell wall. Unlike plant cells, animal cells do not contain plastids as they are not autotrophs.

Q27. Which cell organelle is responsible for packing?

Answer: Golgi apparatus

Q28. Draw the plant cell structure with major parts.

Answer: Refer to **Fig. 1.5**.

Q29. Define homeostasis.

Answer: Homeostasis is the ability of a living organism to maintain a stable internal environment, such as temperature, pH, water balance, and glucose level, despite changes in the external environment.

Example: In humans, body temperature is maintained at around 37°C**.** When the body becomes hot, sweating helps cool it down, and when it becomes cold, shivering helps generate heat.