1. Introduction to Biochemistry

1. Definition: Biochemistry is the branch of science that deals with the chemical substances present in living organisms and the chemical reactions and processes occurring within them.

It helps us understand how the human body produces energy, digests food, synthesizes proteins, maintains normal body functions and responds to drugs.

Examples of biochemistry in pharmacy:

- Understanding how glucose is converted into energy.
- Studying enzymes involved in drug metabolism.
- Understanding the role of proteins, carbohydrates and lipids in the body.
- Studying biochemical changes associated with diseases such as diabetes mellitus.
- Understanding how drugs affect biochemical pathways.

2. The Cell

Definition: The cell is the structural and functional unit of life.

It is also considered the basic unit of biological activity.

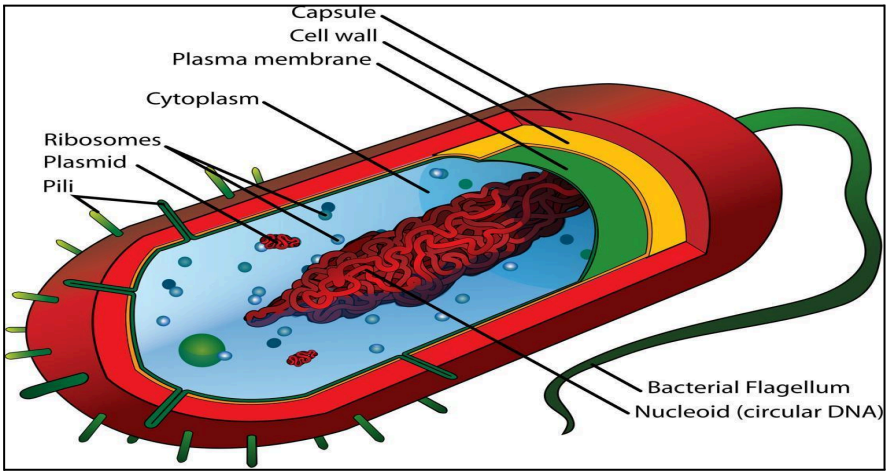
The human body consists of different types of specialized cells, such as nerve cells, muscle cells, red blood cells and liver cells.

Cells are classified into two major types based on their structure and organization:

1. Prokaryotic cells
2. Eukaryotic cells

1. Prokaryotic Cells

Definition: Prokaryotic cells are cells that lack a true, membrane-bound nucleus and membrane-bound organelles.



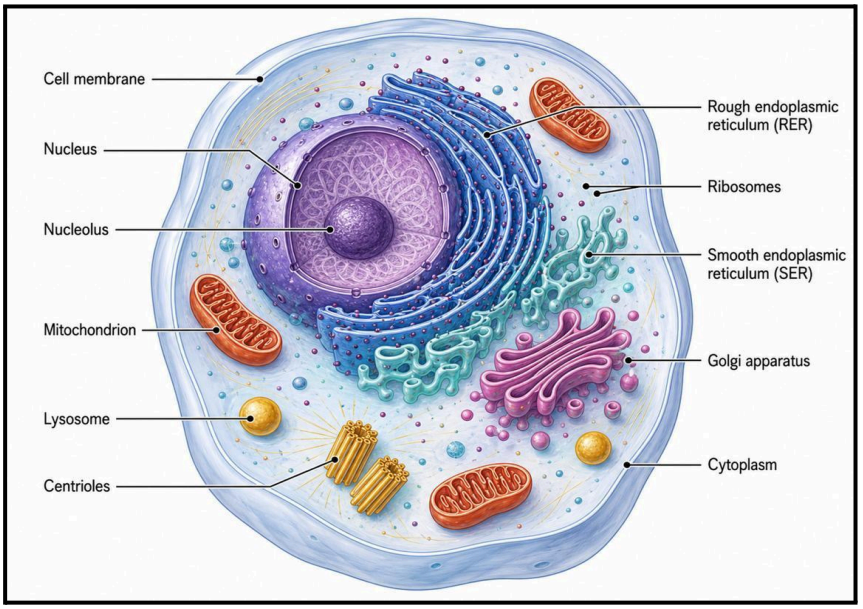
Characteristics:

1. They do not have a true nucleus.
2. Their genetic material is present in a region called the nucleoid.
3. They lack membrane-bound organelles such as mitochondria and Golgi apparatus.
4. They generally have a smaller and simpler structure than eukaryotic cells.
5. They reproduce mainly by binary fission.

Examples: Bacteria, including Escherichia coli.

2. Eukaryotic Cells

Definition: Eukaryotic cells are cells that possess a true, membrane-bound nucleus and membrane-bound organelles.



Characteristics:

1. They have a well-defined nucleus enclosed by a nuclear membrane.
2. They contain membrane-bound organelles such as mitochondria, endoplasmic reticulum and Golgi apparatus.
3. Their genetic material is organized into chromosomes.
4. They are generally more complex than prokaryotic cells.
5. They divide by mitosis or meiosis, depending on the cell and biological process.

Examples: Human cells, animal cells, plant cells and fungal cells.

Differences Between Prokaryotic and Eukaryotic Cells

Prokaryotic Cells	Eukaryotic Cells
1. True nucleus is absent.	True nucleus is present.
2. Nuclear membrane is absent.	Nuclear membrane is present.
3. DNA is usually circular.	Nuclear DNA is organized into linear chromosomes.
4. Membrane-bound organelles are absent.	Membrane-bound organelles are present.
5. Generally smaller in size (0.1–5 µm).	Generally larger in size (10–100 µm).
6. Ribosomes are 70S.	Cytoplasmic ribosomes are 80S.
7. Cell division occurs mainly by binary fission.	Cell division occurs by mitosis or meiosis.
8. Cellular organization is relatively simple.	Cellular organization is more complex.
9. Examples: Bacteria.	Examples: Human, animal and plant cells.

Cell Organelles: Structure and Functions

1. Plasma Membrane (Cell Membrane)

Structure:

- It is the outer boundary of the cell.
- It is mainly composed of a phospholipid bilayer, proteins, cholesterol and carbohydrates.
- It is selectively permeable in nature.

Functions:

1. Encloses and protects the cell.
2. Regulates the movement of substances into and out of the cell.
3. Contains receptors for hormones and other chemical messengers.
4. Helps maintain the ionic balance of the cell.

2. Nucleus

Structure:

- It is generally the largest organelle in a typical animal cell.

- It is surrounded by a double-layered nuclear membrane.
- It contains DNA, chromatin, nucleoplasm and nucleolus.
- Nuclear pores allow the exchange of substances between the nucleus and cytoplasm.

Functions:

1. Stores genetic information in the form of DNA.
2. Regulates cellular activities through gene expression.
3. Controls DNA replication before cell division.
4. Participates in RNA synthesis.
5. The nucleolus helps in ribosome assembly.

3. Mitochondria

Mitochondria are called the powerhouses of the cell because they produce most ATP in many aerobic human cells.

Structure:

- Mitochondria are double-membrane-bound organelles.
- The inner membrane forms folds called cristae.
- The inner compartment is called the matrix.
- They contain their own DNA and ribosomes.

Functions:

1. Produce ATP through aerobic energy metabolism.
2. Participate in the citric acid cycle and oxidative phosphorylation.
3. Help regulate programmed cell death.
4. Participate in cellular calcium regulation.

4. Endoplasmic Reticulum (ER)

Structure:

- It is a network of membrane-bound tubules and flattened sacs present in the cytoplasm.
- It is continuous with the outer nuclear membrane in many regions.
- It is of two types: rough ER and smooth ER.

Functions of Rough ER (RER):

1. Ribosomes are attached to its surface.

2. Synthesizes proteins destined for secretion, membranes and certain organelles.
3. Helps in protein folding and initial modification.
4. Transports newly synthesized proteins towards the Golgi apparatus.

Functions of Smooth ER (SER):

1. Does not have ribosomes on its surface.
2. Synthesizes lipids and phospholipids.
3. Participates in drug metabolism, especially in liver cells.
4. Helps in calcium storage in specialized cells.

5. Ribosomes

Structure:

- Ribosomes are small, non-membrane-bound structures.
- They are composed of ribosomal RNA (rRNA) and proteins.
- They may be found freely in the cytoplasm or attached to the rough ER.

Functions:

1. Act as the sites of protein synthesis.
2. Translate the information carried by messenger RNA (mRNA) into proteins.
3. Free ribosomes mainly synthesize proteins used within the cell.
4. Ribosomes attached to the rough ER synthesize many secreted and membrane proteins.

6. Golgi Apparatus

Structure:

- It consists of stacks of flattened, membrane-bound sacs called cisternae.
- It has a receiving side called the cis face and a shipping side called the trans face.
- Small transport vesicles are associated with it.

Functions:

1. Modifies proteins and lipids received from the ER.
2. Sorts and packages proteins and lipids.
3. Transports substances to their appropriate destinations.
4. Participates in lysosome formation.

7. Lysosomes

Structure:

- Lysosomes are small, single-membrane-bound organelles.
- They contain digestive enzymes called acid hydrolases.
- Their internal environment is acidic, which supports enzyme activity**.**

Functions:

1. Digest substances taken into the cell.
2. Break down damaged and worn-out organelles.
3. Recycle cellular components.
4. Help destroy certain microorganisms inside the cell.

8. Peroxisomes

Structure:

- They are small, single-membrane-bound organelles.
- They contain oxidative enzymes, including catalase.

Functions:

1. Participate in the oxidation of certain fatty acids.
2. Break down hydrogen peroxide using catalase.
3. Help detoxify certain harmful substances.
4. Participate in lipid metabolism.

9. Cytoplasm

Structure:

- It is the region between the plasma membrane and the nucleus.
- It includes the cytosol, organelles and other suspended cellular components.
- The cytosol contains water, ions, proteins and enzymes.

Functions:

1. Provides a medium for biochemical reactions.
2. Contains enzymes and metabolites required for cellular metabolism.
3. Supports cellular organelles.

4. Serves as the site of glycolysis and several other metabolic reactions.

10. Nucleolus

Structure:

- It is a dense region located inside the nucleus.
- It is not surrounded by a membrane.
- It contains RNA and proteins.

Functions:

1. Synthesizes ribosomal RNA (rRNA).
2. Participates in ribosomal subunit assembly.
3. Helps in the formation of functional ribosomes.

11. Centrosome

Structure:

- It is generally located near the nucleus in animal cells.
- It usually contains a pair of centrioles surrounded by pericentriolar material.

Functions:

1. Organizes microtubules.
2. Helps form the mitotic spindle during cell division.
3. Assists in chromosome separation during cell division.

12. Cytoskeleton

Structure:

- It is a network of protein filaments present throughout the cytoplasm.
- It consists of microfilaments, intermediate filaments and microtubules.

Functions:

1. Maintains the shape of the cell.
2. Provides mechanical support.
3. Helps in intracellular transport.
4. Participates in cell movement and cell division.

13. Cilia and Flagella

Structure:

- They are hair-like or whip-like projections associated with certain cells.
- Their internal framework contains microtubules.
- Motile cilia and the flagellum of human sperm generally have a characteristic 9+2 microtubule arrangement.

Functions of Cilia:

1. Move substances across the cell surface.
2. Help move mucus in the respiratory tract.
3. Assist in the movement of material through certain reproductive passages.

Functions of Flagella:

1. Help in cell movement.
2. The flagellum of human sperm provides propulsion for sperm movement.

Biochemical Organization of the Cell

1. Definition

- The biochemical organization of the cell refers to the chemical composition of the cell and the arrangement of different chemical substances that are essential for its structure and functions.
- The cell contains both inorganic and organic substances that work together to maintain life.

2. Chemical Composition of the Cell

The chemical constituents of the cell are classified into two major groups:

Chemical Constituents of the Cell

Inorganic Substances	Organic Substances
Water and minerals acids	Carbohydrates, proteins, lipids and nucleic

A. Inorganic Substances

1. Water

Water is the major constituent of most living cells.

Functions:

- Acts as a solvent for many biochemical reactions.

- Helps in the transport of nutrients and waste products.
- Participates in metabolic reactions.
- Helps maintain cell volume and temperature.

2. Minerals

Minerals are inorganic elements required for normal cellular activities.

Mineral	Function
Sodium (Na^+)	Maintains fluid balance and helps in nerve impulse transmission.
Potassium (K^+)	Maintains membrane potential and normal muscle function.
Calcium (Ca^{2+})	Helps in muscle contraction and cell signalling.
Magnesium (Mg^{2+})	Acts as a cofactor for many enzymes.
Phosphorus	Forms part of ATP, DNA, RNA and phospholipids.
Iron (Fe)	Required for haemoglobin-mediated oxygen transport.

B. Organic Substances

Organic substances contain carbon and are essential for cellular structure and function.

1. Carbohydrates

Carbohydrates are organic compounds composed mainly of carbon, hydrogen and oxygen.

Functions:

- Provide energy to cells.
- Store energy in the form of glycogen.
- Participate in cell recognition.

Examples: Glucose, fructose and glycogen.

2. Proteins

Proteins are biomolecules composed of amino acids linked by peptide bonds.

Functions:

- Act as enzymes and catalyse biochemical reactions.
- Provide structural support.
- Transport substances.
- Participate in immunity and cell signalling.

Examples: Haemoglobin, insulin and antibodies.

3. Lipids

Lipids are biomolecules that are generally insoluble or poorly soluble in water.

Functions:

- Store energy.
- Form the structural components of cell membranes.
- Provide insulation and protection.
- Serve as precursors for certain hormones.

Examples: Triglycerides, phospholipids and cholesterol.

4. Nucleic Acids

Nucleic acids are biomolecules composed of nucleotides.

Types and functions:

- DNA (Deoxyribonucleic acid): Stores genetic information.
- RNA (Ribonucleic acid): Participates in gene expression and protein synthesis.

Major Chemical Constituents of the Human Body

The approximate composition of a normal adult human body is shown below. These values vary with age, sex and body composition.

Constituent	Approximate percentage
Water	61.6%
Protein	17.0%
Lipids	13.8%
Carbohydrates	1.5%
Minerals	6.1%

Importance of Biochemical Organization

1. Helps maintain normal cellular structure and function.
2. Provides energy for cellular activities.
3. Supports the synthesis of proteins and other biomolecules.
4. Maintains cellular fluid and electrolyte balance.
5. Helps explain drug action, metabolism and toxicity.

Transport Process Across Cell Membrane

1. Definition

Transport across the cell membrane is the movement of substances such as water, ions, nutrients and waste products into and out of the cell through the plasma membrane.

The cell membrane is selectively permeable, which means it allows certain substances to pass through while restricting others.

Transport across the cell membrane is essential for maintaining cellular homeostasis, nutrient uptake, waste removal and normal cell function.

2. Types of Transport Across the Cell Membrane

There are three main types of membrane transport:

A. Passive Transport

Passive transport is the movement of substances from a region of higher concentration to a region of lower concentration **without requiring cellular energy (ATP).**

Types of passive transport:

1. Simple Diffusion: Simple diffusion is the movement of molecules from a region of higher concentration to a region of lower concentration directly through the membrane, without the help of a transport protein.

Example: Oxygen (O_2) entering cells.

Carbon dioxide (CO_2) leaving cells.

Movement of certain lipid-soluble drugs across membranes.

2. Facilitated Diffusion: Movement of substances across the membrane through specific carrier or channel proteins without using ATP.

Example: Transport of glucose through GLUT proteins.

3. Osmosis: Osmosis is the net movement of water across a selectively permeable membrane from a region of higher water potential to a region of lower water potential.

In simple terms, water moves towards the side with the higher effective concentration of non-penetrating solutes.

Examples:

- Movement of water across cell membranes.
- Swelling or shrinking of cells when placed in solutions of different tonicities.

Types of solutions and their effects:

Solution	Effect on a typical animal cell

Isotonic	Cell volume remains approximately unchanged.
Hypotonic	Water enters the cell; it swells and may burst.
Hypertonic	Water leaves the cell; it shrinks.

B. Active Transport

Active transport is the movement of substances against their concentration gradient, from lower to higher concentration, using energy directly or indirectly.

Active transport is classified into primary and secondary active transport.

Types of active transport:

1. Primary Active Transport:

Definition: Primary active transport uses energy directly from ATP hydrolysis to move substances across the membrane.

Example: Sodium-Potassium Pump (Na^+/K^+-ATPase)

This pump transports:

- 3 sodium ions (Na^+) out of the cell.
- 2 potassium ions (K^+) into the cell.

One ATP molecule is hydrolysed per transport cycle.

2. Secondary Active Transport:

Definition: Secondary active transport uses the energy stored in an ion gradient, established by primary active transport, to move another substance against its own gradient.

It does not directly hydrolyse ATP at the cotransporter itself.

Example: Sodium-glucose cotransport, which helps absorb glucose along with sodium ions.

Types:

1. Symport (Co-transport)

Two substances move in the same direction across the membrane.

Example: Sodium-glucose cotransporter (SGLT), which uses the sodium gradient to transport glucose into cells.

2. Antiport (Counter-transport)

Two substances move in opposite directions across the membrane.

Example: Sodium-calcium exchanger, which commonly allows sodium to enter the cell while calcium moves out.

C. Vesicular Transport

Vesicular transport is the movement of large molecules or particles through membrane-bound vesicles.

Types:

1. Endocytosis: The process by which substances enter the cell through the formation of vesicles.

Types include:

- Phagocytosis: Uptake of solid particles.
- Pinocytosis: Uptake of fluids and dissolved substances.
- Receptor-mediated endocytosis: Uptake of specific substances through membrane receptors.

2. Exocytosis: The process by which substances are released outside the cell when vesicles fuse with the plasma membrane.

Example: Release of insulin, hormones and neurotransmitters.

Difference Between Passive and Active Transport

Passive Transport	Active Transport
1. It does not require energy (ATP).	1. It requires energy directly or indirectly.
2. Substances move from higher to lower concentration.	2. Substances can move against their concentration gradient.
3. It may occur directly through the membrane or with the help of transport proteins.	3. It generally requires specific transport proteins or pumps.
4. It occurs down the concentration gradient.	4. It can occur against the concentration gradient.
5. It includes simple diffusion, facilitated diffusion and osmosis.	5. It includes primary and secondary active transport.
6. Example: Movement of oxygen and carbon dioxide.	6. Example: Sodium-potassium pump (Na^+/K^+ pump).

3. Biological Significance

1. Helps in the absorption of nutrients and drugs.
2. Maintains water and electrolyte balance in the body.

3. Helps in the removal of waste products from cells.
4. Maintains the ionic concentration required for normal cellular functions.
5. Helps in the secretion of hormones and neurotransmitters.

Energy-Rich Compounds: ATP, Cyclic AMP and Their Biological Significance

1. Energy-Rich Compounds

Definition

Energy-rich compounds are substances that contain high-energy bonds and release usable energy when these bonds are hydrolysed.

They provide energy for various biochemical reactions and cellular activities.

Examples

- ATP (Adenosine triphosphate)
- GTP (Guanosine triphosphate)
- Creatine phosphate
- Phosphoenolpyruvate (PEP)
- 1,3-Bisphosphoglycerate

Biological Significance of Energy-Rich Compounds

1. Provide energy for muscle contraction.
2. Help in the synthesis of proteins and other biomolecules.
3. Support active transport across cell membranes.
4. Provide energy for various metabolic reactions.
5. Help maintain normal cellular activities.

ATP (Adenosine Triphosphate)

Definition

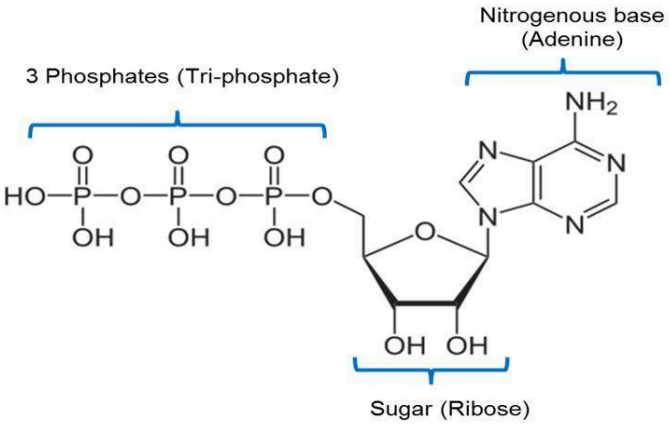
ATP is the primary energy currency of the cell.

It stores and transfers energy required for various cellular activities.

Structure of ATP

ATP consists of three components:

1. Adenine: A nitrogenous base.
2. Ribose: A five-carbon sugar.
3. Three phosphate groups: Connected in a chain.



ATP contains two phosphoanhydride bonds between its phosphate groups that release usable energy during hydrolysis.

Formation and Breakdown of ATP

ATP is formed by the addition of inorganic phosphate to ADP using energy.

$$ADP + P_i + Energy \rightarrow ATP$$

ATP releases energy by hydrolysis:

$$ATP + H_2O \rightarrow ADP + P_i + Energy$$

Approximately 30.5 kJ/mol (7.3 kcal/mol) is released under standard biochemical conditions for ATP hydrolysis to ADP and inorganic phosphate. The actual energy change in cells varies with cellular conditions.

Biological Significance of ATP

1. Muscle contraction: Provides energy for muscle movement.
2. Active transport: Powers pumps such as the sodium-potassium pump.
3. Biosynthesis: Provides energy for the synthesis of proteins, lipids and nucleic acids.
4. Cellular metabolism: Supplies energy for various biochemical reactions.
5. Phosphorylation: Donates phosphate groups to molecules during cellular reactions.
6. Nerve function: Supports the maintenance of ion gradients necessary for nerve impulse transmission.

Cyclic AMP (cAMP)

Definition

Cyclic AMP (**cyclic adenosine monophosphate**) is a second messenger that carries signals from cell-surface receptors to intracellular targets.

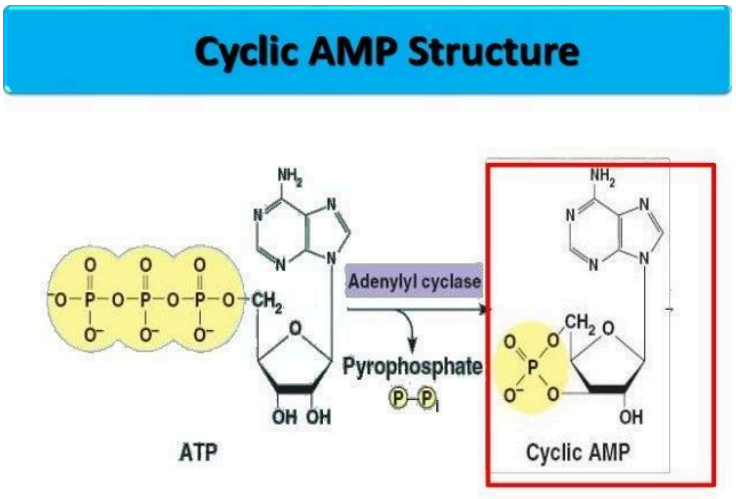
It is formed from ATP by the enzyme adenylyl cyclase.

Formation of cAMP

$$ATP \xrightarrow{Adenylyl\ cyclase} cAMP + PP_i$$

cAMP is broken down into 5′-AMP by the enzyme phosphodiesterase.

$$cAMP \xrightarrow{Phosphodiesterase} 5' - AMP$$



Biological Significance of cAMP

1. Second messenger: Transmits signals from hormones to target cells.
2. Glycogen metabolism: Promotes glycogen breakdown through activation of protein kinase A.
3. Glucose regulation: Glucagon increases cAMP formation in the liver, helping increase blood glucose levels.
4. Fat metabolism: Promotes breakdown of stored fats in response to certain hormonal signals.
5. Enzyme regulation: Activates protein kinase A (PKA), which regulates several cellular processes.
6. Cellular response: Helps regulate secretion, metabolism and gene expression.

Examples of hormones that act through cAMP: Glucagon and adrenaline (in several target tissues).

Difference Between ATP and cAMP

ATP	cAMP
Full form: Adenosine triphosphate.	Full form: Cyclic adenosine monophosphate.
It is the primary energy currency of the cell.	It is a second messenger in cell signalling.
Contains three phosphate groups.	Contains one phosphate group in a cyclic arrangement.
Provides energy for cellular activities.	Transmits signals and regulates cellular responses.
Formed during cellular energy-producing processes.	Formed from ATP by adenylyl cyclase.
Example: Energy supply for muscle contraction.	Example: Glucagon-mediated signalling.