Chapter

1

Introduction to Biochemistry of Eukaryotic Cells, Anabolic and Catabolic Reactions

SAQ: Short answer question: Marks: 2
BAQ: Brief answer question: Marks: 4 or 5
LAQ: Long answer question: Marks: 9 or 10
MCQs: Marks: 0.5 each

INTRODUCTION

SAQ: Define biochemistry.

Ans: Biochemistry is a science that deals with the chemical constituents of living cells, including the biochemical reactions and processes in living organisms. Biochemistry governs all living organisms and living processes. The study of biochemistry is essential to understand medicine as well as all the subjects of life sciences.

SAQ: Define medical biochemistry.

Ans: Medical biochemistry is the branch of biochemistry that studies the chemical compositions and metabolic reactions in the human body as well as the changes that take place in chemical processes and metabolic reactions in various disorders and diseases and their effects on the general health of a person. Medical biochemistry has an enormous impact on the understanding and maintenance of health and understanding and effective treatment of diseases.

SAQ: Define clinical biochemistry.

Ans: Clinical biochemistry deals with biochemistry laboratory applications to find out the cause of a disease.

Importance of Clinical Biochemistry

BAQ: Write a brief on the importance of clinical biochemistry.

Ans: The chemical constituents of various body fluids such as blood serum, plasma, urine, cerebrospinal fluid (CSF), and other body fluids are analyzed in a clinical biochemistry laboratory. These determinations are useful in diagnosing various clinical conditions such as diabetes mellitus, jaundice, gout, hyperlipidemia, hypo- and hyperthyroidism, pancreatitis, rickets, etc. Biochemistry tests are very useful in determining the severity of diseases related to many organs, such as the heart, kidneys, lungs, liver, stomach, brain, etc., as well as the endocrine disorders and related status of acid–base balance of the body. The clinical biochemistry tests, concerning the various clinical conditions, can be useful to reveal the causes of the diseases and suggest effective treatment. The biochemistry test reports can assist in monitoring the progress of a pathological condition and help in assessing response to therapy.

Early clinical exposure: For the students of medicine, the medical biochemistry subject is an extremely important pre-clinical subject along with anatomy and physiology for the "early clinical exposure concept" introduced by the National Medical Commission.

The knowledge acquired in medical biochemistry will be useful for the students to integrate molecular events with the structures and functions of the human body in health and disease.

EUKARYOTIC CELL (Fig. 1.1)

Competency achievement: The student should be able to:

BI1.1: Describe the molecular and functional organization of a cell and its subcellular components

BAQ: Briefly describe the nucleus of a cell.

Ans: The nucleus of a cell is surrounded by a double membrane. It contains a colloidal solution of proteins with various salts called nucleoplasm. It is acidic in nature.

The nucleus contains the important nucleic acid, deoxyribonucleic acid (DNA), which is associated with histone (protein) to form nucleosomes. Most of this protein is bound to DNA. The nucleus generally contains one or two refractile particles called nucleoli. Nucleoli are not membrane-bound structures. In nucleoli, ribosomal RNA (rRNA) is synthesized according to the directions from the DNA.

The outer membrane of the nucleus exhibits nuclear pores, which are open to the cytoplasm. Through these pores, contact with the cytoplasmic (or endoplasmic) reticulum is possible. The size of the nucleus is about 6 μm.

SAQ: What are the functions of DNA?

Ans: Functions of DNA:

A. DNA plays a very important role in cell division and transmission of hereditary characteristics.
B. With the help of various forms of RNA, it also plays an important role in the synthesis of various proteins.

SAQ: Briefly describe the cytoplasm.

Ans: The cytoplasm is a watery and homogeneous solution of protein, sugars, and various salts. It is basic in nature.

The cytoplasmic fluid has osmotic pressure equal to 0.9 g/dl sodium chloride (normal saline). It contains: (1) Cytoplasmic (endoplasmic) reticulum, (2) Golgi apparatus, (3) mitochondria, (4) centrosome, (5) lysosome, and (6) cytoplasmic inclusions.

SAQ: What is a cytoplasmic (endoplasmic) reticulum?

Ans: It is a complicated system of internal membranes lined by dots that are rich in RNA and called ribosomes.

SAQ: What are the important functions of the cytoplasmic (endoplasmic) reticulum?

Ans: Following are important functions of the cytoplasmic (endoplasmic) reticulum:

A. The free ribosomes are involved in the synthesis of proteins necessary for the cell itself.
B. The ribosomes attached to the membrane play an important role in the synthesis of various proteins secreted by the cell.

SAQ: What is the Golgi apparatus?

Ans: The Golgi apparatus is an organelle found in the cytoplasm of most eukaryotic cells. It forms a part of the cellular endomembrane (group of membranes) system.

SAQ: What is an endoplasmic reticulum?

Ans: The endoplasmic reticulum is a continuous membrane system in the form of a series of flattened sacs within the cytoplasm of eukaryotic cell. There are two types: Rough endoplasmic reticulum containing ribosomes, attached to the outer surface and smooth endoplasmic reticulum that does not contain ribosomes (Fig. 1.1). The endoplasmic reticulum is situated adjacent to the cell nucleus, and its membrane is continuous with the outer membrane of the nuclear envelope.

SAQ: What are two important functions of the endoplasmic reticulum?

Ans: The following are two important functions of the endoplasmic reticulum:

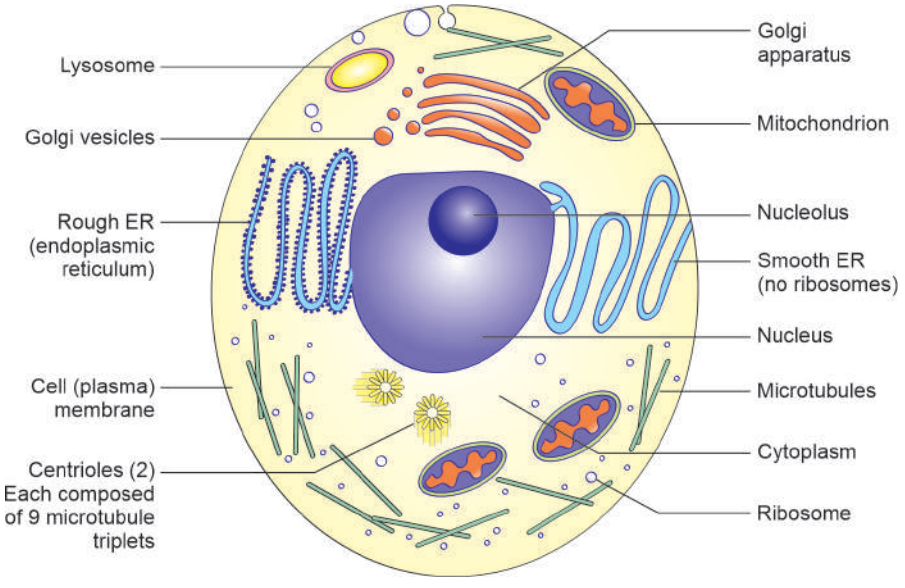

Fig. 1.1: Eukaryotic cell

1. Ribosomes of rough endoplasmic reticulum play an important role in the synthesis of proteins, which are modified and transported to Golgi bodies for further modifications, sorting and processing.
2. The smooth ER is involved in the synthesis of lipids such as cholesterol and phospholipids.

BAQ: Describe the composition of the Golgi apparatus.

Ans: The Golgi apparatus is composed of stacks of membrane-bound structures known as cisternae. A mammalian cell contains approximately 40 to 100 such stacks. Each cisterna appears like a flat disc enclosed by a membrane.

The two sides of a Golgi stack are referred to as a *cis* face, which means a receiving part near the endoplasmic reticulum (ER) and a *trans* face means a shipping part away from the ER. The transport vesicles from the ER carry material to the *cis* face from where they enter the Golgi and after getting processed and packaged into vesicles. Then they are shipped out from the *trans* face to the various parts of the cell.

BAQ: What are the functions of the Golgi apparatus?

Ans: Functions of Golgi apparatus:

A. Golgi apparatus primarily modifies proteins delivered from the rough endoplasmic reticulum.

B. It is also involved in the transport of lipids around the cell and the creation of lysosomes.

C. The cisterna contains special Golgi enzymes which modify cargo proteins that travel through it. Enzymes within the cisternae can modify the proteins by the addition of carbohydrates and phosphates by importing substances such as nucleotide sugars from the cytosol. These modifications also form a signal sequence that determines the final destination of the protein.

SAQ: Describe mitochondria briefly.

Ans: Mitochondria are fluid-filled vessels enclosed by inner involuted membrane folds (cristae) and a single outer layer of the protein molecule, which is internally lined by phospholipid molecules. These are minute

bodies scattered throughout the cytoplasm. The components of the electron transport chain and oxidative phosphorylation are present in the inner mitochondrial membrane. The average size of mitochondria is about 0.5–10 μm.

BAQ: What are the functions of mitochondria?

Ans: Functions of mitochondria:

A. The internal chamber of mitochondria (matrix) contains various enzymes which participate in the metabolism of amino acids, lipids, and carbohydrates.

B. The mitochondria are power plants that are responsible for the process of respiration and phosphorylation in the cell, which involve the interaction of many enzymes and coenzymes. They supply energy for metabolic reactions in the form of ATP.

C. The mitochondrial matrix also contains circular double-stranded DNA, RNA, and ribosome, which are responsible for the synthesis of mitochondrial protein.

SAQ: What are centrosomes (centriole)?

Ans: These are small refractile bodies (one or two) found near the nucleus of most living cells in condensation of protoplasm.

SAQ: What are the functions of centrosomes?

Ans: During mitosis, the two centrioles move to the opposite poles of the cell and support skin with fine protoplasmic rays. Along this spindle, the chromosomes arrange themselves after division.

SAQ: What are peroxisomes and their functions?

Ans: Peroxisomes are spherical or oval single-membrane cellular organelles.

The functions of the peroxisomes: Peroxisomes contain the enzyme catalase, which protects the cell from toxic substances produced during metabolic reactions.

SAQ: Describe briefly the cytoskeleton of a cell.

Ans: The cytoskeleton of a cell is in the form of a complex mesh of protein filaments. It includes microfilaments and microtubules. It extends throughout the cell cytoplasm.

SAQ: What are the important functions of the cytoskeleton?

Ans: Functions of cytoskeleton:

A. It maintains the shape of the cell.

B. It controls the position of cell organelles by anchoring them to the plasma membrane.

C. It is involved with cytoplasmic streaming, which means the flow of the cytoplasm.

D. It anchors the cell properly by interacting with extracellular elements.

SAQ: What are the microtubule organizing centers (MTOCs) of a cell and their functions?

Ans: Centrioles and centrosomes are the non-membranous structures that are present outside the nuclear membranes.

SAQ: What are the functions of MTOCs?

Ans: MTOCs organize spindle fibers and give rise to the formation of spindle apparatus which is required for cell division.

BAQ: Briefly describe cytoplasmic membrane and its functions.

Ans: The cell is bounded by an approximately 10 nm thick, double-layered, semipermeable membrane. It is made up of protein and lipid components.

Functions of cell membrane:

A. *Exchange of food and secretory products:* Cytoplasmic membrane conducts the exchange of food and secretory products in the following ways: Passive transport: When the movement of substances is under the influence of osmotic pressure.

Active transport: When the movement of substances is mediated by chemical interactions and electrical changes.

B. *Pinocytosis:* The cytoplasmic membrane plays an important role in pinocytosis (cell drinking) and phagocytosis (cell eating).

C. *Signal transduction:* It plays a very important role in the signal transduction

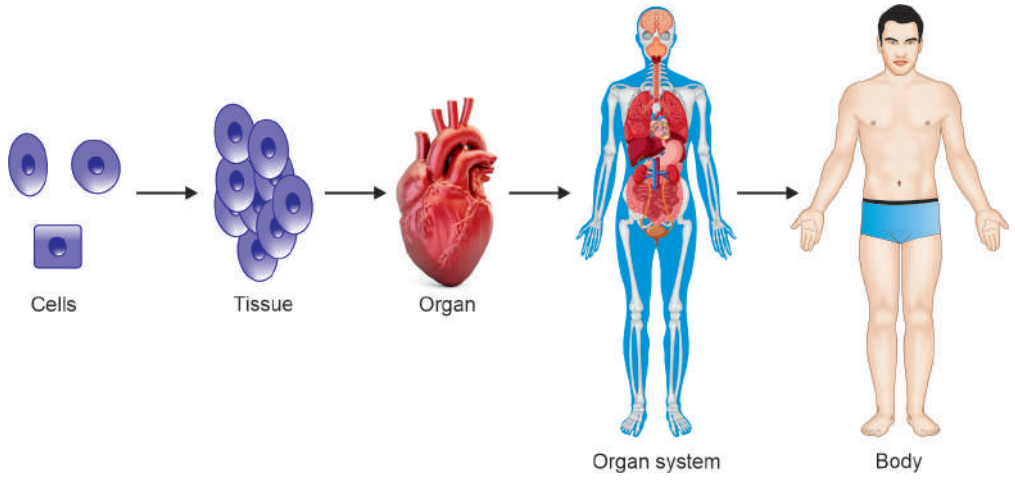

Fig. 1.2: Basic levels of body organization

process using one membrane-bound enzyme adenylate cyclase, which synthesizes cyclic AMP (cAMP) from ATP. A specific membrane protein changes shape and relays the message inside the cell.

D. *Cell-to-cell recognition:* Specific glycoproteins present on cell membranes play an important role as recognition molecules by other cells.

E. Cell-to-cell attachments: Various proteins like desmosomes play an important role in attachment to the cytoskeleton and extracellular matrix. This is useful in maintaining cell shape and stability.

BASIC LEVELS OF BODY ORGANIZATION

BAQ: Utilizing a line diagram show basic levels of body organization.

Ans: Figure 1.2 shows basic levels of body organization formed from cells to tissues to organs to the body.

CELLULAR INJURY AND DEATH

BAQ: Write a brief on cellular injury and death.

Ans: The normal cellular function requires a balance between the physiological demands of a cell and its metabolic capability, which maintains a state of homeostasis, which means maintenance of a stable and constant condition of properties like temperature and pH. Cells can alter their functional state in response to any stress to maintain homeostasis by undergoing hypertrophy (increase in mass) or hypotrophy (decrease in mass). Cell injury can be averted if any situation that leads to stress is checked.

Irreversible injury to the cells can lead to pathological changes leading to cellular death. Cellular injury can be caused by the following factors: Nutritional imbalances (related to protein calories, vitamins, etc.), infectious agents (e.g. bacteria, viruses), chemical agents (drugs and nontherapeutic agents), physical agents (radiations, electric shock, trauma, heat, cold, etc.), adverse immunological reactions, genetic derangements, and oxygen deprivation. There are following two morphological patterns of cellular death—

1. *Necrosis:* It is a type of cellular death caused by excessive cell swelling and denaturation of proteins, leading to cellular rupture.
2. *Apoptosis:* It occurs when a cell dies as an internal program organized to eliminate unwanted cells produced during embryogenesis and pathological conditions, without disrupting a normal tissue.

SAQ: Define necrosis and apoptosis.
Ans: Refer to upper paragraphs.

SAQ: Give an example of how a damaged cell leads to a specific disease.

Ans: Due to COVID-19 infection of lung cells, the infection can spread to the lung tissue and severe infection can affect many organs such as the liver, kidneys, blood cells, and ultimately the entire body of an individual.

METABOLIC REACTIONS

Life is a chemical process that involves thousands of various types of chemical reactions occurring in an organized manner. These are metabolic reactions and are collectively called metabolism.

SAQ: Define metabolism.

Ans: Metabolism is defined as the total of all chemical reactions that occur in the body, which is a sum of catabolism and anabolism.

SAQ: Define catabolism.

Ans: Catabolism is that part of metabolism that involves the breakdown of large, complex molecules into smaller, more simplified products.

SAQ: Describe catabolism.

Ans: Catabolism takes place during digestion, removal of hydrogen (dehydrogenation), carboxyl groups (decarboxylation) and amino groups (deamination), oxidation, etc. Catabolic rections are energy-yielding. ATP molecules are obtained by the main catabolic reactions, such as the breakdown of glucose, amino acids, and fatty acids.

Catabolic reactions are energy-yielding. They are involved in the breakdown of more complex molecules into simpler ones.

SAQ: Describe anabolism.

Ans: Anabolism is that part of metabolism that involves the synthesis of larger, more complex molecules from small, simple reactants. Examples of anabolism include the synthesis of glycogen from glucose, protein from amino acids, fat from glycerol and fatty acids, and the construction of new antibodies and new enzymes. Anabolic reactions require energy.

Rate-Limiting and Committed Steps in Metabolism

Metabolic reactions are controlled according to the requirements of a cell. For example, in a fed state, when plenty of glucose is available to poduce ATP molecules, glycolysis (breakdown of glucose) will continue till sufficient ATP molecules are produced, and later on, other metabolic reactions will start to store excess glucose into glycogen and fat.

Metabolic reactions (pathways) require strict regulations so that the proper compounds get produced in the proper amounts. Such regulations ensure that the products formed in metabolic reactions do not accumulate and lead to a situation that can be wasteful or even harmful to the cell. A rate-limiting reaction is a slow reaction that controls the rate of reactions of metabolism by decreasing the speed of a metabolic pathway. In every metabolic pathway, there is at least one enzyme-catalyzed reaction that is "rate-limiting", due to the low concentration of reaction catalyzing "enzyme". Rate-limiting reaction is not dependent on the specific substrate (a substance on which an enzyme acts) but it is dependent on the concentration of the reaction-catalyzing enzyme.

A committed step in metabolic pathways (reactions) is an effective first irreversible enzymatic reaction. After this step, the metabolic reactions end up in the required "final product" (e.g. the formation of ATP molecules at the end of glycolysis).

NOTE

1. Often, the first committed step is regulated by processes such as feedback inhibition and activation of enzymes.
2. Rate-limiting steps are different from committed steps. However, in a specific metabolic pathway, a rate-limiting step can also be a committed step, e.g. in the case of glycolysis Step 3 is both a rate-limiting as well as committed (Fig. 4.5, p 45).

Homeostasis

Competency achievement: The student should be able to:

SU1.1: Describe the basic concept of homeostasis

BAQ: Describe the basic concept of homeostasis.

Ans: Homeostasis is a state of steady internal balance among all the body systems needed for the body to survive and function normally. In homeostasis, the body's levels of energy, oxygen, blood pressure, blood sugar, proteins, blood buffers, electrolytes, hormones, proteins, and temperature are constantly adjusted to respond to changes inside and outside the body, to keep them at normal levels.

All the homeostatic control mechanisms have a minimum of three interdependent components for the regulation of changes that may disturb homeostasis:

1. A receptor,
2. A control center, and
3. An effector.

1. A receptor acts as a sensing component and it monitors and responds to changes in the environment, either internal or external. Examples of receptors are mechanoreceptors and thermoreceptors. Mechanoreceptors are a specific type of somatosensory receptors that relay extracellular stimulus to intracellular signal transduction. A thermoreceptor is a sensory receptor, the receptive portion of a sensory neuron that senses absolute and relative changes in temperature.
2. Control centers include the renin–angiotensin system and the respiratory center. The renin–angiotensin system is a hormone-regulated system that regulates blood pressure, body fluids, and electrolyte balance.
3. An effector acts to bring about the change back to the normal state. At the cellular level, effectors are the nuclear receptors that bring about changes in gene expression through down-regulation or up-regulation of specific processes and act in negative feedback mechanisms.

The following are the main components of the homeostasis action:

1. *Receptor:* Cutaneous receptors of the skin senses high humidity and temperature
2. *Control center:* The brain acts by the action of the nervous system.
3. *Effector:* Causes vasodilation of blood vessels to drop body temperature and secretion of sweat through sweat glands in the skin and evaporation of sweat on the surface of the skin to keep the body cool. If the external temperature is too cold, the blood vessels constrict (vasoconstriction) and the body can retain heat.

Homeostasis breakdown: The failure of homeostasis due to accidents or severe disease may lead to disability and death. The following are the common factors that may affect homeostasis: Physical condition, nutrition, toxins, and adverse effects of medicines and medical procedures.

Competency achievement: The student should be able to relate:
Horizontal and vertical integration of subjects

BAQ: What is the meaning of horizontal integration of a specific biochemical topic with other pre-medical subjects such as anatomy, physiology, and nutrition? Give examples.

Ans: Horizontal integration of a specific biochemical topic with other pre-medical subjects is useful to understand the effects of a specific biochemical change on anatomical and physiologic aspects of an individual and support of nutrition to get rid of the biochemical change.

For example, when the iron is deficient, normal formation of red blood cells will not take place (anatomical effect), the oxygen-carrying capacity of the body will decrease (physiological change), and by nutritional treatment (nutritional therapy), supported by iron tonics, and treating the root cause of the disease, it is possible to get rid of iron deficiency.

BAQ: What is the meaning of vertical integration of a specific biochemical topic with other paramedical subjects such as microbiology and pharmacology?

Ans: Vertical integration of a specific biochemical topic with other paramedical subjects such as microbiology and pharma-

cology is useful to understand; whether the effects of a specific biochemical change are related to microbial infection. Vertical integration with pharmacology will give an idea about the study of the specific drug to treat microbial disease.

Example: In the case of a patient suffering from severe diarrhea, the biochemical change is the loss of water and electrolytes from the gastrointestinal tract. Identification of the specific microorganism and use of appropriate antibiotics will be useful to control diarrhea and loss of water and electrolytes.

Multiple Choice Questions

Q1. Which of these are located in the mitochondria?
A. Cytochrome oxidase
B. Succinate dehydrogenase
C. Amylase
D. A and B

Q2. The most active site of protein synthesis is
A. Nucleus B. Ribosome
C. Mitochondrion D. Cell sap

Q3. Mitochondrial DNA is
A. Circular double-stranded
B. Circular single-stranded
C. Linear double helix
D. None of these

Q4. Which of the following cellular organelles are called "suicide bags"?
A. Lysosomes B. Ribosomes
C. Nucleolus D. Golgi bodies

Q5. The Golgi complex
A. Synthesizes proteins
B. Produces ATP
C. Provides a pathway for transporting chemicals
D. Forms modified components like glycoproteins

Q6. The following points about microfilaments are true *except*
A. They form cytoskeleton with microtubules
B. They provide support and shape
C. They form intracellular conducting channels
D. They are involved in muscle cell contraction

Q7. The following substances are cell inclusions *except*
A. Melanin B. Glycogen
C. Lipids D. Vitamins

Q8. Enzymes catalyzing electron transport are present mainly in the
A. Ribosomes
B. Endoplasmic reticulum
C. Lysosomes
D. Inner mitochondrial membrane

Q9. rRNA is produced mainly in the
A. Endoplasmic reticulum
B. Ribosome
C. Nucleolus
D. Nucleus

Q10. Genetic information of nuclear DNA is transmitted to the site of protein synthesis by
A. rRNA B. mRNA
C. tRNA D. Polysomes

Q11. The powerhouse of the cell is
A. Nucleus
B. Cell membrane
C. Mitochondria
D. Lysosomes

Q12. The digestive enzymes of cellular compounds are confined to
A. Lysosomes B. Ribosomes
C. Peroxisomes D. Polysomes

Q13. Which group is involved in manufacturing substances needed by the cell?
A. Lysosome, vacuole, ribosome
B. Ribosome, rough ER, smooth ER
C. Vacuole, rough ER, smooth ER
D. Smooth ER, ribosome, vacuole

Q14. Which of the following clues would tell you whether a cell is prokaryotic or eukaryotic?
A. The presence or absence of a rigid cell wall
B. Whether or not the cell is partitioned by internal membranes
C. The presence or absence of ribosomes
D. Whether or not the cell contains double-stranded DNA

Answers

1. D **2.** B **3.** A **4.** A **5.** D **6.** C **7.** D **8.** D **9.** C **10.** B
11. C **12.** A **13.** B **14.** D