

Introduction

Biology is not merely the first step in the study of Medicine; it is the “language” through which we decipher life itself. From the foundations of cellular structure to the intricate interactions of the genome, proteome, and metabolism, understanding the fundamental principles of Biology shapes the way we approach health and disease.

Today, this knowledge is charting the course of the Medicine of the future: from Precision Medicine, which tailors prevention and treatment to the molecular profile of each patient, to cell and gene therapies that transform once incurable diseases into manageable conditions. At the same time, synthetic biology is opening new horizons, enabling us to design tissues, regenerate organs, and—perhaps in the future—even create forms of life that serve human health. In this way, Biology is not simply a scientific foundation, but the cornerstone upon which the medical revolution of the 21st century is being built.

This book offers a practical and focused approach to learning. Through multiple-choice exercises, open-ended questions, and critical thinking scenarios, it goes beyond the transmission of knowledge to cultivate the ability to connect theory with clinical practice and research. It is addressed to students of Medicine and Biology, candidates preparing for national and international examinations such as the USMLE, as well as any reader who wishes to meaningfully understand Biology as a guide to the Medicine of tomorrow.

Students are encouraged to study the corresponding chapters in their main textbook and use this volume as a companion for revision and practice. Each “Key Concepts” section highlights the essential points that must be mastered, while the different types of exercises—ranging from multiple-choice to open-ended and critical thinking questions—allow readers to test their understanding at various levels of difficulty. The inclusion of indicative answers not only facilitates self-assessment but also fosters deeper comprehension and the development of critical reasoning skills essential for medical training.

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Athens, May 2026

Chapter 2

Chemical Components of Cells

2.1. Learning Objectives

By studying the relevant material in your textbook and by the end of this chapter, you should be able to:

- ✓ Identify the different types of chemical bonds and their significance in cell biology.
 - ✓ Understand the properties of water that contribute to its role in cellular functions.
 - ✓ Describe the major classes of biological macromolecules, their building blocks, and their roles in the cell.
 - ✓ Explain how the structure of macromolecules determines their function.
 - ✓ Differentiate between the structure and function of carbohydrates, lipids, proteins, and nucleic acids.
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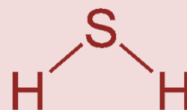
2.2. Key Concepts

- The chemistry of life revolves around carbon, which can form a wide variety of stable and complex molecules. This versatility enables the construction of the intricate molecular structures required for biological functions.
- Cellular processes depend on chemical reactions occurring in water, which acts as a universal solvent. The stability of these reactions is maintained within a narrow temperature range, critical for sustaining life.
- Large polymeric molecules, such as proteins, nucleic acids, and polysaccharides, dominate biological systems. These macromolecules are built from smaller subunits, like amino acids or nucleotides, providing both diversity and specificity in their functions.
- Carbon, hydrogen, oxygen, and nitrogen constitute approximately 96% of the mass of living organisms. Their ability to form stable bonds and participate in diverse chemical interactions makes them essential for life.
- Cells construct their macromolecules from a limited set of small organic molecules, such as amino acids, sugars, nucleotides, and fatty acids. These building blocks can also act as energy sources or signaling molecules within the cell.

- The shape, stability, and function of biological molecules are determined by the interplay of covalent bonds (which provide strength and stability) and noncovalent bonds (which enable dynamic interactions and flexibility).
- The ability of water to form hydrogen bonds and its polar nature underpins its critical role in cellular processes, from acting as a solvent to enabling molecular interactions and maintaining the structural integrity of macromolecules.
- Lipids are amphipathic molecules with hydrophobic and hydrophilic regions. This property allows them to assemble into bilayers, forming cellular membranes that act as selective barriers and enable compartmentalization of cellular functions.
- Molecules like glucose, glycogen, and fatty acids are central to cellular metabolism. They serve as energy sources, storage molecules, and substrates for metabolic pathways, being important for maintaining cellular energy balance.

Did You Know?

Hydrogen sulfide (H_2S) and water (H_2O) may seem similar in their chemical formulas, but their physical and chemical properties are strikingly different. While water exists as a liquid at room temperature due to its ability to form strong hydrogen bonds, H_2S is a gas under the same conditions because sulfur, being much less electronegative than oxygen, cannot form hydrogen bonds. This lack of hydrogen bonding makes H_2S more volatile and less cohesive than water. Interestingly, despite being toxic at high concentrations, H_2S plays a signaling role in cells at very low concentrations, regulating processes like inflammation and vasodilation.



2.3 Practice Questions

2.3.1. Multiple choice

1. Which of the following is a property of water that makes it essential for life?

A	High surface tension
B	Low specific heat capacity
C	Low heat of vaporization
D	Good solvent for polar molecules

2. Which type of bond is responsible for the primary structure of a protein?

A	Hydrogen bond
B	Ionic bond
C	Covalent bond
D	Van der Waals forces

3. Which of the following elements is most abundant in living organisms?

A	Silicon
B	Nitrogen
C	Hydrogen
D	Iron

4. What type of reaction links two monosaccharides to form a disaccharide?

A	Hydrolysis
B	Dehydration synthesis
C	Redox reaction
D	Ionic bonding

5. The formation of a peptide bond involves which of the following groups?

A	Hydroxyl and carboxyl
B	Amino and carboxyl
C	Carbonyl and amino
D	Phosphate and carboxyl

6. Which of the following best describes the function of nucleotides in cells?

A	Energy storage and transmission of genetic information
B	Enzyme catalysis and protein folding
C	Structural support and cell signaling
D	Lipid metabolism and membrane formation

7. Which macromolecule is primarily responsible for catalyzing biochemical reactions in cells?

A	Lipids
B	Nucleic acids
C	Proteins
D	Carbohydrates

8. What type of molecule is primarily used for long-term energy storage in animals?

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|----------|-----------------|
| A | Polysaccharides |
| B | Lipids |
| C | Proteins |
| D | Nucleic acids |

9. What unique role does hydrogen bonding play in the structure and function of nucleic acids compared to other macromolecules?

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|----------|--|
| A | Enabling base pairing for accurate genetic replication and transcription |
| B | Forming covalent bonds that stabilize the sugar-phosphate backbone |
| C | Contributing to the hydrophobic interactions in the double helix |
| D | Catalyzing enzymatic reactions involved in RNA processing |

10. Which chemical property allows phospholipids to form the bilayer structure of cell membranes?

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|----------|---|
| A | Hydrophobic tails and hydrophilic heads |
| B | Covalent bonding of hydrophilic groups |
| C | The presence of a double-bonded oxygen atom |
| D | High boiling point and melting point |

11. Which type of macromolecule is most diverse in terms of structure and function?

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|----------|---------------|
| A | Carbohydrates |
| B | Proteins |
| C | Nucleic acids |
| D | Lipids |

12. What determines the specificity of an enzyme for its substrate?

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|----------|---|
| A | The temperature and pH of the environment |
| B | The active site of the enzyme |
| C | The concentration of the substrate |
| D | The ionic bonds within the enzyme |

13. The unique properties of water molecules are due to which of the following?

- | | |
|----------|----------------------|
| A | Covalent bonding |
| B | Ionic bonding |
| C | Hydrogen bonding |
| D | van der Waals forces |

14. What is the term for a molecule that has both hydrophobic and hydrophilic regions?

A	Amphipathic
B	Hydrophobic
C	Polar
D	Hydrophilic

15. Which of the following is a characteristic of unsaturated fatty acids?

A	Presence of double bonds between carbon atoms
B	Solid at room temperature
C	Found primarily in animal fats
D	Lower melting point than saturated fats

16. Which of the following is true about macromolecules?

A	They are formed by the polymerization of monomers
B	They are always composed of the same types of atoms
C	Their structure is unaffected by environmental changes
D	They are typically found only in prokaryotic cells

17. What determines the three-dimensional shape of a protein?

A	The sequence of amino acids
B	The type of cells producing the protein
C	The pH of the environment
D	The concentration of the protein in the cell

18. Which of the following best describes a bio-polymer?

A	A molecule composed of repeating subunits
B	A molecule made of one single subunit
C	A non-reactive macromolecule
D	A molecule used only for storing energy

19. Which chemical group is always found in amino acids?

A	Phosphate group
B	Methyl group
C	Carboxyl group
D	Hydroxyl group

20. What is the primary role of carbohydrates in the cell?

A	Catalyzing reactions
B	Storing and transferring genetic information
C	Serving as a source of energy
D	Forming structural frameworks in cells

21. Which of the following macromolecules is the most abundant in cells by dry weight?	
A	Proteins
B	Carbohydrates
C	Lipids
D	Nucleic acids

22. What property of carbon makes it the primary element in organic molecules?	
A	Its ability to form ionic bonds with many elements
B	Its electronegativity
C	Its ability to form four covalent bonds
D	Its abundance in the atmosphere

23. Which type of bond is most important for maintaining the secondary structure of proteins?	
A	Ionic bonds
B	Covalent bonds
C	Hydrogen bonds
D	Hydrophobic interactions

24. Which of the following is a distinguishing feature of a phospholipid?	
A	It consists entirely of hydrophobic regions
B	It contains a phosphate group in its hydrophobic tail
C	It has both hydrophilic and hydrophobic regions
D	It contains only saturated fatty acids

25. What type of chemical reaction breaks down polymers into monomers?	
A	Hydrolysis
B	Dehydration synthesis
C	Oxidation-reduction
D	Ionic interaction

26. Which of the following is true regarding the polarity of water?	
A	It is a nonpolar molecule because it does not have a net charge
B	It is polar and its polar nature allows it to form hydrogen bonds
C	It has an equal distribution of charge, making it hydrophobic
D	It does not interact with charged particles

27. Nucleotides are the building blocks of:	
A	Proteins
B	Lipids
C	DNA and RNA
D	Polysaccharides

28. Which of the following macromolecules serves as the primary energy storage in animal cells?

A	Starch
B	Glycogen
C	Cellulose
D	Nucleic acids

29. What type of bond links amino acids in a protein?

A	Glycosidic bond
B	Peptide bond
C	Phosphodiester bond
D	Hydrogen bond

30. What type of bond links galactose and glucose in the molecule of lactose?

A	Peptide bond
B	Glycosidic bond
C	Phosphodiester bond
D	Hydrogen bond

31. Which of the following are true about the similarities between unsaturated fats and saturated fats?

A	Both are triglycerides
B	They are formed from condensation of glycerol and fatty acids with removal of water
C	Hydrolysis of triglycerides produces glycerol and fatty acids.
D	They function as energy store and act as a source of energy for cellular metabolism
E	All of the above

32. For which of the following cholesterol is a precursor ?

A	Vitamin A
B	Steroid hormones
C	Vitamin D
D	All of the above

33. What is the hydrogen to oxygen ratio in carbohydrates?

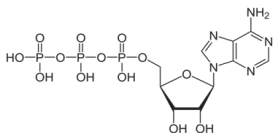
A	1:2
B	2:1
C	2:2
D	3:1

34. In the human alimentary canal, carbohydrate is digested as below: Starch → Maltose → Glucose. Enzyme 1 catalyzes the digestion of starch to maltose and Enzyme 2 the digestion of maltose to glucose. Which of the following combinations describes the Enzymes 1 and 2?

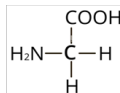
A	Amylase and Lipase
B	Amylase and Maltase
C	Lipase and Pepsin
D	Maltase and Amylase

2.3.2. Comprehension Questions

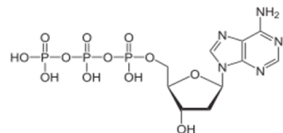
1. Name the type of the following biomolecules and their primary role in the cell:



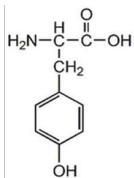
A.



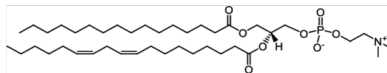
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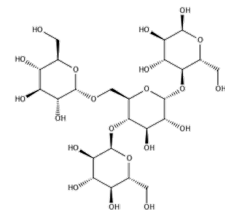
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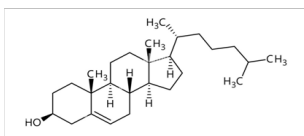
D.



E.



F.



G.

2. Describe the role of hydrogen bonds in maintaining the structure of biological molecules.

3. Explain why carbon is uniquely suited to form large and complex biological molecules.

4. What is the significance of a molecule's three-dimensional shape for its biological function?
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5. Compare the structures and functions of cellulose and glycogen.
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6. Discuss the role of phospholipids in cell membrane formation.
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7. What are the differences between a protein's primary, secondary, and tertiary structures?
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8. Explain why water is an effective solvent for polar molecules.
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9. Describe the process of dehydration synthesis and how it relates to macromolecule formation.
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10. Explain the difference between a saturated and an unsaturated fatty acid.
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11. Fatty acids are said to be amphipathic. What is meant by this term, and how do amphipathic molecules such as fatty acids behave inside the cell?
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12. Briefly describe how enzyme activity can be regulated in cells.
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13. You prepare a solution by dissolving 18 grams of glucose ($C_6H_{12}O_6$) in enough water to make 500 mL of solution. The molecular weight of glucose is 180 g/mol. What is the molarity of the glucose solution?
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14. To create a 1.5 M solution of sodium chloride (NaCl), you measure out 87.75 g of NaCl and dissolve it in water. What final volume of solution (in liters) is required if the molecular weight of NaCl is 58.44 g/mol?
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15. Match the following molecules with their primary function:

A- Glycogen	I- Storage of genetic information
B- Phospholipid	II- Stabilization of cell membranes
C- Enzyme	III - Structural component of cell membranes
D- DNA	IV- Short-term energy storage
E- Cholesterol	V- Catalysis of biochemical reactions

16. Fatty acids are hydrophobic. In what state are they typically found inside the cell?

2.3.3. Critical Thinking Questions

17. A 55-year-old male presents to the clinic with complaints of fatigue and muscle weakness. His medical history reveals a high-fat diet, and lab results show elevated serum triglycerides. Upon examination, the patient's body mass index (BMI) is 32. The physician suspects that his dietary intake has contributed to an imbalance in lipid metabolism. Given this scenario, which of the following biochemical mechanisms is most likely altered in this patient's cells?

- A.** Increased glycolysis due to elevated glucose intake
- B.** Enhanced β -oxidation of fatty acids in the mitochondria
- C.** Decreased formation of acetyl-CoA from fatty acids
- D.** Increased synthesis of fatty acids in the liver
- E.** Decreased incorporation of fatty acids into cell membranes

18. A 32-year-old woman presents to the emergency department with confusion, tachycardia, and severe dehydration. She has a known history of diabetes mellitus type 1 and admits to neglecting her insulin injections for the past 3 days. Laboratory results show elevated blood glucose levels and the presence of ketones in the blood and urine. Which of the following best explains the underlying biochemical pathway contributing to her current condition?

- A.** Increased glycogen synthesis and decreased gluconeogenesis
 - B.** Decreased fatty acid oxidation and enhanced lipogenesis
 - C.** Increased breakdown of fatty acids and production of ketone bodies
 - D.** Increased glucose uptake by cells and inhibition of lipolysis
 - E.** Enhanced glycolysis and decreased oxidative phosphorylation
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