Chapter 10: Biomolecules

Exercises — Exercises

Q1 What are monosaccharides?

SOLUTION

Monosaccharides are the simplest carbohydrates that cannot be hydrolysed further into smaller polyhydroxy aldehyde or ketone units.

They are the basic (monomeric) building blocks of all carbohydrates.

They are classified based on:

(a) The number of carbon atoms present — trioses (3C), tetroses (4C), pentoses (5C), hexoses (6C), heptoses (7C).

(b) The type of carbonyl group present — aldoses (contain an aldehyde group, –CHO) or ketoses (contain a keto group, C=O).

All monosaccharides are reducing sugars — they reduce Fehling's solution and Tollens' reagent.

Examples: glucose (aldohexose), fructose (ketohexose), ribose (aldopentose), 2-deoxyribose (aldopentose).

Answer: Monosaccharides are the simplest carbohydrates that cannot be hydrolysed further into simpler polyhydroxy aldehyde or ketone units. About 20 monosaccharides are known in nature; common examples are glucose, fructose, and ribose.

Q2 What are reducing sugars?

SOLUTION

Reducing sugars are carbohydrates that reduce Fehling's solution (a blue alkaline solution of cupric ions, Cu^{2+}) to a brick-red precipitate of cuprous oxide (Cu_2O), and reduce Tollens' reagent (ammoniacal silver nitrate) to give a silver mirror.

A carbohydrate is a reducing sugar if it has a free aldehydic (–CHO) or ketonic (C=O) group that can act as a reducing agent under alkaline conditions.

All monosaccharides (whether aldoses or ketoses) are reducing sugars.

Among disaccharides, maltose and lactose are reducing sugars because they have a free anomeric –OH group (i.e., a potential free –CHO).

Sucrose is a non-reducing sugar because both the anomeric carbons of glucose and fructose are involved in the glycosidic bond, leaving no free –CHO or

reducible C=O group.

Polysaccharides such as starch and cellulose are non-reducing sugars.

Answer: Reducing sugars are carbohydrates that reduce Fehling's solution and Tollens' reagent. They contain a free aldehydic or ketonic group capable of acting as a reducing agent. All monosaccharides and disaccharides such as maltose and lactose are reducing sugars. Sucrose is a non-reducing sugar.

Q3 Write two main functions of carbohydrates in plants.

SOLUTION

Two main functions of carbohydrates in plants are:

1. Storage of energy: Starch is the main storage polysaccharide in plants. It is formed from glucose produced during photosynthesis and stored in seeds, tubers, roots, and other plant parts. It serves as a reserve food material that can be mobilised when required.

2. Structural support (building material): Cellulose is a polysaccharide that forms the cell wall of plant cells. It provides mechanical strength and rigidity to the cell wall, maintaining the shape and structure of plant cells. Plants also use cellulose to build fibres used for structural support.

Answer: (1) Carbohydrates (as starch) serve as the main food storage material in plants, providing energy when needed. (2) Carbohydrates (as cellulose) form the structural material (cell wall) of plant cells, providing mechanical support and rigidity.

Q4 Classify the following into monosaccharides and disaccharides. Ribose, 2-deoxyribose, maltose, galactose, fructose and lactose.

SOLUTION

Classification:

Monosaccharides (cannot be hydrolysed into simpler sugar units):

1. Ribose — aldopentose (5C), present in RNA
2. 2-Deoxyribose — aldopentose (5C), present in DNA (lacks –OH at C-2)
3. Galactose — aldohexose (6C), obtained on hydrolysis of lactose
4. Fructose — ketohexose (6C), found in fruits and honey

Disaccharides (yield two monosaccharide units on hydrolysis):

1. Maltose — yields 2 molecules of D-glucose (alpha-1,4-glycosidic linkage)

2. Lactose — yields 1 molecule of D-galactose and 1 molecule of D-glucose (beta-1,4-glycosidic linkage)

Answer: Monosaccharides: Ribose, 2-deoxyribose, galactose, fructose. Disaccharides: Maltose, lactose.

Q5 What do you understand by the term glycosidic linkage?

SOLUTION

A glycosidic linkage is the oxide (ether-type) linkage that joins two monosaccharide units together in oligo- and polysaccharides.

It is formed by the condensation reaction between the anomeric hydroxyl group (–OH on the anomeric carbon, C-1 for aldoses or C-2 for fructose) of one monosaccharide and a hydroxyl group of another monosaccharide, with the elimination of one molecule of water.

The oxygen atom serves as the bridge between the two sugar units: $Sugar_1–O–Sugar_2$.

The position and configuration (alpha or beta) of the glycosidic bond determines the properties of the resulting carbohydrate.

Examples:

• Sucrose: alpha-1,2-glycosidic linkage between C-1 of alpha-D-glucose and C-2 of beta-D-fructose.

• Maltose: alpha-1,4-glycosidic linkage between C-1 of one alpha-D-glucose and C-4 of the next alpha-D-glucose.

• Lactose: beta-1,4-glycosidic linkage between C-1 of beta-D-galactose and C-4 of beta-D-glucose.

Answer: A glycosidic linkage is an oxide (ether) linkage formed between two monosaccharide units by the condensation of the anomeric –OH group of one sugar with a hydroxyl group of another sugar, with loss of water. It is written as $Sugar_1–O–Sugar_2$, and its type (alpha or beta) and position (e.g., 1,4 or 1,6) define the properties of the carbohydrate formed.

Q6 What is glycogen? How is it different from starch?

SOLUTION

Glycogen:

Glycogen is the storage polysaccharide found in animals (and in yeast and fungi). It is also called animal starch. It is stored mainly in the liver, muscles, and brain. When the body needs glucose, enzymes break glycogen down to release glucose.

Structurally, glycogen is a branched polymer of alpha-D-glucose units, similar to amylopectin (the branched component of starch), but is more highly branched than amylopectin.

Differences between Glycogen and Starch:

1. Occurrence:
   Glycogen: Found in animals (liver, muscles, brain), yeast, and fungi.
   Starch: Found in plants (cereals, roots, tubers, seeds).

2. Structure:
   Glycogen: Highly branched polymer of alpha-D-glucose; branching occurs at C_1–C_6 glycosidic linkage more frequently than in amylopectin.
   Starch: Consists of two components — amylose (linear, C_1–C_4 linkage, water-soluble, 15–20%) and amylopectin (branched, C_1–C_4 main chain and C_1–C_6 at branch points, insoluble, 80–85%).

3. Degree of branching:
   Glycogen: More extensively branched than amylopectin.
   Starch (amylopectin): Less branched than glycogen.

4. Solubility:
   Glycogen: Soluble in water (forms a colloidal suspension).
   Starch: Amylose is water-soluble; amylopectin is insoluble in water.

Answer: Glycogen is the storage polysaccharide in animals, stored in liver and muscles; it is a highly branched polymer of alpha-D-glucose (more branched than amylopectin). Starch is the plant storage polysaccharide consisting of amylose (linear) and amylopectin (branched). Key differences: glycogen occurs in animals, starch in plants; glycogen is more extensively branched than amylopectin; glycogen is water-soluble, while amylopectin (the major starch component) is not.

Q7 What are the hydrolysis products of (i) sucrose and (ii) lactose?

SOLUTION

(i) Hydrolysis of sucrose:

Sucrose ($C_{12}H_{22}O_{11}$) on hydrolysis with dilute acid (HCl or H_2SO_4) or with the enzyme sucrase/invertase gives:

$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$

Sucrose Glucose Fructose

Products: one molecule of D-(+)-glucose (aldohexose) and one molecule of D-(-)-fructose (ketohexose).

The mixture is called invert sugar because the sign of optical rotation changes from dextro (+) to laevo (-) upon hydrolysis.

(ii) Hydrolysis of lactose:

Lactose ($C_{12}H_{22}O_{11}$) on hydrolysis with dilute acid or with the enzyme lactase gives:

$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$

Lactose Galactose Glucose

Products: one molecule of beta-D-galactose (aldohexose) and one molecule of beta-D-glucose (aldohexose).

Answer: (i) Sucrose on hydrolysis gives D-(+)-glucose and D-(-)-fructose (one molecule each). (ii) Lactose on hydrolysis gives beta-D-galactose and beta-D-glucose (one molecule each).

Q8 What is the basic structural difference between starch and cellulose?

SOLUTION

Both starch and cellulose are polysaccharides made up entirely of D-glucose units, but they differ fundamentally in the type of glycosidic linkage joining the glucose units:

Starch:

- Is a polymer of alpha-D-glucose units.
- The glucose units are joined by alpha-1,4-glycosidic linkage in the linear (amylose) component, and by alpha-1,6-glycosidic linkage at the branch points in the branched (amylopectin) component.
- The alpha-1,4-linkage causes the chain to coil into a helical structure.
- Starch can be digested by humans (alpha-amylase enzyme).

Cellulose:

• Is a polymer of beta-D-glucose units.

• The glucose units are joined exclusively by beta-1,4-glycosidic linkage.

• The beta-1,4-linkage causes the chains to be linear and stack in parallel sheets, stabilised by intermolecular hydrogen bonds, giving cellulose its rigidity and strength.

• Cellulose cannot be digested by humans (we lack the cellulase enzyme to hydrolyse beta-1,4-linkages).

Summary: The key difference is the configuration of glucose (alpha in starch vs. beta in cellulose) and hence the type of glycosidic linkage (alpha-1,4 in starch vs. beta-1,4 in cellulose), which leads to completely different three-dimensional structures and biological functions.

Answer: Starch is made of alpha-D-glucose units joined by alpha-1,4-glycosidic linkages (with alpha-1,6 at branch points in amylopectin), giving it a helical/branched structure that is digestible. Cellulose is made of beta-D-glucose units joined by beta-1,4-glycosidic linkages, giving it a linear, sheet-like structure with high tensile strength that humans cannot digest.

Q9 What happens when D-glucose is treated with the following reagents? (i) HI (ii) Bromine water (iii) HNO_3

SOLUTION

(i) Treatment of D-glucose with HI (Hydriodic acid):

On prolonged heating with HI, D-glucose undergoes reduction/deoxygenation. All the –OH groups are replaced and the ring oxygen is also removed, yielding n-hexane (n-hexyl iodide as an intermediate, finally giving hexane).

D-Glucose + HI (prolonged heating) -> n-Hexane (+ H_2O + I_2 or HI eliminated)

This reaction confirms that all six carbon atoms in glucose are in a straight (unbranched) chain.

(ii) Treatment of D-glucose with Bromine water (mild oxidation):

Bromine water is a mild oxidising agent that selectively oxidises the aldehydic group (–CHO) of glucose without affecting the –OH groups.

$CHO\text{-}(CHOH)_4\text{-}CH_2OH + Br_2/H_2O \rightarrow COOH\text{-}(CHOH)_4\text{-}CH_2OH$

D-Glucose D-Gluconic acid

Product: D-Gluconic acid (a monocarboxylic acid).

This confirms the presence of an aldehydic (–CHO) group in glucose (since bromine water oxidises only aldehydes, not ketones under these conditions).

(iii) Treatment of D-glucose with HNO_3 (concentrated nitric acid, a stronger oxidising agent):

HNO_3 is a stronger oxidant that oxidises both the aldehydic group (–CHO) at C-1 and the primary alcohol group ($–CH_2OH$) at C-6.

$CHO-(CHOH)_4-CH_2OH + HNO_3$ (dil./conc.) -> $COOH-(CHOH)_4-COOH$

D-Glucose Saccharic acid (D-glucaric acid)

Product: Saccharic acid (a dicarboxylic acid, also called glucaric acid).

This reaction confirms the presence of a primary –OH group ($–CH_2OH$) at C-6 of glucose, in addition to the –CHO group.

Answer: (i) With HI: D-Glucose -> n-Hexane (all C–O bonds reduced, confirming a straight 6-carbon chain). (ii) With Bromine water: D-Glucose -> D-Gluconic acid (–CHO oxidised to –COOH; confirms aldehydic group). (iii) With HNO_3: D-Glucose -> Saccharic acid (both –CHO and $–CH_2OH$ oxidised to –COOH; confirms primary alcohol at C-6).

Q10 Enumerate the reactions of D-glucose which cannot be explained by its open chain structure.

SOLUTION

The open chain (Fischer) structure of D-glucose ($CHO-(CHOH)_4-CH_2OH$) cannot explain the following reactions/observations:

1. Absence of Schiff's test: Despite having an aldehydic (–CHO) group, glucose does not give Schiff's test (which detects free aldehydes). The open-chain structure predicts a positive Schiff's test.

2. No addition product with $NaHSO_3$: Glucose does not form a hydrogen sulphite (bisulphite) addition product with $NaHSO_3$, even though aldehydes typically do. The open-chain structure predicts this addition should occur.

3. Pentaacetate does not react with hydroxylamine: The pentaacetate of glucose (formed by acetylation of all five –OH groups) does not react with hydroxylamine (NH_2OH), indicating that there is no free aldehydic group. The open-chain structure predicts reaction with hydroxylamine.

4. Existence of two anomeric forms (alpha and beta): Glucose exists in two crystalline forms — alpha-D-glucose (m.p. 419 K, obtained from concentrated

solution at 303 K) and beta-D-glucose (m.p. 423 K, obtained from hot saturated aqueous solution at 371 K). The open-chain structure cannot account for the existence of these two forms.

These observations are explained by the cyclic (pyranose) hemiacetal structure of glucose, in which the –OH at C-5 adds across the –CHO at C-1 to form a six-membered ring. This eliminates the free –CHO group and creates a new asymmetric centre at C-1 (the anomeric carbon), giving rise to the alpha and beta anomers.

Answer: The following reactions of D-glucose cannot be explained by its open-chain structure: (1) It does not give Schiff's test. (2) It does not form a bisulphite addition product with $NaHSO_3$. (3) Its pentaacetate does not react with hydroxylamine (no free –CHO). (4) It exists in two crystalline anomeric forms (alpha, m.p. 419 K; beta, m.p. 423 K). All are explained by the cyclic hemiacetal (pyranose) structure.

Q11 What are essential and non-essential amino acids? Give two examples of each type.

SOLUTION

Essential amino acids:
These are amino acids that cannot be synthesised in the human body (or are not synthesised in adequate amounts) and therefore must be obtained through diet.
There are 10 essential amino acids (marked with asterisk in NCERT Table 10.2).
Examples: Valine (Val), Leucine (Leu), Isoleucine (Ile), Lysine (Lys), Methionine (Met), Threonine (Thr), Phenylalanine (Phe), Tryptophan (Trp), Arginine (Arg), Histidine (His).
Two examples: Valine and Leucine.

Non-essential amino acids:
These are amino acids that can be synthesised in the human body from other available precursors and so are not required to be supplied through diet.
Examples: Glycine (Gly), Alanine (Ala), Serine (Ser), Aspartic acid (Asp), Glutamic acid (Glu), Tyrosine (Tyr), Cysteine (Cys), Proline (Pro), Asparagine (Asn), Glutamine (Gln).
Two examples: Glycine and Alanine.

Answer: Essential amino acids cannot be synthesised in the body and must be obtained from diet (e.g., Valine, Leucine). Non-essential amino acids can be synthesised in the body and do not need to be supplied through diet (e.g., Glycine, Alanine).

Q12 Define the following as related to proteins: (i) Peptide linkage (ii) Primary structure (iii) Denaturation.

SOLUTION

(i) Peptide linkage:

A peptide linkage (or peptide bond) is the amide linkage formed between the carboxyl group (–COOH) of one amino acid and the amino group ($–NH_2$) of another amino acid, with the elimination of one molecule of water.

The linkage is: –CO–NH– (an amide bond).

For example, when the –COOH of glycine reacts with the $–NH_2$ of alanine:

$H_2N\text{-}CH_2\text{-}COOH + H_2N\text{-}CH(CH_3)\text{-}COOH \rightarrow H_2N\text{-}CH_2\text{-}CO\text{-}NH\text{-}CH(CH_3)\text{-}COOH + H_2O$

Glycine Alanine Glycylalanine (dipeptide)

(ii) Primary structure of proteins:

The primary structure of a protein refers to the specific linear sequence in which amino acids are covalently linked by peptide bonds in a polypeptide chain.

Each protein has a unique, genetically determined sequence of amino acids.

Any change in this sequence (e.g., substitution, insertion, deletion of an amino acid) results in a different protein with different properties — as seen in sickle-cell anaemia where a single amino acid change in haemoglobin changes its function.

(iii) Denaturation of proteins:

Denaturation is the process by which a protein in its native (natural) three-dimensional form loses its biological activity due to disruption of its secondary and/or tertiary structure, without breakage of peptide bonds (so the primary structure remains intact).

Denaturation is caused by physical factors (heat, UV radiation, mechanical shearing) or chemical factors (change in pH, addition of organic solvents, detergents, urea, heavy metal salts).

These factors break the weak interactions (hydrogen bonds, disulphide bonds, electrostatic and van der Waals forces) that maintain the 3D structure.

Examples: coagulation of egg white on boiling (heat denaturation); curdling of milk

by lactic acid bacteria (pH change).

Answer: (i) Peptide linkage: amide bond (–CO–NH–) formed by condensation of –COOH of one amino acid with $–NH_2$ of the next, with loss of water. (ii) Primary structure: the unique, specific linear sequence of amino acid residues in a polypeptide chain, connected by peptide bonds. (iii) Denaturation: disruption of the secondary and tertiary structures of a protein (without breaking peptide bonds) by heat or change in pH, causing loss of biological activity (e.g., boiling of egg white, curdling of milk).

Q13 What are the common types of secondary structure of proteins?

SOLUTION

The secondary structure of a protein refers to the regular, localised arrangement (conformation) adopted by portions of the polypeptide chain, stabilised mainly by hydrogen bonds between the –NH– and –C=O– groups of the peptide backbone. The two common types of secondary structure are:

1. alpha-Helix (alpha helix):

• The polypeptide backbone coils into a right-handed (clockwise) helical structure.

• The helix is stabilised by intramolecular hydrogen bonds between the –NH– group of one amino acid residue and the C=O group of the amino acid residue in the next turn of the helix (i.e., 4 residues ahead).

• The side chains (R groups) of amino acids project outward from the helix axis.

• It is the most common secondary structure found in proteins such as keratin (hair, wool) and myosin.

2. beta-Pleated Sheet (beta sheet):

• In this structure, the polypeptide chains are fully extended and run parallel (or antiparallel) to each other.

• The extended chains are stabilised by intermolecular hydrogen bonds between the –NH– and C=O groups of adjacent parallel chains.

• The structure resembles the pleated folds of a draped fabric, hence the name.

• Example: fibroin (silk protein) has a predominantly beta-pleated sheet structure.

Answer: The two common types of secondary structure of proteins are: (1) alpha-Helix — right-handed coil stabilised by intramolecular hydrogen bonds between –NH– and C=O groups within the same chain (4 residues apart). (2) beta-Pleated Sheet — extended polypeptide chains running parallel (or antiparallel), stabilised by intermolecular hydrogen bonds between adjacent chains, giving a pleated sheet-like arrangement.

Q14 What type of bonding helps in stabilising the alpha-helix structure of proteins?

SOLUTION

The alpha-helix structure of proteins is stabilised primarily by hydrogen bonding.

Specifically, intramolecular hydrogen bonds are formed between:

- The –NH– group (hydrogen bond donor) of one amino acid residue
- and the C=O group (hydrogen bond acceptor) of another amino acid residue located 4 residues (one turn) ahead in the same polypeptide chain.

These hydrogen bonds are oriented roughly parallel to the helix axis and run along the backbone of the polypeptide chain as it spirals.

Since every –NH– and C=O group in the main chain (except near the ends of the helix) participates in hydrogen bonding, the large number of hydrogen bonds collectively provide significant stability to the helical structure, even though each individual hydrogen bond is relatively weak.

The R (side chain) groups of the amino acids project outward from the helix and do not participate in the helical hydrogen bonding.

Answer: The alpha-helix structure of proteins is stabilised by intramolecular hydrogen bonds, formed between the –NH– group of one amino acid residue and the C=O group of the amino acid residue four positions ahead in the same polypeptide chain. These bonds run parallel to the helix axis and hold the coiled backbone in its characteristic right-handed helical conformation.

Q15 Differentiate between globular and fibrous proteins.

SOLUTION

Differences between Globular and Fibrous proteins:

1. Shape/Structure:

Fibrous proteins: Polypeptide chains run parallel and are held together by

hydrogen and disulphide bonds, forming long, fibre-like (thread-like) structures.

Globular proteins: Polypeptide chains are tightly folded and coiled around to give a compact, spherical (globular) shape.

2. Solubility in water:

Fibrous proteins: Generally insoluble in water.

Globular proteins: Usually soluble in water (form colloidal solutions).

3. Function:

Fibrous proteins: Mainly structural (provide mechanical strength and support). They form structural materials in cells and tissues.

Globular proteins: Mainly dynamic/functional — they act as enzymes, hormones, antibodies, oxygen carriers, etc.

4. Examples:

Fibrous proteins: Keratin (hair, nails, wool, silk), myosin (muscles), collagen (connective tissue), fibrin (blood clotting).

Globular proteins: Insulin (hormone), haemoglobin (oxygen transport), albumin (blood plasma protein), enzymes such as amylase.

Answer: Fibrous proteins: polypeptide chains run parallel, held by H-bonds and disulphide bonds into long fibre-like structures; generally insoluble in water; serve structural roles (e.g., keratin, myosin, collagen). Globular proteins: polypeptide chains coil into compact spherical shapes; usually water-soluble; serve functional roles as enzymes, hormones, and antibodies (e.g., insulin, haemoglobin, albumin).

Q16 How do you explain the amphoteric behaviour of amino acids?

SOLUTION

Amino acids contain both an acidic carboxyl group (–COOH) and a basic amino group ($–NH_2$) in the same molecule.

In aqueous solution, an intramolecular proton (H^+) transfer occurs:

• The –COOH group donates a proton (H^+) and becomes $–COO^-$ (acts as an acid).

• The $–NH_2$ group accepts the proton and becomes $–NH_3^+$ (acts as a base).

This produces a dipolar ion called a Zwitter ion (or zwitterion):

H_3N^+-CH(R)-COO^-

The Zwitter ion is electrically neutral overall but carries both a positive and a negative charge.

Amphoteric behaviour:

- In acidic medium (low pH): The Zwitter ion accepts a proton on $–COO^-$:
  $H_3N^+-CH(R)-COO^- + H^+ \rightarrow H_3N^+-CH(R)-COOH$
  The amino acid acts as a base (proton acceptor).
- In basic medium (high pH): The Zwitter ion loses a proton from $–NH_3^+$:
  $H_3N^+-CH(R)-COO^- + OH^- \rightarrow H_2N-CH(R)-COO^- + H_2O$
  The amino acid acts as an acid (proton donor).

Thus, amino acids can react with both acids and bases — they are amphoteric.

Answer: Amino acids contain both an acidic –COOH group and a basic $–NH_2$ group. In aqueous solution they exist as Zwitter ions ($H_3N^+-CH(R)-COO^-$). In acidic medium the $–COO^-$ accepts H^+ (amino acid acts as a base); in basic medium the $–NH_3^+$ donates H^+ (amino acid acts as an acid). This dual proton-donor/acceptor capacity makes amino acids amphoteric.

Q17 What are enzymes?

SOLUTION

Enzymes are biological catalysts (biocatalysts) produced by living cells that catalyse and regulate the specific chemical reactions taking place in living organisms.

Key features of enzymes:

1. Chemical nature: Almost all enzymes are globular proteins (a few are RNA molecules, called ribozymes).
2. High efficiency: They are needed only in small (catalytic) amounts and can increase reaction rates dramatically — often by 10^6 to 10^{17} times compared to uncatalysed reactions.
3. High specificity: Each enzyme is specific for a particular substrate (the substance it acts on) and for a particular type of reaction — the 'lock and key' or 'induced fit' model explains this specificity.
4. Mode of action: Enzymes work by reducing the activation energy of the reaction, thereby enabling the reaction to proceed under the mild conditions (body temperature, neutral pH) of living systems.
5. Naming: Enzymes are generally named after the substrate they act on or the reaction they catalyse, with the suffix '-ase' (e.g., maltase acts on maltose; oxidoreductase catalyses oxidation-reduction reactions).

Example: Maltase catalyses the hydrolysis of maltose to glucose:
Maltose + H_2O --[maltase]--> 2 Glucose

Answer: Enzymes are biological catalysts (biocatalysts) — almost all are globular proteins — that speed up specific chemical reactions in living systems by reducing the activation energy. They are highly specific (one enzyme, one substrate), needed in small amounts, and work under mild physiological conditions. They are named after their substrate or reaction type with the suffix '-ase' (e.g., maltase, lactase).

Q18 What is the effect of denaturation on the structure of proteins?

SOLUTION

Denaturation is the process by which a protein loses its native three-dimensional conformation and biological activity due to the disruption of the non-covalent interactions (and sometimes disulphide bonds) that maintain its higher-order structure.

Effect on each level of protein structure:

1. Primary structure: Remains INTACT. Peptide bonds (covalent bonds linking amino acids) are not broken during denaturation.

2. Secondary structure: DESTROYED. The hydrogen bonds between –NH– and C=O groups of the peptide backbone that stabilise the alpha-helix or beta-pleated sheet are broken. The helix uncoils and the pleated sheet unfolds.

3. Tertiary structure: DESTROYED. The three-dimensional folding held together by hydrogen bonds, disulphide bridges, electrostatic (ionic) interactions, and van der Waals forces collapses. Globular proteins unfold; the native compact shape is lost.

4. Quaternary structure (if present): DESTROYED. The non-covalent associations between subunits are disrupted, causing the protein to dissociate into its constituent polypeptide chains.

Net result: The protein loses its specific three-dimensional shape, becomes a random coil (or aggregate), and loses its biological activity (enzymatic, hormonal, structural, etc.). The process is generally irreversible under extreme conditions (e.g., cooked egg white cannot revert to raw).

Examples: Boiling an egg (albumin coagulates), curdling of milk (casein precipitates due to pH drop).

Answer: Denaturation destroys the secondary and tertiary (and quaternary) structures of a protein by breaking hydrogen bonds, disulphide bridges, electrostatic and van der Waals interactions, causing the protein to unfold and lose its biological activity. The primary structure (peptide bond sequence) remains intact. Examples: coagulation of egg white on boiling; curdling of milk.

Q19 How are vitamins classified? Name the vitamin responsible for the coagulation of blood.

SOLUTION

Classification of vitamins:

Vitamins are classified into two groups based on their solubility:

1. Fat-soluble vitamins:
   - Vitamins A, D, E, and K.
   - They are soluble in fats and oils but insoluble in water.
   - They can be stored in the body (liver and adipose tissues), so their deficiency takes longer to develop.
   - Excess accumulation can be toxic (hypervitaminosis).

2. Water-soluble vitamins:
   - B group vitamins (B_1/Thiamine, B_2/Riboflavin, B_6/Pyridoxine, B_{12}/Cobalamin) and Vitamin C (Ascorbic acid).
   - They are soluble in water.
   - They are readily excreted in urine and cannot be stored in the body (except vitamin B_{12}), so they must be supplied regularly in the diet.

Vitamin responsible for blood coagulation:

Vitamin K is responsible for the coagulation (clotting) of blood.

It is required for the synthesis of prothrombin and other clotting factors in the liver.

Deficiency of vitamin K leads to increased blood clotting time (the blood takes longer to clot, increasing the risk of excessive bleeding).

Answer: Vitamins are classified as (1) Fat-soluble: vitamins A, D, E, and K — soluble in fats/oils, stored in body tissues. (2) Water-soluble: B group vitamins and vitamin C — soluble in water, cannot be stored (except B_{12}), excreted in urine. Vitamin K is responsible for the coagulation (clotting) of blood; its deficiency increases blood clotting time.

Q20 Why are vitamin A and vitamin C essential to us? Give their important sources.

SOLUTION

Vitamin A:

Importance/Function:

• Essential for normal vision, particularly in dim light (night vision), as it is a component of the visual pigment rhodopsin.

• Required for the maintenance of healthy epithelial tissues (skin, mucous membranes).

• Supports normal growth and development.

• Deficiency causes: Night blindness (nyctalopia) and Xerophthalmia (hardening and drying of the cornea, which can lead to blindness).

Sources:

• Fish liver oil (cod liver oil), carrots (beta-carotene is a provitamin A), butter, milk, egg yolk, green and yellow vegetables.

Vitamin C (Ascorbic acid):

Importance/Function:

• Essential for the synthesis of collagen (the structural protein of connective tissue, cartilage, bones, and gums).

• Acts as a powerful water-soluble antioxidant, protecting cells from oxidative damage.

• Required for the absorption of iron from the diet.

• Supports immune function.

• Deficiency causes: Scurvy — characterised by bleeding gums, loss of teeth, poor wound healing, and skin haemorrhages.

• It is a water-soluble vitamin and cannot be stored in the body, so daily dietary intake is essential.

Sources:

• Citrus fruits (oranges, lemons, limes), amla (Indian gooseberry, the richest natural source), guava, tomatoes, green leafy vegetables, and capsicums.

Answer: Vitamin A: essential for night vision and maintenance of epithelial tissues; deficiency causes night blindness and xerophthalmia. Sources: fish liver oil, carrots (beta-carotene), butter, milk. Vitamin C (ascorbic acid): essential for collagen synthesis and immune function; not stored in the body; deficiency causes scurvy (bleeding gums). Sources: citrus fruits, amla, green leafy vegetables.

Q21 What are nucleic acids? Mention their two important functions.

SOLUTION

Nucleic acids are high-molecular-mass biomolecules (polynucleotides) found in the nucleus of all living cells. They are polymers of nucleotide monomers linked by phosphodiester bonds.

Complete hydrolysis of a nucleic acid yields:

1. A pentose sugar — 2-deoxyribose (in DNA) or ribose (in RNA)
2. Phosphoric acid (H_3PO_4)
3. Nitrogenous bases — purines (adenine, guanine) and pyrimidines (cytosine, thymine in DNA; cytosine, uracil in RNA)

There are two types: Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA).

Two important functions of nucleic acids:

1. Storage and transmission of genetic information (Heredity):
   DNA is the chemical basis of heredity. It stores all the genetic information that determines the characteristics of an organism and transfers this information from parents to offspring during reproduction. Identical copies of DNA are transmitted to daughter cells during cell division.

2. Protein synthesis (Gene expression):
   The sequence of bases in DNA carries the coded message (genetic code) for the synthesis of specific proteins. RNA molecules (mRNA, tRNA, rRNA) carry out the actual protein synthesis: mRNA carries the message from DNA to the ribosomes; tRNA brings the correct amino acids; rRNA forms part of the ribosome machinery.

Answer: Nucleic acids are polynucleotide biomolecules (DNA and RNA) that store and transmit genetic information. Two important functions: (1) DNA stores genetic information and transmits it to daughter cells during cell division (heredity). (2) Nucleic acids (DNA via RNA intermediates) direct the synthesis of specific proteins in the cell (protein synthesis / gene expression).

Q22 What is the difference between a nucleoside and a nucleotide?

SOLUTION

Nucleoside:

• A nucleoside is formed by the attachment (N-glycosidic bond) of a nitrogenous base to the 1'-position of a pentose sugar.

• Composition: Base + Pentose sugar only.
• Formula: Base–Sugar (no phosphate group).
• Examples: Adenosine (adenine + ribose), Deoxyadenosine (adenine + deoxyribose), Thymidine (thymine + deoxyribose).

Nucleotide:
• A nucleotide is formed when a nucleoside is further esterified by a phosphoric acid molecule at the 5'-position of the pentose sugar.
• Composition: Base + Pentose sugar + Phosphate group.
• Formula: Base–Sugar–Phosphate.
• Nucleotides are the monomeric units of nucleic acids (DNA and RNA).
• Examples: Adenosine 5'-monophosphate (AMP), Deoxyadenosine 5'-monophosphate (dAMP), Thymidine 5'-monophosphate (TMP/dTMP).

Key difference: A nucleotide is a nucleoside with a phosphate group (monophosphate, diphosphate, or triphosphate) attached at the 5' carbon of the sugar. A nucleoside lacks the phosphate group.

Answer: Nucleoside = nitrogenous base + pentose sugar (no phosphate). Nucleotide = nitrogenous base + pentose sugar + phosphate group (phosphate esterified at 5' carbon of sugar). A nucleotide is a phosphorylated nucleoside; it is the monomer of nucleic acids. Example: Adenosine (nucleoside) vs. Adenosine-5'-monophosphate/AMP (nucleotide).

Q23 The two strands in DNA are not identical but are complementary. Explain.

SOLUTION

In the Watson–Crick double helix model of DNA, the two polynucleotide strands run antiparallel (one runs 5'->3' and the other runs 3'->5') and are held together by hydrogen bonds between pairs of nitrogenous bases — one base from each strand.

The base pairing is highly specific (Chargaff's rules):
• Adenine (A) on one strand pairs ONLY with Thymine (T) on the other strand, via 2 hydrogen bonds: A – – T
• Guanine (G) on one strand pairs ONLY with Cytosine (C) on the other strand, via 3 hydrogen bonds: G ≡ C

Complementarity explained:
If one strand has the base sequence: 5'–A–T–G–C–T–A–3'

The complementary strand must be: 3'–T–A–C–G–A–T–5'

• The two strands are NOT identical because their base sequences are different (A on one strand pairs with T on the other — they are not the same).

• The two strands ARE complementary because each base on one strand determines the base on the other strand by the specific A–T and G–C pairing rules.

This complementarity is the molecular basis of:

1. DNA replication — each strand serves as a template to synthesise an identical new double-stranded DNA.
2. Transcription — the template strand directs synthesis of a complementary mRNA.

Chargaff's rule confirms this: [A] = [T] and [G] = [C] in double-stranded DNA.

Answer: In the DNA double helix, the two antiparallel strands are held by specific hydrogen bonds: A pairs only with T (2 H-bonds) and G pairs only with C (3 H-bonds). Because of this base-pairing rule, the sequence of each strand is uniquely determined by (but different from) the other — they are complementary, not identical. This complementarity enables faithful DNA replication and transcription.

Q24 Write the important structural and functional differences between DNA and RNA.

SOLUTION

Differences between DNA and RNA:

Structural differences:

1. Sugar:

DNA: Contains 2-deoxyribose (beta-D-2-deoxyribose) — lacks –OH at C-2' of the sugar.

RNA: Contains ribose (beta-D-ribose) — has –OH at C-2' of the sugar.

2. Nitrogenous bases:

DNA: Adenine (A), Guanine (G), Cytosine (C), Thymine (T).

RNA: Adenine (A), Guanine (G), Cytosine (C), Uracil (U) — uracil replaces thymine.

3. Strand structure:

DNA: Double-stranded — two antiparallel polynucleotide chains wound in a right-handed double helix.

RNA: Single-stranded — one polynucleotide chain (may fold back on itself in tRNA).

4. Stability:

DNA: More stable (due to absence of the 2'-OH group and double-stranded structure).

RNA: Less stable (the 2'-OH makes it more susceptible to hydrolysis under alkaline conditions).

5. Base pairing:

DNA: A–T (2 H-bonds) and G–C (3 H-bonds) in the double helix.

RNA: A–U (2 H-bonds) and G–C (3 H-bonds, in folded regions).

Functional differences:

1. Primary function:

DNA: Stores and transmits genetic information (heredity); acts as the template for its own replication and for transcription (making RNA).

RNA: Carries out protein synthesis — mRNA carries the genetic message from DNA to ribosomes; tRNA brings amino acids; rRNA forms the ribosome.

2. Location:

DNA: Mainly confined to the nucleus (also in mitochondria and chloroplasts).

RNA: Present mainly in the cytoplasm (also nucleus).

3. Amount in cell:

DNA: Amount is constant per cell (for a given species/cell type).

RNA: Amount varies depending on the metabolic activity of the cell.

4. Self-replication:

DNA: Can replicate itself (self-duplication during cell division).

RNA: Cannot self-replicate (except in some viruses with RNA-dependent RNA polymerase).

Answer: Structural: DNA has 2-deoxyribose; RNA has ribose. DNA contains thymine; RNA has uracil. DNA is double-stranded; RNA is single-stranded. DNA is more stable. Functional: DNA stores and transmits genetic information (heredity) and is the template for transcription. RNA executes protein synthesis — mRNA carries the code, tRNA brings amino acids, rRNA forms ribosomes. DNA can self-replicate; RNA generally cannot.

Q25 What are the different types of RNA found in the cell?

SOLUTION

Three main types of RNA are found in the cell, each with a distinct role in protein synthesis:

1. Messenger RNA (mRNA):

• Carries the genetic information (message) from DNA in the nucleus to the ribosomes in the cytoplasm.

• The sequence of codons (3-base triplets) on mRNA specifies the sequence of amino acids in the protein to be synthesised.

• mRNA is a single-stranded, linear molecule synthesised by transcription of the template strand of DNA.

• It is directly translated by ribosomes into protein.

2. Ribosomal RNA (rRNA):

• The most abundant type of RNA in the cell (makes up about 80% of total cellular RNA).

• It is a structural and functional component of ribosomes — the molecular machines where protein synthesis takes place.

• Along with ribosomal proteins, rRNA forms the two subunits of the ribosome and catalyses the formation of peptide bonds (peptidyl transferase activity of the large rRNA is ribozyme activity).

3. Transfer RNA (tRNA):

• The smallest of the three types of RNA; has a characteristic cloverleaf secondary structure (due to intramolecular base pairing).

• Acts as the 'adaptor' molecule: it carries specific amino acids (attached at its 3' CCA end) to the ribosome and recognises the corresponding codon on mRNA via its anticodon loop.

• There is at least one specific tRNA for each of the 20 amino acids.

• It ensures that the correct amino acid is incorporated at each position during translation.

Answer: Three types of RNA are found in cells: (1) mRNA (messenger RNA) — carries the genetic code from DNA to ribosomes, serving as the template for translation. (2) rRNA (ribosomal RNA) — the major structural and catalytic component of ribosomes. (3) tRNA (transfer RNA) — smallest RNA, with a cloverleaf structure; carries specific amino acids to the ribosome and recognises mRNA codons via its anticodon, ensuring correct amino acid incorporation during protein synthesis.