Chapter 9: Biomolecules

Exercises — Exercises

Q1 What are macromolecules? Give examples.

SOLUTION

Macromolecules (biomacromolecules) are large molecular weight compounds found in living organisms. They are generally found in the acid-insoluble fraction when living tissue is ground in trichloroacetic acid.

Key features:
1. Molecular weight is typically in the range of ten thousand daltons (10,000 Da) and above.
2. They are polymeric in nature — made up of repeating monomer units (with the exception of lipids).
3. They form the structural and functional backbone of cells.

The four classes of biomacromolecules are:
- Proteins: polymers of amino acids (e.g., haemoglobin, insulin, collagen, enzymes)
- Polysaccharides (complex carbohydrates): polymers of monosaccharides (e.g., starch, glycogen, cellulose, chitin)
- Nucleic acids: polynucleotides (e.g., DNA and RNA)
- Lipids: though not strictly macromolecules (individual molecules are <800 Da), they are grouped here because membrane fragments appear in the acid-insoluble fraction

Answer: Macromolecules are large polymeric biomolecules (mol. wt. >= 10,000 Da) found in the acid-insoluble fraction of living tissue. Examples: proteins (haemoglobin, collagen), polysaccharides (starch, cellulose, glycogen), and nucleic acids (DNA, RNA).

Q2 What is meant by tertiary structure of proteins?

SOLUTION

Proteins can be described at four structural levels — primary, secondary, tertiary, and quaternary.

Tertiary structure refers to the three-dimensional folding of the entire polypeptide

chain upon itself.

Key points:
1. After the polypeptide adopts secondary structures (alpha-helices and beta-pleated sheets in specific regions), the whole chain folds further into a compact, globular or fibrous 3D shape.
2. This folding is stabilised by various interactions: hydrogen bonds, disulphide bonds (between cysteine residues), hydrophobic interactions, ionic interactions, and van der Waals forces.
3. The tertiary structure creates specific three-dimensional pockets or crevices, one of which is the 'active site' in enzyme proteins.
4. Tertiary structure is absolutely necessary for the biological activity of a protein. If it is disrupted (denaturation), the protein loses its function.

Example: The tertiary structure of an enzyme like lysozyme determines the exact shape of its active site, enabling it to bind and cleave its specific substrate.

Answer: Tertiary structure is the overall three-dimensional folding of the entire polypeptide chain upon itself, stabilised by hydrogen bonds, disulphide bonds, and hydrophobic interactions. It determines the protein's biological activity and creates the active site in enzymes.

Q3 Find and write down structures of 10 interesting small molecular weight biomolecules. Find if there is any industry which manufactures the compounds by isolation. Find out who are the buyers.

SOLUTION

This is a project/activity-based question requiring library or internet research. Below are 10 important small molecular weight biomolecules (mol. wt. < 1000 Da), their general structures, and relevant industrial information:

1. Glucose ($C_6H_{12}O_6$) — Aldohexose sugar; ring form with 6C. Industry: Corn wet milling, fermentation. Buyers: food & beverage, pharma (IV drips).
2. Glycine ($C_2H_5NO_2$) — Simplest amino acid; $H_2N\text{-}CH_2\text{-}COOH$. Industry: Chemical synthesis. Buyers: pharma (antacid), food (seasoning).
3. Adenine ($C_5H_5N_5$) — Purine nitrogen base; bicyclic ring with two N-containing rings. Industry: Fermentation/synthesis. Buyers: pharma, biochemical research.
4. Cholesterol ($C_{27}H_{46}O$) — Steroid with 4 fused rings and OH group. Industry: Extracted from lanolin (wool fat). Buyers: pharma (precursor for steroid hormones,

vitamin D).

5. Palmitic acid ($C_{16}H_{32}O_2$) — Saturated fatty acid; $CH_3(CH_2)_{14}COOH$. Industry: Palm oil processing. Buyers: soap, cosmetics, food industries.

6. Ribose ($C_5H_{10}O_5$) — Pentose sugar; furanose ring. Industry: Fermentation (from glucose). Buyers: pharma (synthesis of RNA-based drugs, nucleotide supplements).

7. ATP (Adenosine triphosphate, $C_{10}H_{16}N_5O_{13}P_3$) — Nucleotide with adenine + ribose + 3 phosphate groups. Industry: Microbial fermentation. Buyers: biochemical research, clinical diagnostics.

8. Ascorbic acid / Vitamin C ($C_6H_8O_6$) — Lactone ring with enediol group. Industry: Reichstein synthesis / fermentation. Buyers: food & beverage (antioxidant), pharma (supplement).

9. Urea (CH_4N_2O) — $H_2N\text{-}CO\text{-}NH_2$; simplest nitrogen compound. Industry: Haber process + CO_2 synthesis. Buyers: fertiliser industry, plastics (urea-formaldehyde resins).

10. Nicotinamide ($C_6H_6N_2O$) — Pyridine ring with amide group; vitamin B3. Industry: Chemical synthesis. Buyers: pharma (coenzyme precursor NAD/NADP), food fortification.

Answer: Ten small biomolecules: glucose, glycine, adenine, cholesterol, palmitic acid, ribose, ATP, ascorbic acid, urea, and nicotinamide. Each is manufactured by dedicated industries (food processing, pharma synthesis, fermentation) and purchased by food, pharmaceutical, and chemical industries.

Q4 Find out and make a list of proteins used as therapeutic agents. Find other applications of proteins (e.g., Cosmetics etc.)

SOLUTION

This is an activity-based question requiring research. Below are proteins used as therapeutic agents and other applications:

Proteins as therapeutic agents:

1. Insulin — Treats Type 1 diabetes mellitus (recombinant human insulin, e.g., Humulin).

2. Erythropoietin (EPO) — Treats anaemia associated with chronic kidney disease.

3. Human Growth Hormone (hGH / Somatotropin) — Treats growth hormone deficiency in children.

4. Interferons (IFN-alpha, IFN-beta) — Antiviral and anticancer therapies.
5. Monoclonal antibodies (e.g., Herceptin/trastuzumab) — Cancer immunotherapy.
6. Streptokinase / Tissue Plasminogen Activator (tPA) — Dissolve blood clots in myocardial infarction (thrombolytics).
7. Factor VIII — Treats haemophilia A (blood clotting disorder).
8. Vaccines (subunit proteins) — e.g., Hepatitis B surface antigen (HBsAg) vaccine.

Other applications of proteins:
- Cosmetics: Keratin in hair straightening treatments; collagen and elastin in anti-aging skin creams.
- Food industry: Casein in cheese making; gluten in baking; gelatin in jellies.
- Textiles: Silk (fibroin) and wool (keratin) are structural proteins used in fabrics.
- Biotechnology: Enzymes (proteases, amylases, lipases) used as industrial catalysts in detergents, leather processing, and paper industry.
- Research: Antibodies used as laboratory diagnostic tools (ELISA, Western blot).

Answer: Therapeutic proteins include insulin, erythropoietin, growth hormone, interferons, monoclonal antibodies, streptokinase, and Factor VIII. Other applications: cosmetics (collagen, keratin), food (casein, gluten, gelatin), textiles (silk fibroin, wool keratin), and industrial enzymes (detergents, leather).

Q5 Explain the composition of triglyceride.

SOLUTION

A triglyceride (also called triacylglycerol) is a type of lipid composed of:

1. Glycerol backbone:
   - Glycerol is a trihydroxy compound (trihydroxy propane) with 3 carbon atoms, each bearing a hydroxyl (-OH) group.

2. Three fatty acid chains:
   - Three fatty acid molecules are esterified to the three -OH groups of glycerol through ester bonds.
   - The fatty acids (R1, R2, R3) may be the same (simple triglyceride) or different (mixed triglyceride).
   - Each fatty acid has a carboxyl group (-COOH) attached to a hydrocarbon chain (R group) that can be:

a. Saturated — no C=C double bonds (e.g., palmitic acid, stearic acid)

b. Unsaturated — one or more C=C double bonds (e.g., oleic acid, linoleic acid)

3. Ester linkage:

- The bond formed between the -COOH of a fatty acid and the -OH of glycerol is called an ester bond; water is released in the process (condensation reaction).

Depending on their melting point, triglycerides are called:

- Fats — solid at room temperature (mostly saturated fatty acids, e.g., butter, ghee)
- Oils — liquid at room temperature (mostly unsaturated fatty acids, e.g., gingelly oil, sunflower oil)

Answer: A triglyceride consists of one glycerol molecule esterified with three fatty acid chains via ester bonds. The fatty acids (R1, R2, R3) can be saturated or unsaturated. Triglycerides are called fats (solid) or oils (liquid) depending on their melting point.

Q6 Can you attempt building models of biomolecules using commercially available atomic models (Ball and Stick models).

SOLUTION

This is a hands-on practical activity question.

Ball and Stick models use colour-coded balls (atoms) and sticks (bonds) to represent molecular structures in three dimensions.

Suggested biomolecules to model:

1. Amino acid (e.g., Glycine or Alanine) — model the alpha-carbon with amino (-NH2), carboxyl (-COOH), hydrogen, and R group.
2. Glucose — ring structure (pyranose form) with C, H, and O atoms showing hydroxyl groups.
3. A dipeptide — join two amino acids showing the peptide bond (-CO-NH-) and the release of water.
4. Fatty acid (Palmitic acid) — a long carbon chain with a carboxyl group at one end.
5. Nucleotide (e.g., Adenosine monophosphate) — adenine base + ribose sugar + phosphate group.
6. A short DNA segment — show two complementary bases connected by

hydrogen bonds, with the sugar-phosphate backbone.

Learning outcome: This activity helps visualise bond angles, molecular geometry, and the three-dimensional nature of biomolecules, which is difficult to grasp from flat diagrams alone.

Answer: Ball and Stick atomic models can be used to build and visualise biomolecules in 3D. Suggested models: amino acids (glycine, alanine), glucose (ring form), a dipeptide, palmitic acid, a nucleotide, or a short DNA segment. The activity reinforces understanding of bond angles and molecular geometry.

Q7 Draw the structure of the amino acid, alanine.

SOLUTION

Alanine is a neutral, non-polar alpha-amino acid. Its R group is a methyl group (-CH3).

Structural formula of Alanine (L-alanine):

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      NH2
       |
H -- C -- COOH
       |
      CH3
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Where:
- The central carbon is the alpha-carbon.
- NH2 = amino group (basic group)
- COOH = carboxyl group (acidic group)
- H = hydrogen atom
- CH3 = methyl group (the R group that distinguishes alanine from other amino acids)

Molecular formula: C3H7NO2
IUPAC name: 2-aminopropanoic acid

In zwitterionic form (at physiological pH), alanine exists as: +H3N-CH(CH3)-COO-

Answer: Alanine (C3H7NO2) is an alpha-amino acid with a methyl (-CH3) R group. Its alpha-carbon carries: -NH2 (amino group), -COOH (carboxyl group), -H, and -CH3. At physiological pH it exists as the zwitterion: +H3N-CH(CH3)-COO-.

Q8 What are gums made of? Is Fevicol different?

SOLUTION

Natural gums are complex polysaccharides (secondary metabolites) secreted by plants, usually as a response to injury.

Composition of plant gums:
- They are heteropolysaccharides made of various monosaccharide units and their derivatives.
- Common sugar components include: galactose, arabinose, glucuronic acid, mannose, xylose, and rhamnose.
- The monosaccharide units are joined by glycosidic bonds in branched configurations.
- Examples: Gum arabic (from Acacia senegal), gum tragacanth (from Astragalus), guar gum, locust bean gum.
- Gum arabic, for instance, is a complex branched polysaccharide made largely of galactose, arabinose, rhamnose, and glucuronic acid.

Fevicol — Is it different?
- Yes, Fevicol is entirely different from natural gums.
- Fevicol is a synthetic polymer adhesive — specifically a polyvinyl acetate (PVA) emulsion.
- It is not a biological macromolecule and has no carbohydrate component.
- Fevicol is manufactured chemically and works by forming a strong polymer film upon drying.

In summary: Natural gums are biological polysaccharides (carbohydrates); Fevicol is a synthetic PVA polymer with no structural resemblance to gums.

Answer: Natural plant gums are branched heteropolysaccharides (e.g., galactose, arabinose, glucuronic acid units) secreted by plants in response to injury. Fevicol is entirely different — it is a synthetic polyvinyl acetate (PVA) emulsion and not a biological molecule.

Q9 Find out a qualitative test for proteins, fats and oils, amino acids and test any fruit juice, saliva, sweat and urine for them.

SOLUTION

This is a laboratory activity question. Below are the standard qualitative tests:

1. Test for Proteins — Biuret Test:
- Add sodium hydroxide (NaOH) solution and a few drops of dilute copper sulphate ($CuSO_4$) to the sample.
- A violet / purple colour indicates the presence of peptide bonds (proteins).
- Ninhydrin test also detects proteins and free amino acids (purple/violet colour).

2. Test for Amino Acids — Ninhydrin Test:
- Heat the sample with ninhydrin reagent.
- A purple (Ruhemann's purple) colour indicates free amino acids.
- (Proline gives a yellow colour.)

3. Test for Fats and Oils — Sudan III / Grease spot test:
- Sudan III or Sudan IV stain: fats stain red-orange.
- Grease spot test: rub sample on paper; a translucent (greasy) spot that does not evaporate indicates fat/oil.
- Emulsification test: fats form an emulsion when shaken with water + a drop of soap solution.

Expected results for common samples:
- Fruit juice (e.g., orange juice): Biuret — negative (no protein); may give positive for reducing sugars. Amino acids — trace positive (ninhydrin).
- Saliva: Biuret — faintly positive (salivary amylase, mucin); no fat; ninhydrin — trace positive.
- Sweat: Biuret — weakly positive (trace proteins); ninhydrin — positive (amino acids and urea).
- Urine (normal): Biuret — negative (protein-free in healthy individuals); ninhydrin — faintly positive (amino acids); Sudan — negative.

Note: This is a practical activity — students should perform these tests carefully under teacher supervision.

Answer: Proteins: Biuret test (violet with NaOH + $CuSO_4$). Amino acids: Ninhydrin test (purple colour). Fats/oils: Sudan III stain (red-orange) or grease spot test. Saliva and sweat test faintly positive for proteins/amino acids; fruit juice is negative for protein; normal urine is protein-free.

Q10 Find out how much cellulose is made by all the plants in the biosphere and compare it with how much of paper is manufactured by man and hence what is the consumption of plant material by man annually. What a loss of vegetation!

SOLUTION

This is a research and estimation activity question. Below are approximate global figures (based on published scientific estimates):

Cellulose production by plants:
- Plants are the primary producers of cellulose on Earth.
- Estimates suggest that approximately 100 billion (10^11) tonnes of cellulose are synthesised annually by all plants in the biosphere.
- This makes cellulose the most abundant organic polymer on Earth.

Paper manufacturing by humans:
- Global paper and paperboard production is approximately 400–420 million tonnes per year (recent decades).
- Producing 1 tonne of paper requires approximately 2–3 tonnes of wood (raw plant material).
- Therefore, global paper manufacturing consumes roughly 800 million to 1.2 billion tonnes of plant biomass annually.

Comparison and implications:
- Human paper consumption uses roughly 0.8 to 1.2 billion tonnes of plant material per year.
- This is a very small fraction (~1%) of total annual cellulose synthesis, but the actual deforestation impact is enormous because:
  a. Only mature trees are felled — they take decades to grow.
  b. Paper production also uses wood for fuel and other forest products.
  c. Associated habitat loss, soil erosion, and loss of biodiversity are severe.

Conclusion: While the fraction of cellulose consumed by paper-making appears small relative to total plant production, the annual destruction of vegetation for paper is significant, and the ecological consequences — deforestation, habitat loss, carbon release — are severe. Recycling paper and reducing consumption are critical conservation measures.

Answer: Plants synthesise approximately 10^11 tonnes of cellulose annually. Global paper production is ~400 million tonnes/year, requiring ~800 million to 1.2 billion tonnes of plant biomass. Though a small fraction of total cellulose, the deforestation, habitat loss, and carbon release caused by this consumption represent a severe ecological loss.

Q11 Describe the important properties of enzymes.

SOLUTION

Enzymes are biological catalysts — almost all are proteins (some RNA molecules called ribozymes also have catalytic activity). Their important properties are:

1. Catalytic power:
   - Enzymes enormously accelerate the rate of chemical reactions, often by factors of 10^6 to 10^12 compared to the uncatalysed reaction.
   - Example: Carbonic anhydrase accelerates CO2 + H2O -> H2CO3 by about 10 million times.

2. Specificity:
   - Each enzyme is highly specific — it acts on only one substrate or a group of closely related substrates.
   - This is due to the precise geometry of the active site (lock and key / induced fit).
   - Example: Sucrase acts only on sucrose; amylase acts on starch.

3. Not consumed in the reaction:
   - Enzymes are not permanently used up; after releasing the product, the free enzyme can bind another substrate molecule and function again.

4. Active site:
   - Enzymes possess a specific crevice or pocket called the active site where the substrate binds and the reaction occurs.
   - The active site is formed by the tertiary structure of the protein.

5. Effect of temperature:
   - Enzyme activity increases with temperature up to an optimum (usually 37-40 degrees C for most human enzymes).
   - Above the optimum, the enzyme is denatured (tertiary structure destroyed) and activity is lost.
   - Low temperatures slow activity but do not denature enzymes.

6. Effect of pH:
- Each enzyme has an optimum pH at which activity is maximum.
- Deviations from optimum pH (too acidic or too basic) reduce activity or denature the enzyme.
- Example: Pepsin works best at pH ~2; trypsin at pH ~8.

7. Effect of substrate concentration:
- Increasing substrate concentration increases reaction velocity up to a maximum (Vmax).
- At Vmax, all enzyme molecules are saturated with substrate; further increase in [S] has no effect.

8. Lowering activation energy:
- Enzymes lower the activation energy of a reaction, making it easier for substrates to reach the transition state and form products without requiring high temperatures.

9. Inhibition:
- Enzyme activity can be inhibited by specific chemicals (inhibitors).
- Competitive inhibitors resemble the substrate and compete for the active site (e.g., malonate inhibits succinic dehydrogenase).
- Non-competitive inhibitors bind elsewhere and alter enzyme shape.

10. Cofactors:
- Many enzymes require non-protein helpers called cofactors for activity.
- Cofactors can be: prosthetic groups (tightly bound, e.g., haem in catalase), coenzymes (loosely bound organic molecules, e.g., NAD, NADP), or metal ions (e.g., Zn2+ in carboxypeptidase).
- The protein portion of such an enzyme is the apoenzyme; apoenzyme + cofactor = holoenzyme (fully active).

Answer: Key properties of enzymes: (1) high catalytic power (up to 10^12-fold rate increase), (2) substrate specificity (active site-dependent), (3) not consumed in reaction, (4) denatured by high temperature, (5) pH-dependent activity, (6) saturation kinetics (Vmax), (7) lower activation energy, (8) inhibited by specific chemicals, (9) require cofactors (prosthetic groups, coenzymes, metal ions) for activity.