Biochemistry: Carbohydrates, Lipids & Proteins

IB HL Study Guide

Contents

Complete Study Guide

Topics Covered

Aligned to IB Biology HL 2025 syllabus — B1.1, B1.2

Section 1: Carbohydrates and Lipids (B1.1)

1.1 Water — The Solvent of Life

Although water (H_2O) is not a carbohydrate or lipid, its unique properties underpin all biochemistry. IB Biology frequently tests water's properties and their biological significance.

MEMORISE THIS

Properties of water and their biological significance:

Property	Explanation	Biological significance
Hydrogen bonding	Partial charges on O (δ^-) and H (δ^+) create weak bonds between water molecules	Gives water its cohesive, adhesive, and thermal properties
High specific heat capacity	Many H-bonds must be broken to raise temperature	Stable environments for aquatic organisms; buffers body temperature
High latent heat of vaporisation	Much energy needed to evaporate water	Sweating / transpiration provides effective cooling
Cohesion and adhesion	Water molecules stick to each other (cohesion) and to surfaces (adhesion)	Transpiration pull in xylem; surface tension supports insects
Solvent properties	Polar nature dissolves ionic and polar substances	Transport medium for metabolites, ions, gases in blood and cytoplasm
Lower density when frozen	Ice is less dense than liquid water (H-bonds form a lattice)	Ice floats, insulating water below and allowing aquatic life to survive winter

⚠ EXAM ALERT

Common exam mistake: Students state that water "has a high boiling point" without explaining *why* — you must link it to **hydrogen bonding** between water molecules. Simply naming the property without the molecular explanation will not earn full marks.

1.2 Monosaccharides

Monosaccharides are the simplest carbohydrates — single sugar units with the general formula $(CH_2O)_n$ where $n = 3$ to 7.

MEMORISE THIS

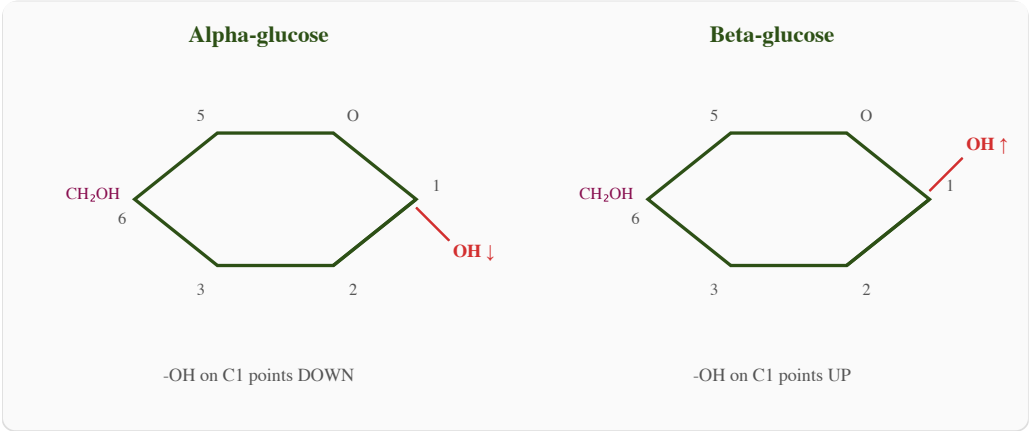
Key monosaccharides:

Monosaccharide	Carbons	Formula	Notes
Glucose	6 (hexose)	$C_6H_{12}O_6$	Main respiratory substrate; exists as α-glucose and β-glucose
Fructose	6 (hexose)	$C_6H_{12}O_6$	Structural isomer of glucose; found in fruits
Galactose	6 (hexose)	$C_6H_{12}O_6$	Structural isomer of glucose; component of lactose
Ribose	5 (pentose)	$C_5H_{10}O_5$	Component of RNA and ATP

α-glucose vs β-glucose:

Both have the same molecular formula ($C_6H_{12}O_6$) but differ in the orientation of the hydroxyl group (-OH) on **carbon 1**:

- **α-glucose:** -OH on carbon 1 is below the ring plane (same side as the $-CH_2OH$ group on carbon 6 is NOT — it points down on the opposite side to the $-CH_2OH$)
- **β-glucose:** -OH on carbon 1 is above the ring plane



-OH on C1 points DOWN

-OH on C1 points UP

IB TIP

IB exam tip: The difference between α and β-glucose may seem minor, but it has enormous consequences: α-glucose polymerises into **starch** (energy storage), while β

-glucose polymerises into **cellulose** (structural). This single -OH flip determines whether a polysaccharide is digestible or not.

1.3 Disaccharides

Disaccharides form when **two monosaccharides** join by a **condensation reaction** (also called a dehydration synthesis), releasing one molecule of water and forming a **glycosidic bond**.

$$\text{monosaccharide} + \text{monosaccharide} \xrightarrow{\text{condensation}} \text{disaccharide} + H_2O$$

The reverse reaction is **hydrolysis** — adding water to break the glycosidic bond.

MEMORISE THIS

Key disaccharides:

Disaccharide	Monosaccharide components	Bond type	Found in
Maltose	α-glucose + α-glucose	α-1,4 glycosidic	Germinating seeds; starch digestion
Sucrose	glucose + fructose	α-1,2 glycosidic	Table sugar; transported in plant phloem
Lactose	glucose + galactose	β-1,4 glycosidic	Mammalian milk

EXAM ALERT

Condensation vs hydrolysis — tested every year:

- **Condensation** (anabolism): two monomers join, releasing H_2O, forming a covalent bond (glycosidic, peptide, or ester)
- **Hydrolysis** (catabolism): water is added across the bond, breaking the polymer into monomers

These reactions apply to ALL biological macromolecules — carbohydrates, proteins, lipids, and nucleic acids. Memorise this principle once and apply it everywhere.

1.4 Polysaccharides

Polysaccharides are polymers of many monosaccharide units linked by glycosidic bonds.

MEMORISE THIS

Structure-function relationships of polysaccharides:

Polysaccharide	Monomer	Bond	Structure	Function
Starch (amylose)	α-glucose	α-1,4	Unbranched helix	Energy storage in plants
Starch (amylopectin)	α-glucose	α-1,4 and α-1,6 (branches)	Branched	Energy storage in plants; branches allow rapid hydrolysis
Glycogen	α-glucose	α-1,4 and α-1,6 (many branches)	Highly branched	Energy storage in animals (liver and muscle); more branched than amylopectin for even faster glucose release
Cellulose	β-glucose	β-1,4	Straight chains with H-bonds between parallel chains forming microfibrils	Structural component of plant cell walls; high tensile strength

⚠ EXAM ALERT

Why is cellulose indigestible to most animals?

Cellulose has β-1,4 glycosidic bonds. Most animals lack the enzyme **cellulase** needed to hydrolyse these bonds. Only certain microorganisms (e.g. bacteria in ruminant stomachs, termite gut symbionts) can digest cellulose. Starch (α-1,4 bonds) is readily digested by **amylase**, which is present in saliva and pancreatic secretions.

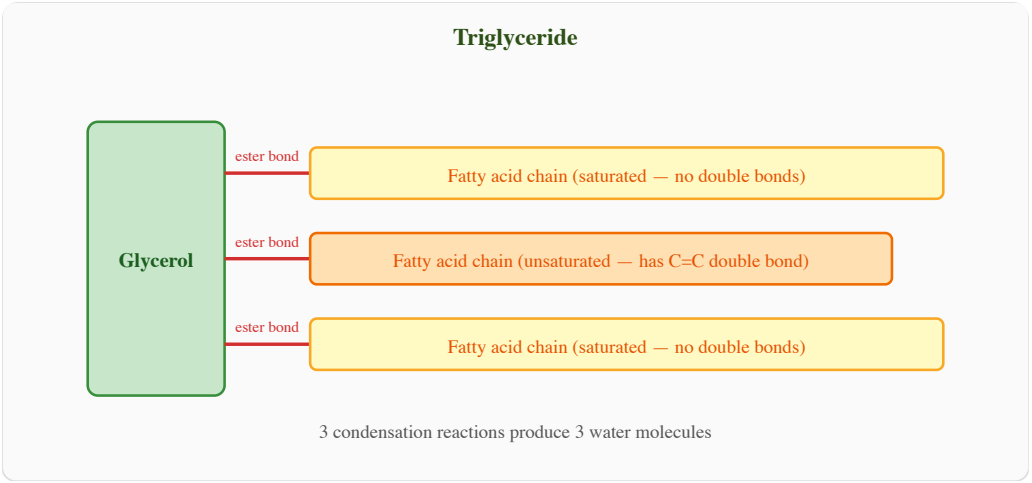
This is a direct consequence of the α vs β glucose difference — the bond orientation prevents amylase from fitting the β-linkage.

1.5 Lipids — Triglycerides

Lipids are a diverse group of hydrophobic (water-insoluble) molecules. The most important lipids for IB are **triglycerides** and **phospholipids**.

A **triglyceride** consists of one molecule of **glycerol** bonded to three **fatty acid** chains by **ester bonds** (formed via condensation reactions).

$$\text{glycerol} + 3\ \text{fatty acids} \xrightarrow{\text{3 condensation reactions}} \text{triglyceride} + 3\text{H}_2\text{O}$$



Functions of triglycerides:

- **Energy storage** — triglycerides store more than twice as much energy per gram as carbohydrates (≈ 38 kJ g^{-1} vs ≈ 17 kJ g^{-1}) because they have a higher proportion of C-H bonds
- **Thermal insulation** — subcutaneous fat reduces heat loss (e.g. blubber in marine mammals)
- **Buoyancy** — lipids are less dense than water
- **Protection** — fat pads around organs provide cushioning

1.6 Saturated vs Unsaturated Fatty Acids

MEMORISE THIS

Saturated vs unsaturated fatty acids:

Feature	Saturated	Unsaturated
Carbon-carbon bonds	All single bonds (C-C)	One or more double bonds (C=C)
Shape	Straight chains; pack closely together	Kinked/bent at each C=C; cannot pack tightly
State at room temperature	Solid (fats) — e.g. butter, lard	Liquid (oils) — e.g. olive oil, sunflower oil
Effect on membrane fluidity	Decrease fluidity (tight packing)	Increase fluidity (prevent close packing)
Mono- vs polyunsaturated	N/A	Monounsaturated: 1 double bond; polyunsaturated: 2+ double bonds

IB TIP

IB exam tip: When explaining why unsaturated fats are liquid at room temperature, the key is the **kink** in the hydrocarbon chain caused by the C=C double bond. This prevents the fatty acid chains from packing closely together, weakening intermolecular (van der Waals) forces, and lowering the melting point.

1.7 Phospholipids

Phospholipids have the same basic structure as triglycerides, but one fatty acid is replaced by a **phosphate group** (which may be linked to an additional small molecule like choline).

This gives phospholipids an **amphipathic** structure:

- **Hydrophilic head** (phosphate group — polar, interacts with water)
- **Hydrophobic tails** (two fatty acid chains — non-polar, repelled by water)

In aqueous environments, phospholipids spontaneously form a **bilayer** — the basis of all biological membranes (the fluid mosaic model).

> ⚠ EXAM ALERT
>
> **Phospholipid orientation in membranes:** Hydrophilic heads face outward (toward the aqueous environment on both sides of the membrane). Hydrophobic tails face inward (toward each other, away from water). This arrangement is thermodynamically stable and forms spontaneously.

1.8 BMI and Health Risks (IB Application)

The **Body Mass Index (BMI)** is used as a simple indicator of whether body mass is within a healthy range:

$$\text{BMI} = \frac{\text{mass (kg)}}{\text{height (m)}^2}$$

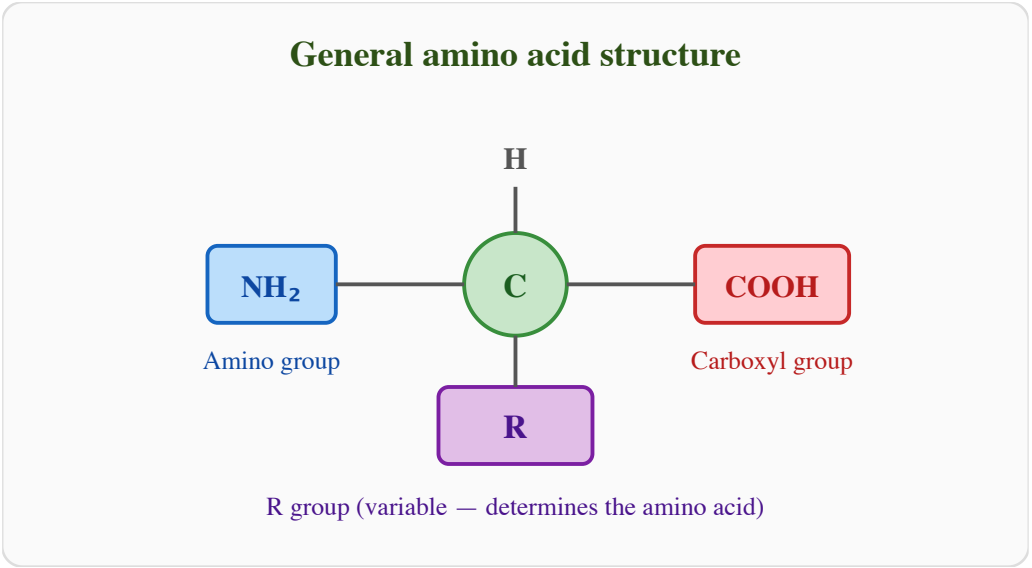
BMI Range	Classification
Below 18.5	Underweight
18.5 — 24.9	Normal
25.0 — 29.9	Overweight
30.0 and above	Obese

> 💡 IB TIP
>
> **IB exam tip:** BMI has significant limitations — it does not distinguish between muscle mass and fat mass (athletes may have high BMI but low body fat), and it does not account for fat distribution (visceral fat around organs is more dangerous than subcutaneous fat). If asked to "evaluate" BMI, always discuss both its utility and its limitations.

Section 2: Proteins (B1.2)

2.1 Amino Acid Structure

Proteins are polymers of **amino acids**. All amino acids share the same basic structure:



There are **20 different amino acids** used in protein synthesis, each with a different **R group** (side chain). The R group determines the chemical properties (polar, non-polar, charged, etc.) of each amino acid.

2.2 Peptide Bonds

Amino acids join by **condensation reactions** to form **peptide bonds** between the amino group (-NH_2) of one amino acid and the carboxyl group (-COOH) of another, releasing water.

$$\text{amino acid}_1 + \text{amino acid}_2 \xrightarrow{\text{condensation}} \text{dipeptide} + H_2O$$

A chain of many amino acids linked by peptide bonds is called a **polypeptide**. A functional protein may consist of one or more polypeptide chains.

EXAM ALERT

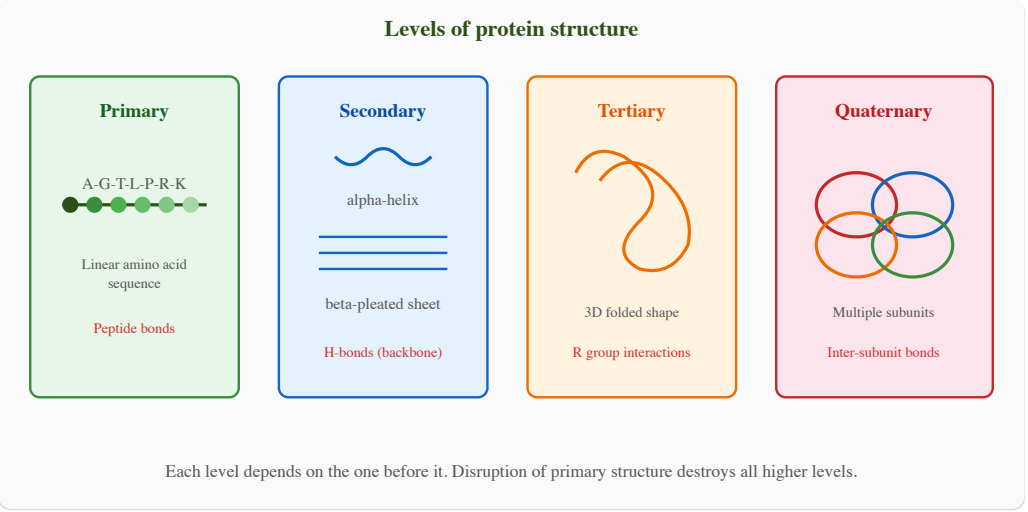
Key distinction: A polypeptide is a chain of amino acids. A protein is a functional molecule — it may be a single polypeptide that has folded into its functional shape, or it may consist of multiple polypeptide subunits (quaternary structure). Not all polypeptides are proteins — they must fold correctly and may require post-translational modifications to become functional.

2.3 Levels of Protein Structure

MEMORISE THIS

Four levels of protein structure:

Level	Description	Bonds involved
Primary	The linear sequence of amino acids in the polypeptide chain, determined by the gene	Peptide bonds (covalent)
Secondary	Local folding into α-helices or β-pleated sheets	Hydrogen bonds between C=O and N-H groups of the backbone
Tertiary	The overall 3D shape of a single polypeptide, formed by interactions between R groups	Hydrogen bonds, ionic bonds, disulfide bridges (S-S, covalent), hydrophobic interactions, van der Waals forces
Quaternary	Two or more polypeptide chains (subunits) associate to form a functional protein	Same interactions as tertiary, but *between* subunits; may include non-protein components (prosthetic groups, e.g. haem in haemoglobin)



Each level depends on the one before it. Disruption of primary structure destroys all higher levels.

2.4 R Group Interactions in Tertiary Structure

The tertiary structure is stabilised by interactions between the **R groups** (side chains) of amino acids:

MEMORISE THIS

Types of R group interactions (from weakest to strongest):

Interaction	Description	Strength
Van der Waals forces	Weak attractions between all atoms at close range	Very weak; collectively significant
Hydrogen bonds	Between polar R groups (-OH, -NH)	Weak individually; many contribute significantly
Ionic bonds	Between positively and negatively charged R groups (e.g. $-NH_3^+$ and $-COO^-$)	Moderate; broken by pH changes
Hydrophobic interactions	Non-polar R groups cluster in the protein interior, away from water	Moderate; important for globular protein folding
Disulfide bridges	Covalent S-S bonds between cysteine residues	Strong (covalent); only broken by reducing agents

⚠ EXAM ALERT

Denaturation revisited: Changes in temperature, pH, or heavy metal ions disrupt these R group interactions (except disulfide bridges, which are covalent and harder to break). This changes the tertiary structure, altering the shape of the active site (for enzymes) or the functional shape (for other proteins). The **primary structure** (amino acid sequence) is unchanged — only the higher-order folding is disrupted.

2.5 Fibrous vs Globular Proteins

MEMORISE THIS

Comparison of fibrous and globular proteins:

Feature	Fibrous proteins	Globular proteins
Shape	Long, elongated, rope-like	Compact, roughly spherical
Solubility	Generally insoluble in water	Generally soluble in water
Function	Structural support	Metabolic and regulatory roles
Examples	Collagen (connective tissue), keratin (hair, nails)	Haemoglobin (oxygen transport), enzymes, antibodies
Structure	Predominantly secondary (repetitive); limited tertiary	Complex tertiary and often quaternary structure
R groups	Hydrophobic R groups on outside	Hydrophilic R groups on outside (in aqueous environments); hydrophobic core

Collagen:

- Triple helix of three polypeptide chains wound around each other
- Every third amino acid is glycine (smallest R group, fits inside the helix)
- Hydrogen bonds between chains provide tensile strength
- Found in tendons, ligaments, bone, cartilage, skin

Haemoglobin:

- Quaternary structure: 4 polypeptide subunits (2 α-chains, 2 β-chains)
- Each subunit contains a **haem group** (prosthetic group) with an iron (Fe^{2+}) ion that binds one O_2 molecule
- Exhibits **cooperative binding** — binding of O_2 to one subunit increases the affinity of the remaining subunits for O_2

2.6 Proteomics

Proteomics is the study of the complete set of proteins (the **proteome**) produced by an organism, tissue, or cell at a given time.

IB TIP

IB exam tip: A key concept is that **one gene can produce multiple proteins**. This occurs through:

- **Alternative RNA splicing** — different combinations of exons are joined together from the same pre-mRNA, producing different mRNA sequences and thus different polypeptides
- **Post-translational modifications** — after translation, proteins may be modified by phosphorylation, glycosylation, cleavage, etc., altering their function

This means the proteome is much larger and more complex than the genome. The same gene can be expressed differently in different cell types.

Section 3: HL Extensions — Chromatography, Electrophoresis & Biochemical Tests

3.1 Paper Chromatography

Chromatography separates mixtures based on differential solubility in a mobile phase (solvent) vs a stationary phase (paper).

The R_f **value** (retardation factor) identifies substances:

$$R_f = \frac{\text{distance travelled by substance}}{\text{distance travelled by solvent front}}$$

WORKED EXAMPLE

Worked Example: Calculating R_f

A student uses paper chromatography to separate amino acids. The solvent front travels 12.0 cm from the origin. An amino acid spot is found 7.2 cm from the origin.

$$R_f = \frac{7.2}{12.0} = 0.60$$

By comparing this R_f value to a table of known amino acid R_f values under the same conditions, the amino acid can be identified.

Important: R_f values are specific to the solvent system and conditions (temperature, paper type) used. They are always between 0 and 1.

EXAM ALERT

Common chromatography mistakes:

1. Measuring from the wrong point — always measure from the **origin line** (start line), not from the bottom of the paper
2. Using a pen instead of pencil for the origin line — ink from a pen will dissolve in the solvent and interfere
3. Forgetting that R_f values are only comparable when obtained under **identical conditions**

3.2 Gel Electrophoresis

Gel electrophoresis separates **proteins or DNA fragments** by size (and, for proteins, charge) in an electric field through a gel matrix.

How it works:

1. Samples are loaded into wells in a gel (polyacrylamide for proteins; agarose for DNA)
2. An electric field is applied across the gel
3. Molecules migrate through the gel toward the electrode of opposite charge
4. **Smaller molecules** move faster and further through the gel pores
5. After separation, bands are visualised using staining (e.g. Coomassie blue for proteins, ethidium bromide or SYBR green for DNA)

IB TIP

IB exam tip: For DNA electrophoresis, all DNA fragments carry a negative charge (due to phosphate groups), so they all migrate toward the positive electrode (anode). Separation is purely by size. For proteins, both size and charge affect migration — proteins are often treated with **SDS** (sodium dodecyl sulfate) to denature them and give uniform negative charge, so separation is by size only (SDS-PAGE).

3.3 Biochemical Tests for Macromolecules

MEMORISE THIS

Summary of biochemical identification tests:

Test	Tests for	Reagent	Positive result	Negative result
Benedict's test	Reducing sugars (glucose, maltose, lactose)	Benedict's reagent; heat in water bath	Blue → green → yellow → orange → brick red (semi-quantitative)	Stays blue
Iodine test	Starch	Iodine solution (I_2/KI)	Yellow-brown → blue-black	Stays yellow-brown
Biuret test	Proteins (peptide bonds)	Biuret reagent (NaOH + dilute $CuSO_4$)	Blue → purple / violet	Stays blue
Emulsion test	Lipids	Ethanol then water	White / milky emulsion forms	Solution stays clear
Sudan III / IV	Lipids	Sudan III or IV dye	Red-stained lipid layer	No red staining

⚠ EXAM ALERT

Benedict's test details (frequently tested):

- Benedict's reagent contains copper(II) sulfate (Cu^{2+}, blue)
- Reducing sugars reduce Cu^{2+} to Cu^{+} (copper(I) oxide, brick red precipitate)
- The colour change is **semi-quantitative** — the more reducing sugar, the further the colour shifts toward brick red
- **Sucrose** is a **non-reducing sugar** and gives a negative result with Benedict's test. To test for sucrose: first hydrolyse with dilute HCl (acid hydrolysis), neutralise with $NaHCO_3$, then test with Benedict's — a positive result confirms the presence of a non-reducing sugar
- Must be heated in a water bath (not over a Bunsen flame directly) for safety and consistent temperature

Section 4: Exam Strategy & Common Mistakes

⚠ EXAM ALERT

Top mistakes in biochemistry exams:

1. **Confusing condensation and hydrolysis** — condensation *removes* water and *forms* bonds; hydrolysis *adds* water and *breaks* bonds
2. **Saying "enzymes break peptide bonds"** without context — digestion breaks peptide bonds via hydrolysis; peptide bonds form via condensation during translation
3. **Confusing α and β glucose** — remember: α-glucose $\rightarrow$ starch (storage); β-glucose $\rightarrow$ cellulose (structural)
4. **Describing proteins as having quaternary structure when they consist of a single polypeptide** — quaternary structure requires two or more polypeptide subunits
5. **Not linking properties of water to hydrogen bonding** — every property (high specific heat, cohesion, solvent ability) must be linked to H-bonding for full marks
6. **Confusing fibrous and globular proteins** — fibrous = structural, insoluble, elongated; globular = functional, soluble, compact
7. **Forgetting to heat Benedict's test** — it requires heating in a water bath

IB Exam-Style Questions

Question 1 *(3 marks)*

Describe the structure of a triglyceride and explain how it forms from its components.

▶ Markscheme

Question 2 *(4 marks)*

Compare and contrast the structure and function of starch and cellulose.

▶ Markscheme

Question 3 *(3 marks)*

Explain why haemoglobin is described as having a quaternary structure while myoglobin does not.

▶ Markscheme

Question 4 *(4 marks)*

A student performs Benedict's test on three solutions: glucose solution, sucrose solution, and water. Predict and explain the results.

▶ Markscheme

Mixed Practice — Exam Style

> **IB TIP**
>
> **How to use this section:** Unlike topic-specific practice, these questions are interleaved — they mix all topics from this guide in random order. Before answering, identify *which concept or topic area* the question is testing. This is exactly the skill you need on Paper 1 and Paper 2, where you don't know in advance which topic each question covers.

1. **[Carbohydrates]** Which of the following is a disaccharide formed from glucose and galactose?

   A. Maltose

   B. Sucrose

   C. Lactose

   D. Cellulose

2. **[Protein Structure]** The tertiary structure of a protein is primarily determined by:

   A. Peptide bonds between amino acids

   B. Hydrogen bonds between backbone C=O and N-H groups

   C. Interactions between R groups (side chains) of amino acids, including hydrogen bonds, ionic bonds, disulfide bridges, and hydrophobic interactions

   D. Hydrogen bonds between separate polypeptide chains

3. **[Lipids]** Which statement correctly describes the difference between saturated and unsaturated fatty acids?

   A. Saturated fatty acids have double bonds between carbon atoms; unsaturated fatty acids have only single bonds

   B. Saturated fatty acids have only single bonds between carbon atoms, making them straight; unsaturated fatty acids have one or more double bonds, creating kinks

   C. Saturated fatty acids are always liquid at room temperature; unsaturated fatty acids are always solid

   D. Saturated and unsaturated fatty acids have identical melting points

4. **[Water Properties — Distractor]** A student states: "Water has a high specific heat capacity because it is a liquid." Evaluate this claim:

   A. Correct — all liquids have high specific heat capacity

   B. Incorrect — water has a high specific heat capacity because hydrogen bonds between water molecules require significant energy to break, meaning more heat energy is needed to raise the temperature

   C. Correct — specific heat capacity is a property of the liquid state

   D. Incorrect — water actually has a low specific heat capacity

5. **[Condensation and Hydrolysis]** Which pair correctly matches the reaction type to the process?

   A. Condensation — digestion of starch to maltose

   B. Hydrolysis — formation of a peptide bond between two amino acids

   C. Condensation — synthesis of a polypeptide from amino acids (removing water)

   D. Hydrolysis — synthesis of a triglyceride from glycerol and fatty acids

6. **[Protein Function]** Collagen is a fibrous protein. Which structural feature contributes most to its high tensile strength?

   A. Globular shape allowing it to dissolve in blood plasma

   B. Triple-helix structure with hydrogen bonds between three polypeptide chains and staggered covalent cross-links

   C. Quaternary structure with four subunits each containing a haem group

   D. Single polypeptide chain folded into a compact sphere

7. **[Biochemical Tests]** A solution gives a negative result with Benedict's test but a positive result after acid hydrolysis followed by Benedict's test. The solution most likely contains:

   A. Glucose

   B. Starch

   C. Sucrose

   D. A protein

8. **[Polysaccharides — Distractor]** A student claims that glycogen and cellulose have the same structure because they are both made of glucose. Evaluate this claim:

   A. Correct — both are identical polymers of glucose

   B. Incorrect — glycogen is made of α-glucose with α-1,4 and α-1,6 bonds (highly branched); cellulose is made of β-glucose with β-1,4 bonds (straight chains forming microfibrils); the different bond types give completely different structures and functions

   C. Correct — the only difference is that glycogen is found in animals and cellulose in plants

   D. Incorrect — glycogen is made of fructose, not glucose

9. **[Gel Electrophoresis]** In SDS-PAGE, proteins are separated primarily by:

   A. Their charge, because each protein has a unique charge at physiological pH

   B. Their size (molecular mass), because SDS gives all proteins a uniform negative charge, so smaller proteins migrate further through the gel

   C. Their colour, allowing visual separation without staining

   D. Their primary amino acid sequence, which determines migration speed directly

10. **[Proteomics]** The human proteome is larger than the human genome (in terms of number of distinct proteins vs number of genes). The best explanation is:

    A. Humans have more proteins than genes because each protein codes for multiple genes

    B. Alternative RNA splicing allows one gene to produce multiple different mRNA sequences and thus multiple different proteins; post-translational modifications further increase protein diversity

C. Each gene produces exactly one protein, so the proteome and genome are the same size

D. Mutations increase the number of proteins beyond the number of genes

▶ Show Answers

May 2026 Prediction Questions

> ⚠ EXAM ALERT
>
> **These are NOT official IB questions.** These are trend-based practice questions written to reflect the topic areas and question styles most likely to appear on the May 2026 IB Biology HL Paper 2. Based on recent exam patterns (2022—2025), expect heavy weighting on: protein structure-function relationships (enzyme active sites, membrane proteins, fibrous vs. globular proteins), the functional properties of water, and carbohydrate structure linked to function (starch vs. cellulose vs. glycogen).

▶ **Question 1 — Protein Structure and Function [8 marks]**

▶ **Question 2 — Polysaccharide Structure and Function [7 marks]**

▶ **Question 3 — The Role of Water in Living Systems [6 marks]**

IB Biology HL — Biochemistry: Carbohydrates, Lipids & Proteins — Complete Study Guide — 2025 Syllabus — Good luck!