Cambridge AS & A Level · Biology 9700 · Notes

Biological molecules AS

Read online at **pastopic.com/cambridge/biology-9700/notes/biological-molecules**

Last checked 29 September 2026

What you need to know

By the end of this topic you should be able to:

Testing for biological molecules

1. **Carry out the four food tests**: Benedict's (reducing sugars), iodine (starch), emulsion (lipids) and biuret (proteins).
2. **Estimate a reducing sugar's concentration** with a standardised, semi-quantitative Benedict's test, using the time to the first colour change or colour standards.
3. **Test for non-reducing sugars** by acid hydrolysis followed by Benedict's.

Carbohydrates and lipids

4. **Describe and draw the rings of α-glucose and β-glucose.**
5. **Define** monomer, polymer, macromolecule, monosaccharide, disaccharide and polysaccharide.
6. **State that covalent bonds join small molecules into polymers.**
7. **State that glucose, fructose and maltose are reducing sugars** and sucrose is non-reducing.
8. **Describe how a glycosidic bond forms by condensation** (disaccharides, including sucrose, and polysaccharides).
9. **Describe how hydrolysis breaks a glycosidic bond**, as in the non-reducing sugar test.
10. **Describe starch (amylose and amylopectin) and glycogen**, and relate their structures to their functions.
11. **Describe cellulose** and outline how its molecules are arranged to make plant cell walls strong.
12. **Describe triglycerides**: non-polar and hydrophobic, made of glycerol and fatty acids (saturated or unsaturated) joined by ester bonds.
13. **Relate the structure of triglycerides to their functions.**
14. **Describe phospholipids**: a hydrophilic (polar) phosphate head and hydrophobic (non-polar) fatty acid tails.

Proteins

15. **Describe and draw an amino acid**, and how a peptide bond forms and breaks.
16. **Explain primary, secondary, tertiary and quaternary structure.**

17. **Describe what holds proteins in shape**: hydrophobic interactions, hydrogen bonds, ionic bonds and covalent bonds, including disulfide bonds.
18. **State that globular proteins are usually soluble with physiological roles**, and fibrous proteins usually insoluble with structural roles.
19. **Describe haemoglobin**: two α-globin chains, two β-globin chains and haem, forming a quaternary structure.
20. **Relate haemoglobin's structure to its function**, including the iron in haem.
21. **Describe collagen molecules** and how they are arranged into collagen fibres.
22. **Relate the structure of collagen molecules and fibres to their function.**

Water

23. **Explain hydrogen bonding between water molecules**, and link it to water's roles as a solvent and through its high specific heat capacity and high latent heat of vaporisation.

Nucleic acids are Topic 6, oxygen loading by haemoglobin Topic 8, and membranes Topic 4.

Understand it

Building blocks and big molecules

Most large molecules in cells are made by joining small ones.

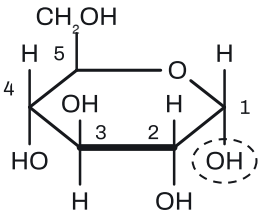
- A **monomer** is a small molecule that can join with others like it, such as glucose or an amino acid.
- A **polymer** is a long molecule made of many **repeating** monomers, such as starch (glucose) or a protein (amino acids).
- A **macromolecule** is simply a very large molecule. Polysaccharides, proteins and nucleic acids are macromolecules and polymers. A triglyceride is large enough to count as a macromolecule, but it is **not** a polymer: one glycerol and three fatty acids are not a chain of repeating units.

Monomers are joined by **covalent bonds**: **glycosidic** bonds between sugars, **peptide** bonds between amino acids and **ester** bonds between glycerol and fatty acids. Each forms by **condensation**: two molecules join and one **water** molecule is removed. **Hydrolysis** is the reverse: water is used to break the bond. Joining n monomers into a chain releases $n - 1$ water molecules; breaking it down uses $n - 1$.

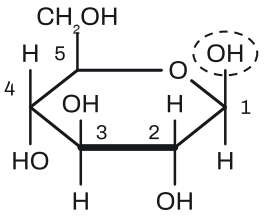
Sugars

Carbohydrates contain only carbon, hydrogen and oxygen. **Monosaccharides** are single sugar units, $(\mathrm{CH_2O})_n$: glucose, fructose and galactose are **hexoses** ($\mathrm{C_6H_{12}O_6}$); ribose and deoxyribose are **pentoses**. A **disaccharide** is two monosaccharides joined by a glycosidic bond; a **polysaccharide** is many.

Glucose forms a ring of five carbons and one oxygen. The carbons are numbered from the one to the right of the ring oxygen; carbon 6 is in the $\mathrm{CH_2OH}$ group outside the ring. The two forms differ only at **carbon 1**: in **α-glucose** its OH points **down**; in **β-glucose** it points **up**.



α-glucose



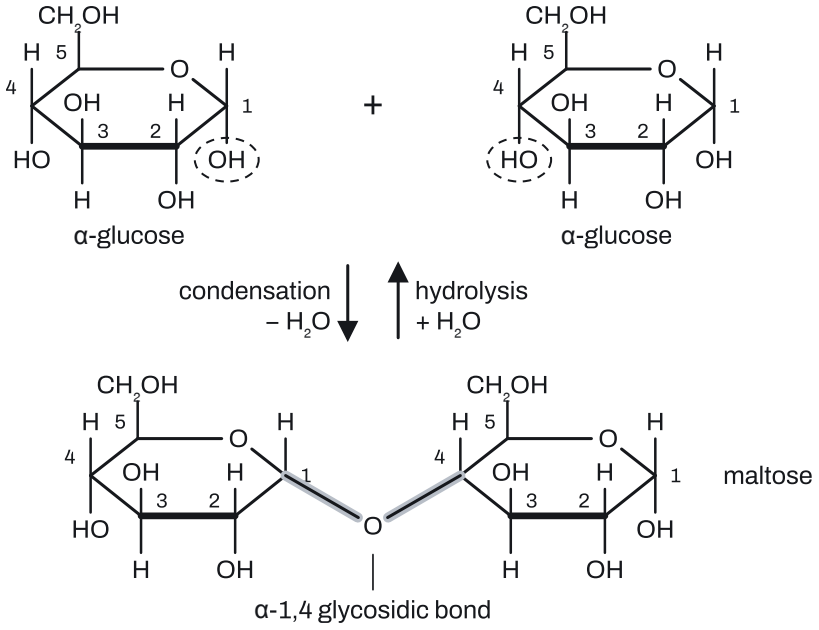
β-glucose

Disaccharide	Made from	Reducing?
Maltose	α-glucose + α-glucose (α-1,4 bond)	Yes
Sucrose	α-glucose + fructose	**No**
Lactose	glucose + galactose	Yes

The glycosidic bond

The OH on carbon 1 of one sugar reacts with an OH on another (on carbon 4 for maltose). An H and an OH leave as water, and the remaining oxygen bridges the two rings: this $\mathrm{C{-}O{-}C}$ link is the **glycosidic bond**, named from the carbons it joins (**1,4** in maltose, **1,6** at a branch point).

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



Hydrolysis puts the water back, so each monomer gets back its OH. In cells, enzymes (such as amylase) catalyse it; in the laboratory, boiling with dilute acid does it.

Reducing and non-reducing sugars

A **reducing sugar** reduces the blue copper(II) ions in Benedict's solution to a red-brown copper(I) oxide precipitate. It can because its ring opens to show a reactive C=O group. All monosaccharides, maltose and lactose are reducing. In **sucrose**, the glycosidic bond joins carbon 1 of glucose to carbon 2 of fructose, using up **both** reactive groups, so sucrose is **non-reducing**. Hydrolyse it and you get glucose and fructose, which both reduce Benedict's. That is the basis of the non-reducing sugar test.

Food tests

Test for	Method	Positive	Negative
Reducing sugar	Add an equal volume of Benedict's solution; heat in a water bath at 80–100 °C	Blue → green → yellow → orange → brick-red precipitate	Stays blue
Non-reducing sugar	Benedict's first (stays blue). New sample: boil with dilute hydrochloric acid, cool, neutralise with sodium hydrogencarbonate, then Benedict's and heat	Now changes colour	Still blue
Starch	Add iodine in potassium iodide solution	Yellow-brown → blue-black	Stays yellow-brown
Lipid (emulsion)	Shake with ethanol to dissolve any lipid, then pour into water	Cloudy white emulsion	Stays clear
Protein	Add biuret reagent (sodium hydroxide + dilute copper(II) sulfate)	Blue → purple	Stays blue

- The **acid** hydrolyses the glycosidic bonds; **neutralising** matters because Benedict's only works in alkaline conditions.
- If reducing sugar is already present, a non-reducing sugar shows up as **more** precipitate (a colour further along) after hydrolysis.
- Biuret reacts with **peptide bonds**, so it detects proteins and polypeptides, not single amino acids.

The semi-quantitative Benedict's test

The colour reached shows how much reducing sugar there is: **blue (none)** → **green** → **yellow** → **orange** → **brick-red (most)**. To estimate a concentration, **standardise** the test: the same volume of sample, the same volume of Benedict's (in **excess**, so it never runs out), the same water-bath temperature and the same heating time for every tube.

1. Make **standards** of known concentration by diluting a stock glucose solution.
2. Test the standards and the unknown the same way.

3. Either **compare colours** (the unknown lies between the two standards that bracket it), or **time the first colour change**: more sugar gives a **shorter** time. Read the unknown off a graph of time against concentration.

It is only "semi"-quantitative because colour judgements are subjective, so the answer is an estimate or a range.

Starch and glycogen: storage

Starch (plants) is a mixture of two polymers of **α-glucose**:

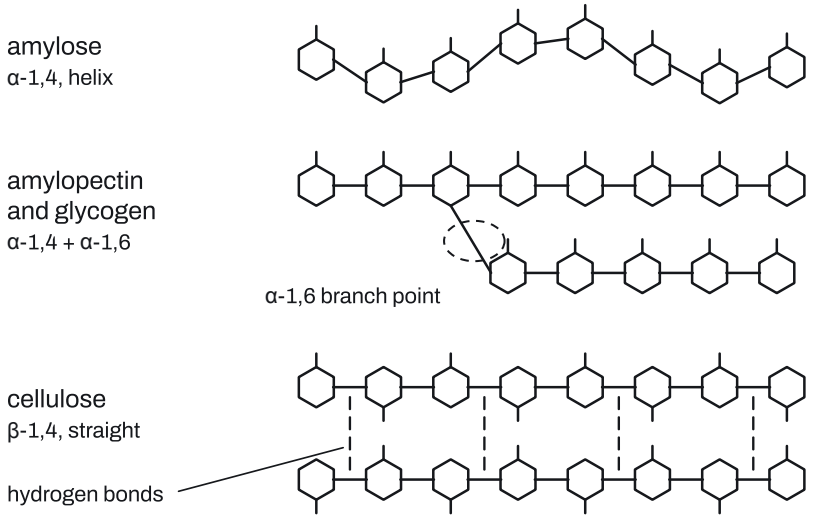
- **amylose**: α-1,4 bonds only; the unbranched chain coils into a compact **helix**, held by hydrogen bonds within the chain;
- **amylopectin**: α-1,4 bonds with **α-1,6** bonds at **branch points** about every 25–30 units.

Glycogen (animals and fungi, in liver and muscle) is like amylopectin but **more branched** (about every 8–12 units), so it is more compact and has many more chain ends.

Why these suit storage: they are **insoluble**, so they don't change the cell's water potential or diffuse out; **compact**, so a lot fits in a small space; and **branched**, so enzymes working from the many ends can release glucose **quickly** for respiration.

Cellulose: structure

Cellulose is a polymer of **β-glucose** joined by **β-1,4** bonds. For the OHs on carbons 1 and 4 to meet, each monomer is **rotated 180°** relative to the one before. The result is a **long, straight, unbranched** chain with OH groups sticking out on both sides.



How the arrangement makes cell walls strong:

1. Neighbouring chains lie **parallel**, linked by **many hydrogen bonds**. One is weak; thousands together are strong.

2. About 60–70 chains form a **microfibril**; microfibrils bundle into **fibres**.
3. Fibres are laid in **layers** running in different directions.

This gives **high tensile strength**: the wall stops a cell bursting when it takes in water, so cells stay turgid and support the plant. The gaps between fibres make the wall **freely permeable**.

Feature	Amylose	Amylopectin	Glycogen	Cellulose
Monomer	α-glucose	α-glucose	α-glucose	β-glucose
Bonds	α-1,4	α-1,4 and α-1,6	α-1,4 and α-1,6	β-1,4
Shape	Unbranched helix	Branched	Highly branched	Straight; alternate monomers rotated 180°
Between molecules	Nothing	Nothing	Nothing	Many hydrogen bonds
Role	Storage (plants)	Storage (plants)	Storage (animals)	Structure (cell walls)

Triglycerides

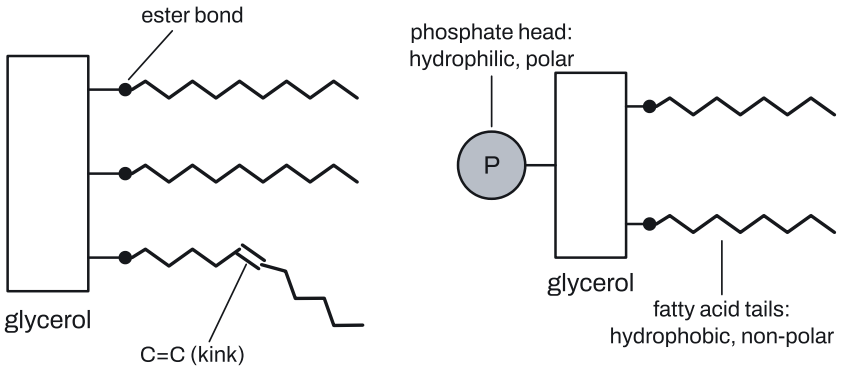
A **triglyceride** is one **glycerol** (three carbons, three OH groups) joined to **three fatty acids**. A fatty acid is a **carboxyl group** ($-\mathrm{COOH}$) on a **hydrocarbon tail** of $\mathrm{CH_2}$ groups ending in $\mathrm{CH_3}$. Each OH of glycerol and the COOH of a fatty acid join by condensation into an **ester bond**, so

$$\text{glycerol} + 3\ \text{fatty acids} \longrightarrow \text{triglyceride} + 3\,\mathrm{H_2O}.$$

Lipase hydrolyses the three ester bonds again.

- **Saturated** fatty acids have **no C=C** in the tail ($\mathrm{C}_n\mathrm{H}_{2n}\mathrm{O}_2$). Straight tails pack closely, so saturated fats (mostly animal) are **solid** at room temperature.
- **Unsaturated** fatty acids have **one or more C=C**. Each means two fewer hydrogens and puts a **kink** in the tail, so the molecules can't pack closely and unsaturated fats (mostly plant oils) are **liquid**.

With no charged groups and very few polar ones, triglycerides are **non-polar** and **hydrophobic**: insoluble in water but soluble in ethanol.



triglyceride phospholipid

Function	The structure behind it
Energy store	Many C–H bonds and little oxygen: about twice the energy per gram of carbohydrate
Compact, light store	Insoluble, so no effect on water potential and stored without water; less mass to carry for the same energy
Insulation, buoyancy, protection	Fat conducts heat poorly, is less dense than water, and cushions organs
Metabolic water	Respiring it releases a lot of water (desert animals)

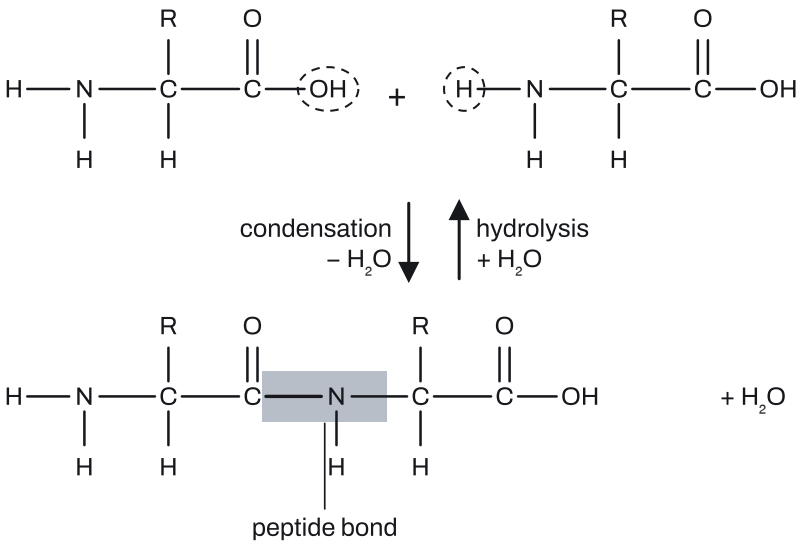
Phospholipids

A **phospholipid** is a triglyceride with one fatty acid replaced by a **phosphate group**. The phosphate is charged, so the head is **polar** and **hydrophilic**; the two fatty acid tails are **non-polar** and **hydrophobic**. In water they form a **bilayer**, heads facing the water and tails hidden inside: the basis of cell membranes. Unsaturated (kinked) tails pack less tightly and make a membrane more fluid.

Amino acids and the peptide bond

Every amino acid has a central carbon carrying an **amine group** ($-\mathrm{NH_2}$), a **carboxyl group** ($-\mathrm{COOH}$), a **hydrogen** and an **R group**, which differs in each of the 20 amino acids. **Glycine** has the smallest: R = H. R groups can be **non-polar** (hydrocarbon, hydrophobic), **polar** (such as OH), **charged** ($-\mathrm{COO^-}$ or $-\mathrm{NH_3^+}$), or contain **sulfur** (cysteine's $-\mathrm{SH}$).

In condensation, the **OH of one carboxyl group** and an **H of the other's amine group** leave as water, and the C bonds to the N: this C–N bond is the **peptide bond**. Two amino acids make a **dipeptide**; many make a **polypeptide**, and n amino acids in a chain have $n - 1$ peptide bonds. Proteases (or boiling with acid) hydrolyse them.



Four levels of protein structure

Level	What it is	Held by
Primary	The **sequence** (number, types and order) of amino acids in a polypeptide	Peptide bonds
Secondary	Regular coiling or folding of the chain into an **α-helix** or **β-pleated sheet**	Hydrogen bonds between the C=O of one peptide bond and the N–H of another (backbone, not R groups)
Tertiary	Further folding of the whole polypeptide into a precise **3D shape**	Interactions between **R groups**: hydrogen, ionic and disulfide bonds and hydrophobic interactions
Quaternary	Two or more polypeptides as one protein (sometimes with a non-protein group, such as haem)	The same as tertiary

The primary structure decides the rest: where each R group sits decides which interactions form and so how the chain folds. A protein of one polypeptide has no quaternary structure.

- **Hydrogen bonds** between polar R groups: weak, but many; broken by heat.
- **Ionic bonds** between $-\mathrm{NH}_3^+$ and $-\mathrm{COO}^-$ R groups: broken by pH changes.
- **Disulfide bonds**: **covalent** S–S bonds between two **cysteines**; strong.
- **Hydrophobic interactions**: non-polar R groups cluster in the middle, away from water.

Globular and fibrous proteins

	Globular	Fibrous
Shape	Compact, roughly spherical	Long strands

	Globular	Fibrous
Solubility	Usually **soluble**: hydrophilic R groups outside, hydrophobic inside	Usually **insoluble**
Sequence	Irregular	Often repeating
Role	**Physiological**: enzymes, antibodies, insulin, haemoglobin	**Structural**: collagen, keratin

Haemoglobin

- **Quaternary structure**: **two α-globin** and **two β-globin** chains packed together.
- Each chain holds a **haem group**, a non-protein ring with an **iron ion (Fe^{2+})** in the middle: four haem groups per molecule.
- Each Fe^{2+} reversibly binds **one O_2 molecule**, so one haemoglobin carries up to **four**. Without iron, haem can't bind oxygen.
- **Hydrophobic** R groups point inwards and **hydrophilic** ones outwards, so haemoglobin is **soluble** in the cytoplasm of red blood cells.
- Swap one polar surface amino acid for a non-polar one (as in sickle cell anaemia) and the molecules become less soluble and stick together.

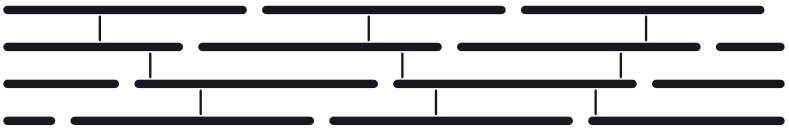
Collagen

Collagen is the main **fibrous** protein of skin, tendons, ligaments, bone, cartilage and artery walls.

1. **Polypeptide**: **every third amino acid is glycine**. Each chain coils into a looser helix, **not** an α-helix.
2. **Molecule**: **three polypeptides wound round each other** into a **triple helix**. Glycine's tiny R group (H) fits in the crowded centre, so the chains pack tightly. **Hydrogen bonds** between the chains hold it together.
3. **Fibril**: many molecules lie **parallel** and **staggered**, so their ends don't line up and there is no weak point. **Covalent cross-links** join R groups (lysine) of neighbouring molecules.
4. **Fibre**: many fibrils bundled together.

collagen molecule: three polypeptides wound into a triple helix

fibril: molecules parallel and staggered, with covalent cross-links

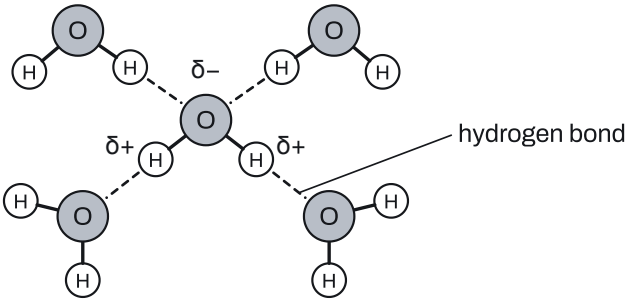


fibre: many fibrils bundled together

All this gives **very high tensile strength** (it doesn't snap when pulled); fibres are **flexible** but hardly stretch, and **insoluble**, so they stay in place.

Water and hydrogen bonds

Oxygen pulls the shared electrons more strongly than hydrogen, so in water the oxygen is slightly negative (δ^-) and each hydrogen slightly positive (δ^+): water is **polar**. A **hydrogen bond** is the attraction between a δ^+ hydrogen of one molecule and the δ^- oxygen of **another**. Each molecule can form up to **four** (two through its hydrogens, two through its oxygen), but two lone molecules can form only **one** between them.



Property	Why	Role in living things
Solvent	Polar water surrounds ions and polar molecules: δ^- O faces positive ions (such as Na^+), δ^+ H faces negative ions (such as Cl^-); glucose hydrogen-bonds with water	Reactions happen in solution in the cytoplasm; blood plasma, xylem and phloem **transport** dissolved substances; non-polar triglycerides don't dissolve
High specific heat capacity	Much of the energy supplied goes into breaking hydrogen bonds, so a lot is needed to raise the temperature	Cells, bodies, blood and water habitats change temperature **slowly**; enzymes stay near their optimum
High latent heat of vaporisation	A lot of energy is needed to break the hydrogen bonds so a molecule can evaporate	Evaporating a little water removes a lot of heat: **cooling** by sweating, panting and transpiration

Specific heat capacity is about **resisting temperature change**; latent heat of vaporisation is about **cooling by evaporation**.

Key facts and formulas

None of these is in the formula list printed in the syllabus (that list is for A Level statistics and ecology), so you must learn them all.

Formula	Status
Monosaccharides: $(CH_2O)_n$; hexoses such as glucose and fructose: $C_6H_{12}O_6$	Learn it
$C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$ (maltose or sucrose)	Learn it
Glucose polymer of n units: $(C_6H_{10}O_5)_n$ (plus one H_2O for the chain ends)	Learn it
A chain of n monomers has $n - 1$ bonds; making it releases $n - 1$ water molecules, and hydrolysing it uses $n - 1$	Learn it
Glycerol + 3 fatty acids → triglyceride + 3 H_2O (three ester bonds)	Learn it
Saturated fatty acid: $C_nH_{2n}O_2$; each C=C in the tail means 2 fewer H	Learn it
Amino acid: $H_2N-CHR-COOH$; glycine has R = H	Learn it
Mass of a product of condensation = total mass of the parts – 18 for each water removed (relative masses: H = 1, C = 12, O = 16)	Learn it
Haemoglobin: 2 α + 2 β chains, 4 haem groups, 4 Fe^{2+}, up to 4 O_2	Learn it

The food test table, the polysaccharide table, the protein structure table and the water table in "Understand it" are the facts to learn by heart.

How to do it

In the 275 questions we have tagged for this topic (227 from Paper 1, 48 from Paper 2, 2021–2025), the types came up this often. 20 of the Paper 2 questions mix more than one type, so the counts add up to 302. Paper 1 questions are single multiple-choice marks; Paper 2 parts often sit inside a question on another topic.

Question type	Questions
Protein structure: amino acids, R groups, the four levels and their bonds	45
Relate polysaccharide structure to function	39
Food tests: method and results	37
Triglycerides and phospholipids: structure and function	35
Haemoglobin and collagen: structure and function	30
Condensation and hydrolysis: bonds and products	30
Hydrogen bonding in water and water's properties	23

Question type	Questions
Identify sugars: α/β-glucose, mono-/disaccharides, reducing or not	20
Count atoms, double bonds or bonds, or calculate a mass	19
Monomer, polymer, macromolecule and saccharide definitions	15
Draw or complete a structure	9

1. Protein structure: amino acids, R groups, levels and bonds (45 questions)

1. **Name the level** from the description, using the protein structure table.
2. **Name its bonds**: peptide bonds only in primary; backbone hydrogen bonds in secondary; hydrogen, ionic, disulfide and hydrophobic (all between R groups) in tertiary and quaternary.
3. **Use the R groups**: non-polar → inside (hydrophobic interactions); polar or charged → on the surface, facing water; charged → ionic bonds; only cysteine → disulfide bonds.

Variations you will meet:

- **"Which part varies?"** or **"Which is the R group?"**: whatever is on the central carbon besides H, NH_2 and COOH.
- **No cysteine**: the shape is held by hydrogen bonds, ionic bonds and hydrophobic interactions.
- **More charged and more hydrophobic amino acids** (for example in a heat-stable enzyme): more ionic bonds and more hydrophobic interactions.
- **Tertiary but not quaternary**: the protein is a single polypeptide.

2. Relate polysaccharide structure to function (39 questions)

1. **Identify the polysaccharide** from the polysaccharide table: α or β, bonds, shape.
2. **Link each feature to its role** with "so": insoluble → no effect on water potential; branched → many ends → fast hydrolysis; alternate monomers rotated → straight chains → hydrogen bonds between chains → microfibrils → tensile strength.
3. **Compare** with both sides in each point, and only features that differ.

Variations you will meet:

- **"Starch vs cellulose"**: α-glucose; monomers all the same way up; two polymers; α-1,6 branches; amylose helical; no hydrogen bonds between molecules. Not "glucose" or "1,4 bonds", which they share.
- **Unfamiliar polysaccharides** (chitin, galactogen): branched α-chains → a store like glycogen; straight chains with flipped monomers → structural like cellulose.
- **An enzyme that only breaks α-1,4 bonds** fully hydrolyses amylose, stops at the branch points of amylopectin and glycogen, and can't touch cellulose.

3. Food tests: method and results (37 questions)

1. **Match reagent, colour and molecule** with the food test table.
2. **Read results row by row**: only a colour change counts as positive.
3. **Non-reducing sugar, in order**: Benedict's (negative) → boil a new sample with dilute HCl → cool and neutralise → Benedict's and heat → colour change.

Variations you will meet:

- **Before and after hydrolysis**: negative then positive → non-reducing sugar only; positive then **more** positive → both; positive then the same → reducing sugar only.
- **A very low concentration** only reaches **green**.
- **Semi-quantitative**: list what is kept constant, use standards, and remember **shorter time = more sugar**. Concentration is the independent variable.
- **Amylase on starch**: iodine stops going blue-black and Benedict's turns positive (maltose). A boiled enzyme changes nothing.

4. Triglycerides and phospholipids (35 questions)

1. **Describe the structure**: glycerol + three fatty acids, three ester bonds, condensation; a phospholipid has two fatty acids and a phosphate group.
2. **Saturated or not?** Look for C=C, or compare the formula with $\mathrm{C}_n\mathrm{H}_{2n}\mathrm{O}_2$.
3. **Link structure to function** with the triglyceride table.

Variations you will meet:

- **Triglycerides can't form membranes**: no hydrophilic head, so no bilayer.
- **Oils vs fats**, and **membrane fluidity**: more C=C → kinks → looser packing → weaker hydrophobic interactions → liquid oil or a more fluid membrane.
- **Lipid rather than glycogen for a long journey**: more energy per gram and no stored water, so less mass to carry.

5. Haemoglobin and collagen (30 questions)

1. **Classify**: globular (soluble, physiological role) or fibrous (insoluble, structural).
2. **Haemoglobin**: give the points in the haemoglobin list, each tied to oxygen transport or solubility.
3. **Collagen**: work up the scales (polypeptide → triple helix → fibril → fibre), then link each to strength, flexibility or insolubility.

Variations you will meet:

- **The three polypeptides**: each a helix, wound tightly into a triple helix. Not α-helices.

- **What holds a fibril together**: **covalent** cross-links between R groups of neighbouring molecules; hydrogen bonds hold the chains **within** a molecule. Glycine has no sulfur, so no disulfide bonds between glycines.
- **Which part carries oxygen**: the haem group (its iron).

6. Condensation and hydrolysis: bonds and products (30 questions)

1. **Name the bond**: sugar–sugar → glycosidic; amino acid–amino acid → peptide; glycerol–fatty acid → ester.
2. **Name the reaction**: water released → condensation; water used → hydrolysis.
3. **Give the products**: maltose → 2 α-glucose; sucrose → glucose + fructose; starch or glycogen → α-glucose; triglyceride → glycerol + 3 fatty acids; protein → amino acids.

Variations you will meet:

- **Circle a glycosidic bond**: the O **between** two rings, not the O inside a ring.
- **Glycoproteins** have peptide and glycosidic bonds; **glycolipids** have ester and glycosidic bonds.
- **One condensation, one water**: only a disaccharide forms that way (a triglyceride needs three).

7. Hydrogen bonding in water and its properties (23 questions)

1. **Describe the bond**: polar molecule; δ^+ H of one molecule attracted to δ^- O of **another**.
2. **Pick the property** from the role, using the water table.
3. **Explain as a chain**: property → hydrogen bonds → role.

Variations you will meet:

- **Counting**: up to 4 per molecule; 1 between two single molecules.
- **Glycerol dissolves but a triglyceride doesn't**: glycerol's three OH groups hydrogen-bond with water; a triglyceride has none free.
- **Anything that breaks hydrogen bonds** (a detergent) lowers both the specific heat capacity and the latent heat of vaporisation.

8. Identify sugars (20 questions)

1. **α or β?** Carbon 1 is right of the ring O: OH down = α, up = β.
2. **Mono, di or poly?** Count the rings.
3. **Reducing?** Everything but sucrose, from the sugars you need to know.

Variations you will meet:

- **An unfamiliar sugar**: find the carbon where the OH has swapped sides (galactose differs from glucose at carbon 4).

- **Sucrose vs fructose**: disaccharide vs monosaccharide, non-reducing vs reducing, $\mathrm{C_{12}H_{22}O_{11}}$ vs $\mathrm{C_6H_{12}O_6}$.

9. Count atoms, double bonds or bonds, or calculate a mass (19 questions)

1. **C=O bonds**: one in every **peptide bond**, every **ester bond** and every **carboxyl group**. A protein has hundreds; a triglyceride at least 3; a saturated fatty acid exactly 1; an unsaturated fatty acid at least 2 (C=O + C=C). Glucose (straight-chain form) has 1; sucrose and glycerol have none.
2. **Hydrogens in a tail** of c carbons, $\mathrm{CH_3(CH_2)_{c-1}}$: $2c + 1$, minus 2 for each C=C. For example, a 13-carbon tail with one C=C has $27 - 2 = 25$.
3. **Peptide bonds**: $n - 1$ for one chain; $n - k$ for n amino acids in k chains.
4. **Masses**: add the parts and subtract 18 for each water removed. Haemoglobin: $2\alpha + 2\beta + 4$ haem.

10. Monomer, polymer, macromolecule definitions (15 questions)

1. **Use the definitions** in "Building blocks and big molecules": a polymer has **many repeating** monomers.
2. **Classify**: monomers (glucose, fructose, ribose, deoxyribose, amino acids); disaccharides (maltose, sucrose, lactose); polymers and macromolecules (starch, glycogen, cellulose, proteins, DNA); macromolecule but not polymer (triglyceride).

Variation: "Why is amylose a polymer but a triglyceride isn't?" Both are large; only amylose is many repeating identical units (α-glucose).

11. Draw or complete a structure (9 questions)

1. **α-glucose**: copy the first diagram, with every H and OH on the right side and OH **down** on carbon 1.
2. **Amino acid**: central C with $\mathrm{H_2N}$ left, COOH right, R above, H below (glycine: R = H).
3. **Condensation**: both monomers, the product with the new bond, and $\mathrm{H_2O}$ beside the arrow. **Hydrolysis products**: put an OH back on each carbon that was in the bond.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A student has three solutions, P, Q and R. Each contains one carbohydrate: glucose, sucrose or starch.

Test	P	Q	R
Benedict's, heated	orange	blue	blue
Iodine	yellow-brown	yellow-brown	blue-black

(a) Identify P, Q and R. **[2]**

(b) Describe how the student could confirm the identity of Q. **[4]**

(c) The student sets up a semi-quantitative Benedict's test with glucose standards and times the first colour change.

Glucose concentration / %	0.2	0.4	0.6	0.8	1.0
Time to first colour change / s	180	95	60	42	30

Solution P took 70 s. Estimate the concentration of glucose in P, and state **two** variables that must be kept the same. **[3]**

(a) P is **glucose** (reducing sugar, no starch); R is **starch** (blue-black with iodine); Q is **sucrose** (neither test positive). **B1** for two correct, **B1** for all three.

(b)

- boil a sample of Q with dilute hydrochloric acid, to hydrolyse the glycosidic bond; **B1**
- cool, then neutralise with sodium hydrogencarbonate; **B1**
- add Benedict's solution and heat in a water bath; **B1**
- a colour change from blue to green/yellow/orange/red shows a (now reducing) sugar, so Q contained the non-reducing sugar sucrose. **B1**

(c) 70 s lies between 95 s (0.4%) and 60 s (0.6%), so the concentration is **between 0.4% and 0.6%** (about 0.5%). **B1**

Any two of: the volume of sample; the volume of Benedict's solution (in excess); the temperature of the water bath; how the end point is judged. **B1 B1**

Example 2

Amylopectin and cellulose are both polymers of glucose.

(a) Name the type of reaction that joins two glucose molecules and the bond it forms. **[2]**

(b) Describe **three** ways in which the structure of amylopectin differs from the structure of cellulose. **[3]**

(c) Explain how the arrangement of cellulose molecules makes plant cell walls strong. **[3]**

(d) A short unbranched chain contains 250 glucose monomers. Calculate how many water molecules are needed to hydrolyse it completely, and the relative molecular mass of the chain. (M_r of glucose = 180, of water = 18.) **[2]**

(a) Condensation **B1**; glycosidic bond **B1**.

(b) Any three, each comparing both:

- amylopectin is made of **α-glucose**, cellulose of **β-glucose**; **B1**
- in amylopectin the monomers are all the same way up; in cellulose alternate monomers are rotated 180°; **B1**
- amylopectin has **α-1,6** bonds as well as α-1,4, so it is **branched**; cellulose has only β-1,4 bonds and is **unbranched** (straight); **B1**
- cellulose chains are held to one another by hydrogen bonds; amylopectin molecules are not. **(B1)**

(c)

- the straight chains lie parallel and form **many hydrogen bonds** between neighbouring chains; **B1**
- about 60–70 chains form a **microfibril**, and microfibrils group into fibres; **B1**
- fibres are laid in layers running in different directions, giving **high tensile strength** so the wall resists turgor pressure without bursting. **B1**

(d) 250 monomers have 249 glycosidic bonds, so hydrolysis needs **249** water molecules. **B1**

$M_r = 250 \times 180 - 249 \times 18 = 45\,000 - 4482 = 40\,518$. **B1**

Example 3

Palmitic acid is a saturated fatty acid with the formula $\mathrm{C_{16}H_{32}O_2}$. Linolenic acid has 18 carbon atoms and the formula $\mathrm{C_{18}H_{30}O_2}$.

(a) Describe how a triglyceride is formed from glycerol and fatty acids. **[3]**

(b) How many C=C double bonds does a linolenic acid molecule have? Explain your answer. **[2]**

(c) A triglyceride contains three palmitic acids. Calculate its relative molecular mass. (M_r values: glycerol 92, palmitic acid 256, water 18.) **[2]**

(d) Explain why a triglyceride made from linolenic acid is liquid at room temperature, but one made from palmitic acid is solid. **[2]**

(a)

- each of the three OH groups of glycerol reacts with the carboxyl group of a fatty acid; **B1**
- by **condensation**, releasing a water molecule each time (three in all); **B1**
- forming three **ester** bonds. **B1**

(b) A saturated fatty acid with 18 carbons would be $\mathrm{C_{18}H_{36}O_2}$ ($\mathrm{C_nH_{2n}O_2}$). Linolenic acid has 6 fewer hydrogens **M1**, and each C=C removes 2, so it has **3** C=C double bonds. **A1**

(c) $92 + 3 \times 256 - 3 \times 18 = 92 + 768 - 54 = 806$. **M1** for subtracting three waters, **A1**

(d) The C=C double bonds put **kinks** in the linolenic acid tails, so the molecules can't pack closely together **B1**; there are fewer/weaker hydrophobic interactions between them, so the melting point is lower and the fat is liquid. The straight saturated palmitic acid tails pack tightly, so that fat is solid. **B1**

Example 4

Haemoglobin is a globular protein and collagen is a fibrous protein.

(a) An enzyme with quaternary structure is made of four polypeptides: two of 120 amino acids and two of 95. Calculate the number of peptide bonds in one molecule of the enzyme. **[2]**

(b) Describe the quaternary structure of haemoglobin, and explain how its structure suits its function. **[4]**

(c) Explain why glycine, which has the smallest R group of any amino acid, is found at every third position in each collagen polypeptide. **[2]**

(d) When a muscle contracts, its tendon is pulled hard but does not snap. Explain how the structure of the collagen fibres in the tendon makes this possible. **[3]**

(a) Amino acids: $2 \times 120 + 2 \times 95 = 430$ in four separate chains. **M1**

Each chain of n amino acids has $n - 1$ peptide bonds: $2 \times 119 + 2 \times 94 = 426$ (that is, $430 - 4$). **A1**

(b) Any four:

- four polypeptides: two α-globin and two β-globin; **B1**
- each with a haem group containing an iron ion ($\mathrm{Fe^{2+}}$); **B1**
- each $\mathrm{Fe^{2+}}$ binds one oxygen molecule, so one haemoglobin carries up to four $\mathrm{O_2}$; **B1**
- hydrophilic R groups on the outside make it soluble, so it stays dissolved in red blood cells; **B1**
- hydrophobic R groups inside help keep its precise compact shape. **(B1)**

(c) Glycine's R group is a single H, so it can fit in the crowded centre of the triple helix **B1**, allowing the three polypeptides to wind tightly and closely together (held by hydrogen bonds). **B1**

(d)

Any three:

- each molecule is a tightly wound triple helix, held by many hydrogen bonds between its three chains; **B1**
- neighbouring molecules lie **parallel**, joined by strong **covalent cross-links** between R groups; **B1**
- the molecules are **staggered**, so their ends don't line up and there is no weak point along a fibril; **B1**
- many fibrils bundle into fibres, so the pulling force is shared across a large number of molecules. **(B1)**

Hydrogen bonds hold the three chains together **within** a molecule; they are not what joins molecules in a fibril.

Common mistakes

- **Mixing up which bonds hold which structure.** Examiners see "peptide bonds hold the tertiary structure" and "glycosidic bonds hold cellulose chains together" every year. Check each bond against the protein and polysaccharide tables before you write it.
- **Treating a positive Benedict's test as proof of a non-reducing sugar.** It only shows a reducing sugar. Non-reducing sugar needs a change **after** hydrolysis that wasn't there before, or a bigger one.
- **Leaving out neutralising**, or naming Benedict's as the test for starch or protein.
- **Calling triglycerides polar**, or forgetting their C=O bonds: every ester bond has one, so every triglyceride has at least three double bonds.
- **Swapping specific heat capacity and latent heat of vaporisation.** Stable temperature is specific heat capacity; cooling by evaporation is latent heat.
- **Drawing hydrogen bonds between two H atoms, two O atoms, or within one molecule.**
- **Saying cellulose has both α- and β-1,4 bonds**, or that it forms a triple helix like collagen.
- **Writing that the haemoglobin chains carry oxygen**, or that one haem carries several O_2.
- **Vague words** such as "sugar bond", "breaks down" or "strong": name the bond, the reaction and the property.

How to get the marks

- **"State" and "name"** need one precise term: "glycosidic bond", "hydrolysis", "biuret reagent", "haem group". "Sugar bond" or "breaks down" scores nothing.
- **"Describe"** a test: give the **reagent**, the **condition** (heat, add acid, neutralise), and the **colour change** from and to ("blue to purple", not just "purple").
- **"Describe the structure"** needs the name of the monomer (α- or β-glucose), the bond with its carbons (α-1,4, α-1,6) and the shape (helix, branched, straight).
- **"Explain"** or **"relate structure to function"**: each mark is a feature **linked** to its use with "so" or "because": "insoluble, **so** it does not affect water potential".
- **"Compare"** or **"differences"**: both sides in every point, and only features that really differ.
- **"Suggest"** means use what you know on something new (chitin, an unfamiliar protein, a mutated enzyme). Say which known molecule it resembles and why.
- **Drawings**: every atom in the right place; the α-glucose carbon 1 OH must point down; show water leaving (condensation) or entering (hydrolysis) beside the arrow.
- **Calculations**: show the working; a correct method usually earns a mark even with a slip.
- **Multiple choice with numbered statements**: judge each statement on its own, then choose the option that matches.

Quick check

1. A sample of food stays blue when heated with Benedict's solution. Another sample is boiled with dilute acid, neutralised and heated with Benedict's solution; it turns orange. What does the food contain, and why was the acid needed?
2. How many water molecules are released when (a) one triglyceride forms, (b) a polypeptide of 120 amino acids forms?
3. A fatty acid has the formula $\mathrm{C_{20}H_{32}O_2}$. How many C=C double bonds does it have?
4. Which of these contain at least three C=O double bonds: sucrose, a saturated fatty acid, a saturated triglyceride, haemoglobin?
5. Explain why sweating cools the body.

Answers

1. A **non-reducing sugar** (such as sucrose) and no reducing sugar. The acid **hydrolyses** the glycosidic bonds, releasing reducing monosaccharides (glucose and fructose) that then react with Benedict's solution.
2. (a) **3** (one per ester bond). (b) $120 - 1 =$ **119** (one per peptide bond).
3. A saturated fatty acid with 20 carbons would be $\mathrm{C_{20}H_{40}O_2}$. This one has $40 - 32 = 8$ fewer hydrogens, and each C=C removes 2, so it has **4** C=C double bonds.
4. The **saturated triglyceride** (one C=O in each of its three ester bonds, so 3) and **haemoglobin** (a C=O in every one of its hundreds of peptide bonds). Sucrose has none; a saturated fatty acid has only 1.
5. Water has a **high latent heat of vaporisation**: a lot of energy is needed to break the hydrogen bonds between water molecules so that they can evaporate. That energy is taken as heat from the skin, so evaporating a small amount of sweat removes a lot of heat.

Past questions to try

- **9700/21/M/J/23 Q2**: the structures of glycogen and cellulose compared, and how they suit their roles.
- **9700/23/M/J/24 Q2**: the structure of collagen molecules and fibres.
- **9700/21/M/J/22 Q4**: triglyceride formation and why triglycerides are not used in membranes.
- **9700/21/M/J/21 Q2**: hydrogen bonding in water and in protein structure.