MEGA LECTURE

IB DP BIOLOGY

Theme B: Form and Function

B1.1 Carbohydrates and Lipids

Revision Notes · Standard and Higher Level

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Original notes prepared for the IB Diploma Programme Biology course (first assessment 2025)

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What the syllabus requires

B1.1 introduces the two great families of energy-related biological molecules: carbohydrates and lipids. Use this checklist to confirm you can meet every understanding before the exam.

Understanding	You should be able to...
Carbon and macromolecules	Explain why carbon, with four covalent bonds, is the framework of biological molecules, and how monomers join into macromolecules.
Condensation and hydrolysis	Describe how condensation joins subunits with the loss of water, and how hydrolysis breaks them apart with the addition of water.
Monosaccharides	State the formula $C_6H_{12}O_6$, recognise α- and β-glucose, ribose and fructose, and their role as an energy source.
Disaccharides	Name maltose, sucrose and lactose and identify the monosaccharides and glycosidic bond that make each.
Polysaccharides	Relate the structure of starch, glycogen and cellulose to their storage or structural function.
Lipids	Describe triglycerides, phospholipids and steroids, and the bonds that form them.
Fatty acids	Distinguish saturated, unsaturated, cis and trans forms and link them to melting point, fluidity and health.
Comparing energy stores	Compare lipids and carbohydrates as storage compounds.

> **Exam note:** Most of B1.1 is common to SL and HL. Points marked **(HL)** in these notes are examined only at Higher Level, but reading them will deepen your SL answers too.

1. Carbon: the backbone of life

Almost every molecule that makes up a living organism is built on a skeleton of carbon atoms. The chemistry of life is, to a large extent, the chemistry of carbon compounds, and understanding why carbon is so versatile explains the structures of everything that follows in this topic.

Why carbon?

- A carbon atom forms **four covalent bonds**. This lets it bond to up to four other atoms at once and build stable, three-dimensional structures.
- Carbon bonds readily to **other carbon atoms**, forming long **chains**, branched skeletons and closed **rings**. This gives an almost unlimited variety of molecular shapes.
- It also bonds to hydrogen, oxygen, nitrogen, phosphorus and sulfur, so a huge range of functional groups (and therefore properties) can be attached to the same carbon framework.
- Carbon-carbon and carbon-hydrogen bonds are **strong and stable**, so the molecules built from them persist long enough to do their biological jobs.

Monomers and macromolecules

Large biological molecules are usually **polymers** (macromolecules): long molecules built by joining many small repeating units called **monomers**. Because the same few monomers are combined in different

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numbers and orders, cells produce an enormous diversity of molecules from a limited toolkit.

Macromolecule	Monomer (subunit)	Example role
Polysaccharide	Monosaccharide (e.g. glucose)	Energy storage; structural support
Polypeptide / protein	Amino acid	Enzymes, transport, structure
Nucleic acid	Nucleotide	Storage of genetic information

Lipids such as triglycerides are large molecules too, but they are **not** polymers: they are assembled from a small, fixed number of subunits (one glycerol and three fatty acids) rather than a long repeating chain. This is a common exam distinction.

Functional groups

The carbon skeleton is chemically rather unreactive on its own; the **functional groups** attached to it give a molecule its characteristic properties and reactions. A few appear again and again in this topic: the **hydroxyl** group (–OH) makes sugars and glycerol soluble and takes part in condensation; the **carboxyl** group (–COOH) makes fatty acids weakly acidic and forms ester bonds; and the **phosphate** group gives a phospholipid head its charge. Recognising these groups helps you predict how a molecule behaves.

> **Definition check:** A **monomer** is a single repeating unit; a **polymer** is many monomers joined; a **macromolecule** is any very large molecule. All polymers are macromolecules, but not every macromolecule (a triglyceride, for instance) is a polymer.

2. Condensation and hydrolysis

Cells build and break down almost all of their large molecules using the same pair of opposite reactions. Learning them once tells you how carbohydrates, lipids, proteins and nucleic acids are all made and digested.

Condensation

In a **condensation** reaction two subunits are joined by a new covalent bond, and a molecule of **water is released**. One subunit loses an –OH group and the other loses an –H; together these form the water. Building a polymer of n monomers therefore releases $n - 1$ molecules of water.

$$\textbf{monomer –OH + HO– monomer} \rightarrow \textbf{monomer–O–monomer + } H_2O$$

Hydrolysis

Hydrolysis is the reverse: a molecule of **water is added** across a bond to split one large molecule into two smaller ones. The word means “water splitting” (*hydro* = water, *lysis* = breaking). This is how digestion breaks food polymers into absorbable monomers.

$$\textbf{monomer–O–monomer + } H_2O \rightarrow \textbf{monomer –OH + HO– monomer}$$

Feature	Condensation	Hydrolysis
Overall effect	Builds larger molecules (anabolic)	Breaks down larger molecules (catabolic)
Water	Released (one per bond formed)	Added (one per bond broken)

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Feature	Condensation	Hydrolysis
Bond	New covalent bond formed	Covalent bond broken
Biological example	Synthesising glycogen or a triglyceride	Digesting starch; mobilising fat stores

> **Memory hook:** Con**densation** con**denses** two molecules into one and squeezes out water; hydro**lysis** uses water to **lyse** (break) a molecule apart.

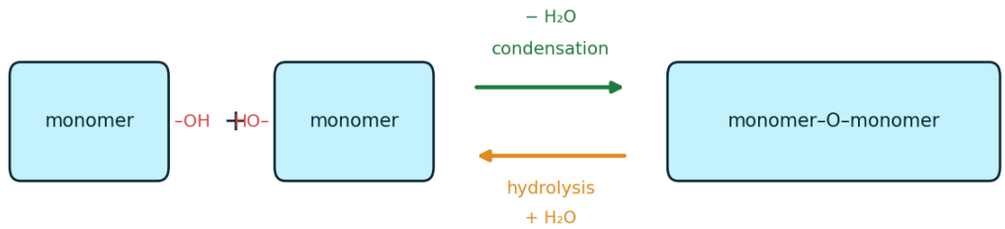


Figure 1. Condensation joins two subunits with a new covalent bond and releases one water molecule; hydrolysis is the exact reverse, adding one water molecule to break the bond. Joining n monomers forms n − 1 bonds and releases n − 1 water molecules (e.g. 5 monomers → 4 H_2O).

3. Monosaccharides

Monosaccharides (“single sugars”) are the simplest carbohydrates and the monomers from which larger carbohydrates are built. Most contain carbon, hydrogen and oxygen in the ratio expressed by the general formula $(CH_2O)_n$, and the hexoses (six-carbon sugars) share the molecular formula $C_6H_{12}O_6$.

Monosaccharide	Carbons	Formula	Note
Glucose	6 (hexose)	$C_6H_{12}O_6$	Main respiratory substrate; exists as α and β forms
Fructose	6 (hexose)	$C_6H_{12}O_6$	Fruit sugar; same formula as glucose, different structure (an isomer)
Galactose	6 (hexose)	$C_6H_{12}O_6$	Combines with glucose to form lactose
Ribose	5 (pentose)	$C_5H_{10}O_5$	Sugar of RNA and of nucleotides such as ATP

Alpha and beta glucose

In water, glucose closes into a six-membered ring. Depending on how the ring forms, the –OH group on carbon 1 can point **below** the ring (α-glucose, alpha) or **above** it (β-glucose, beta). The two forms have the same formula but a different arrangement at one carbon. This tiny difference has enormous consequences: α-glucose builds starch and glycogen, while β-glucose builds cellulose, and the resulting molecules could hardly be more different in their properties.

Function as an energy source

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Glucose is the central fuel of metabolism. Its carbon-hydrogen bonds hold chemical energy that is released in a controlled way during **cell respiration**, transferring energy to ATP. Being small and soluble, glucose is also easily **transported** in blood (in animals) and, as sucrose, in phloem (in plants). Its solubility is useful for transport but, as we will see, makes it a poor long-term store.

Pentoses and the wider role of sugars

Not all monosaccharides are fuels. The pentose **ribose** (and its relative deoxyribose) forms part of the sugar-phosphate backbone of nucleic acids and of energy-carrying molecules such as ATP. Monosaccharides also join to proteins and lipids on cell surfaces, where they act in cell recognition. So although you meet sugars first as an energy source, the same small molecules are used as **building blocks** and **recognition markers** too.

> **Watch the formula:** Always write $C_6H_{12}O_6$ with proper subscripts. Glucose, fructose and galactose are **isomers** – same atoms, different arrangement, different properties.

4. Disaccharides

A **disaccharide** forms when two monosaccharides join by condensation. The new bond linking them is a **glycosidic bond**, and a molecule of water is released as it forms. Three disaccharides are named in the course.

Disaccharide	Monosaccharides joined	Where found
Maltose	Glucose + glucose	Germinating seeds; product of starch digestion
Sucrose	Glucose + fructose	Transport sugar in plants (table sugar)
Lactose	Glucose + galactose	Sugar in mammalian milk

Because each disaccharide is held together by a glycosidic bond, each can be split back into its monosaccharides by **hydrolysis** – for example, the enzyme lactase hydrolyses lactose into glucose and galactose during digestion.

$$\textbf{glucose + fructose} \rightarrow \textbf{sucrose + } H_2O$$

> **Common trap:** Sucrose and maltose both contain glucose, but only maltose is glucose + glucose. Learn the partner sugar for each: malt**ose** = two glucose, su**crose** = glucose + fructose, lact**ose** = glucose + galactose.

5. Polysaccharides

Polysaccharides are polymers of many monosaccharides joined by glycosidic bonds. The three you must know – starch, glycogen and cellulose – are all made from glucose, yet they behave completely differently. The reason is a textbook example of the **structure determines function** principle.

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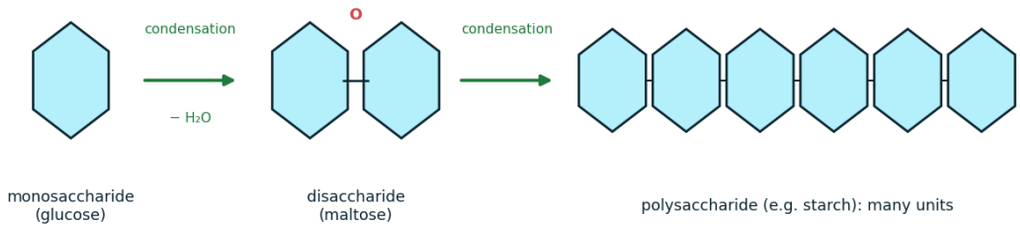


Figure 2. Carbohydrates are built up in stages: a monosaccharide (glucose) → two joined by a glycosidic bond give a disaccharide (maltose) → many joined give a polysaccharide (starch). Every glycosidic bond forms by condensation, releasing one water; the 6-unit chain shown contains 5 bonds.

Starch (energy storage in plants)

Starch is a store of α-glucose in plant cells, laid down as grains in chloroplasts, seeds and tubers. It is a mixture of two molecules: **amylose**, an unbranched chain that coils into a compact helix, and **amylopectin**, which is branched. Being **insoluble** and coiled, starch is an excellent store: it does not affect the cell's water balance and packs many glucose units into a small space, ready to be hydrolysed when energy is needed.

Glycogen (energy storage in animals)

Glycogen is the animal equivalent, stored mainly in liver and muscle cells. It too is a polymer of α-glucose, but it is **more highly branched** than amylopectin. The many branch ends can be added to or removed from quickly, so glycogen can be built up or broken down rapidly – ideal for animals with high, variable energy demands. Like starch it is compact and insoluble.

Cellulose (structural support in plants)

Cellulose is a polymer of β-glucose and forms the main component of plant **cell walls**. Because alternate β-glucose units are flipped when they join, cellulose forms **straight, unbranched chains** rather than a helix. Many parallel chains lie side by side and are cross-linked by large numbers of **hydrogen bonds**, bundling into strong fibres. This gives the cell wall great tensile strength, letting it resist the outward pressure of water entering the cell and stopping the cell from bursting.

Polysaccharide	Monomer	Structure	Function	Found in
Starch (amylose + amylopectin)	α-glucose	Amylose helical & unbranched; amylopectin branched; insoluble	Energy storage	Plant cells (seeds, tubers, chloroplasts)
Glycogen	α-glucose	Highly branched; compact; insoluble	Energy storage, rapidly mobilised	Animal liver and muscle
Cellulose	β-glucose	Straight chains H-bonded into strong fibres	Structural strength	Plant cell walls

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> **Key comparison:** Starch/glycogen use α-glucose → coiled or branched stores that enzymes reach easily. Cellulose uses β-glucose → straight, H-bonded fibres for strength. Same sugar, one structural detail, opposite jobs.

6. Lipids

Lipids are a diverse group of molecules that share one defining property: they are largely **non-polar**, so they are **insoluble in water** (hydrophobic) but dissolve in organic solvents. The three groups named in the course are triglycerides, phospholipids and steroids.

Triglycerides

A **triglyceride** is formed by condensation of one molecule of **glycerol** with **three fatty acids**. Each fatty acid joins to the glycerol by an **ester bond**, and each bond formed releases one molecule of water (three in total). Triglycerides are the fats and oils used for long-term **energy storage**, for **thermal insulation** and, in some animals, for **buoyancy** and protection of organs.

$$\textbf{glycerol + 3 fatty acids} \rightarrow \textbf{triglyceride + 3 } H_2O$$

Phospholipids

A **phospholipid** resembles a triglyceride but with one fatty acid replaced by a **phosphate group**. This makes the molecule **amphipathic** – it has two parts of opposite character: a **hydrophilic ("water-loving") head** containing the phosphate, and two **hydrophobic ("water-fearing") tails** of fatty acid. In water, phospholipids arrange themselves so that the heads face the water and the tails hide from it, forming a **bilayer** – the basis of every cell membrane.

Steroids

Steroids have a quite different structure: four fused carbon rings. **Cholesterol** is a steroid that sits among the phospholipids of animal membranes and helps regulate their fluidity; it is also the raw material from which steroid hormones such as testosterone and oestrogen are made. You need only a brief awareness of steroids at this level.

Functions of lipids

- **Long-term energy storage** as triglycerides in adipose tissue and in seeds.
- **Thermal insulation** – a subcutaneous fat layer reduces heat loss.
- **Membrane structure** – phospholipids form the bilayer of every cell membrane.
- **Protection and cushioning** of delicate organs such as the kidneys.
- **Hormones** – steroid hormones are lipids, and cholesterol is their precursor.
- **Buoyancy** in some aquatic animals, because fat is less dense than water.

> **Amphipathic = the key word:** In an exam, a phospholipid's behaviour is explained by one term: **amphipathic**. Hydrophilic phosphate head outward, hydrophobic tails inward → bilayer. State all three parts to score fully.

7. Fatty acids: saturated, unsaturated, cis and trans

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The fatty acid tails of triglycerides and phospholipids differ in the bonds between their carbon atoms, and these differences change the whole molecule's melting point, fluidity and effect on health.

Type	Bonding in carbon chain	Typical state at room temp.	Example source
Saturated	No C=C double bonds; chain "saturated" with hydrogen; straight	Solid (fat)	Animal fats, butter
Unsaturated	One or more C=C double bonds	Liquid (oil)	Plant and fish oils
Monounsaturated	Exactly one C=C double bond	Liquid	Olive oil
Polyunsaturated	Two or more C=C double bonds	Liquid	Sunflower, fish oils

Why the melting point differs

A double bond in a **cis** configuration puts a permanent **kink** in the fatty acid tail. Kinked chains cannot pack together closely, so the intermolecular forces between them are weaker and the fat melts at a **lower temperature** (it is a liquid oil). Saturated chains are straight, pack tightly, attract each other strongly and so melt at a **higher temperature** (a solid fat). The same logic explains membrane fluidity: more unsaturated (kinked) tails keep a membrane more fluid.

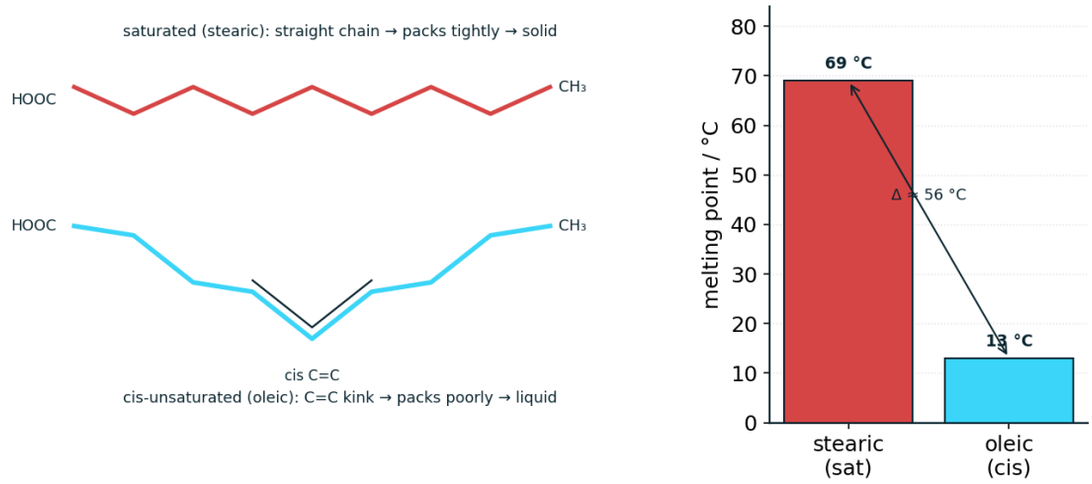


Figure 3. A saturated fatty acid (e.g. stearic acid) has a straight chain that packs tightly, giving a high melting point (≈ 69 °C, solid). A cis-unsaturated fatty acid (e.g. oleic acid) has a C=C double bond that kinks the chain, so it packs poorly and melts far lower (≈ 13 °C, liquid) — a difference of about 56 °C.

Cis and trans

Around a C=C double bond, the chain can take two shapes. In the **cis** form the two chain segments are on the **same side**, producing the kink typical of natural unsaturated fats. In the **trans** form they are on **opposite sides**, so the chain stays almost straight and behaves like a saturated fat. Most trans fats in the diet are produced artificially by hydrogenating oils. They are associated with raised risk of cardiovascular disease, which is why many countries now restrict them.

> **Health link:** Diets high in **saturated** and especially **trans** fats are linked to higher blood cholesterol and heart disease; **cis-unsaturated** fats are generally regarded as healthier. Remember: structure (straight vs kinked) drives both melting point and health effect.

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8. Lipids vs carbohydrates for energy storage

Both fats and carbohydrates store chemical energy, but organisms use them differently. Comparing them is a favourite exam question, so learn the reasons, not just the conclusions.

Property	Lipids (fats)	Carbohydrates (glycogen/starch)
Energy density	About twice the energy per gram (more C–H bonds)	Lower energy per gram
Solubility	Insoluble in water	Larger polysaccharides also insoluble
Osmotic effect	None – does not draw water into cells	None as polymer; but glucose monomers are osmotically active
Mass carried	Light store for the energy held → good for long-term reserves	Heavier store for the same energy
Speed of release	Slower to mobilise and respire	Faster to mobilise – good for quick demand
Typical use	Long-term storage, insulation, buoyancy	Short-term, readily available energy

In short, lipids are the better **long-term** store because they hold more energy per gram without adding mass or disturbing water balance, while carbohydrates are better for energy that must be released **quickly**.

> **Osmosis point:** Storing energy as insoluble starch or glycogen (rather than as free glucose) means the store does **not** lower the cell's water potential, so water is not drawn in by osmosis. This is a frequently rewarded marking point.

9. Higher Level extensions (HL)

The following points extend the core ideas and are assessed only at Higher Level, though they build directly on the SL material above.

Cellulose microfibrils (HL)

- Many parallel cellulose chains are held together by hydrogen bonds to form bundles called **microfibrils**, which in turn group into larger fibres. Although each hydrogen bond is weak, their vast number makes the whole fibre extremely strong.
- Microfibrils are laid down in layers at different angles within the cell wall, giving strength in several directions while still allowing water and solutes to pass through.
- This structural strength lets the wall resist turgor pressure, supporting non-woody plants and helping to hold plants upright.

Phospholipid bilayer properties (HL)

- Because the hydrophobic tails face inward and the hydrophilic heads face the water on both sides, the bilayer is **stable** in an aqueous environment and will spontaneously re-seal if disrupted.
- The non-polar core makes the membrane a **barrier** to large and charged particles, while small non-polar molecules can pass through – the basis of selective permeability.
- The degree of unsaturation of the tails and the amount of cholesterol present together tune the **fluidity** of the membrane.

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Adipose tissue and insulation (HL)

In animals, triglycerides are stored in **adipose tissue** beneath the skin and around organs. Because fat conducts heat poorly, a subcutaneous fat layer provides **thermal insulation** – important in marine mammals such as whales and seals (blubber). Adipose tissue also cushions and protects organs and, being a concentrated energy store, provides a long-term reserve.

Cholesterol transport: LDL and HDL (HL)

Because lipids are insoluble, cholesterol travels in the blood packaged with proteins as **lipoproteins**. **Low-density lipoprotein (LDL)** carries cholesterol to tissues; a high LDL level is associated with the build-up of fatty deposits in artery walls and a raised risk of cardiovascular disease. **High-density lipoprotein (HDL)** carries excess cholesterol back to the liver and is generally regarded as protective. Diets high in saturated and trans fats tend to raise LDL, linking fatty acid structure back to health.

> **HL exam tip:** When explaining cellulose strength or membrane stability, always connect the molecular detail (H-bonds; hydrophilic/hydrophobic regions) to the property (tensile strength; a stable, selectively permeable barrier).

10. Skills and worked examples

These examples rehearse the exact reasoning examiners look for. Cover the answers and attempt each before reading on.

Worked example 1 – identifying bond types

Name the bond joining (a) two glucose molecules in maltose, and (b) a fatty acid to glycerol in a triglyceride.

(a) A **glycosidic bond** links the two monosaccharides.

(b) An **ester bond** links each fatty acid to glycerol.

In both cases the bond forms by **condensation**, releasing water.

Worked example 2 – condensation or hydrolysis?

During digestion in the small intestine, sucrose is converted to glucose and fructose. State the type of reaction and what happens to water.

This is **hydrolysis**: a large molecule is split into two smaller ones.

A molecule of **water is added** across the glycosidic bond as it is broken. (The reverse, joining glucose and fructose into sucrose, would be condensation and would release water.)

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Worked example 3 – why is cellulose strong?

Explain how the structure of cellulose makes it suitable for plant cell walls. (3 marks)

- Cellulose is made of β-glucose, so alternate units are inverted, giving **straight, unbranched chains**.
- Many parallel chains are cross-linked by numerous **hydrogen bonds**, bundling them into strong fibres (microfibrils).
- The resulting high **tensile strength** lets the wall resist turgor pressure and prevent the cell bursting.

Worked example 4 – comparing storage molecules

A student claims that plants and animals should store all their energy as glucose because glucose is the fuel for respiration. Give two reasons why storing it as starch or glycogen is better.

- Starch and glycogen are **insoluble**, so they do not affect the cell's water potential; free glucose would draw in water by osmosis.
- They are **compact** polymers that pack many glucose units into a small space and can be hydrolysed to release glucose when needed.

Worked example 5 – melting point reasoning

Butter (mostly saturated fat) is solid at room temperature; olive oil (mostly unsaturated) is liquid. Explain the difference.

Unsaturated fatty acids contain **cis C=C double bonds** that put **kinks** in their tails. Kinked chains cannot pack closely, so intermolecular forces are weaker and the fat melts at a **lower** temperature (liquid oil). Saturated chains are straight, pack tightly and melt at a **higher** temperature (solid fat).

Identifying molecules in the lab

Simple colour tests let you detect these molecules in a sample – a common practical and data-interpretation skill.

Molecule	Test	Positive result
Reducing sugar (e.g. glucose)	Heat with Benedict's solution	Blue → green/yellow/brick-red precipitate
Starch	Add iodine solution	Orange-brown → blue-black
Lipid	Shake sample with ethanol, then add water (emulsion test)	Cloudy white emulsion forms

The colour change with Benedict's can be treated as semi-quantitative: the more reducing sugar present, the further the colour shifts towards brick-red, so the test can compare the sugar content of different samples.

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Common pitfalls

- Forgetting that α- and β-glucose differ by only one –OH position, yet this single difference decides whether the polymer is a store (starch/glycogen) or a structural fibre (cellulose).
- Writing that condensation *uses* water. It **releases** water; hydrolysis uses (adds) water.
- Describing a phospholipid as simply “hydrophobic”. It is **amphipathic**: a hydrophilic head and hydrophobic tails.
- Calling a triglyceride a polymer. It is a large molecule but not a polymer, and glycerol is not a fatty acid.
- Confusing the disaccharide partners – check which monosaccharides make maltose, sucrose and lactose.
- Quoting “insoluble” as a benefit of starch without explaining *why* (no osmotic effect).

Quick-reference table

Item	Key facts
Condensation	Joins subunits, forms a bond, **releases** H_2O
Hydrolysis	Splits a molecule, breaks a bond, **adds** H_2O
Glucose	$C_6H_{12}O_6$; α and β ring forms; respiratory fuel
Disaccharides	Maltose (glu+glu), sucrose (glu+fru), lactose (glu+gal); glycosidic bond
Starch / glycogen	α-glucose; branched/coiled; insoluble energy store
Cellulose	β-glucose; straight H-bonded fibres; cell-wall strength
Triglyceride	Glycerol + 3 fatty acids; ester bonds; energy store, insulation
Phospholipid	Amphipathic; hydrophilic head + hydrophobic tails; bilayer
Saturated vs unsaturated	No C=C (straight, solid) vs C=C kinks (cis, liquid)

Test yourself

Attempt all eight without notes, then check the worked answers below.

1. State two features of a carbon atom that make it suited to forming biological molecules.

2. Describe what happens to water when three fatty acids join a glycerol molecule.

3. Name the monosaccharides that form (a) maltose, (b) sucrose, (c) lactose.

4. Explain why starch is a better storage molecule than glucose in a plant cell.

5. Cellulose and starch are both polymers of glucose. Explain why only cellulose provides structural strength.

6. Explain, in terms of structure, why an oil is liquid but a saturated fat is solid at room temperature.

7. Explain the term *amphipathic* and how it leads phospholipids to form a bilayer.

8. Give two reasons why a hibernating mammal stores energy mainly as fat rather than as glycogen.

Worked answers

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1. A carbon atom forms **four covalent bonds**, and it can bond to other carbon atoms to build chains, branches and rings; this allows a huge variety of stable molecular structures.

2. Each fatty acid joins glycerol by an ester bond in a **condensation** reaction, and one molecule of water is released per bond, so **three molecules of water** are released in total.

3. (a) glucose + glucose; (b) glucose + fructose; (c) glucose + galactose.

4. Starch is **insoluble**, so it does not lower the cell's water potential and does not draw in water by osmosis; it is also **compact**, packing many glucose units into a small space, and can be **hydrolysed** to release glucose when energy is needed.

5. Cellulose is made of β-glucose, so alternate units are inverted, giving **straight chains** that lie parallel and are held together by many **hydrogen bonds** into strong fibres. Starch is made of α-glucose, which forms coiled or branched molecules suited to storage, not support.

6. Oils contain **cis-unsaturated** fatty acids whose C=C double bonds put **kinks** in the tails; the molecules cannot pack closely, intermolecular forces are weaker and the melting point is **low** (liquid). Saturated fats have straight chains that pack tightly with stronger forces, giving a **higher** melting point (solid).

7. **Amphipathic** means a molecule has both a hydrophilic and a hydrophobic region. A phospholipid has a hydrophilic phosphate **head** and two hydrophobic fatty-acid **tails**. In water the heads face the water and the tails point away from it, so two layers form with tails inward and heads outward – a **bilayer**.

8. Fat stores about **twice the energy per gram** of glycogen, so it is a lighter store for the same energy; it is **insoluble** with no osmotic effect; and a subcutaneous fat layer also gives **thermal insulation** – valuable during hibernation. (Any two.)

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