

Carbohydrates and lipids

Revision notes · IB Biology B1.1: carbon bonding, condensation, hydrolysis, sugars, starch, glycogen, cellulose, glycoproteins, triglycerides, phospholipids and steroids.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Carbohydrates and lipids **Spec B1.1**

Carbon atoms and the diversity of carbon compounds **Spec B1.1.1**

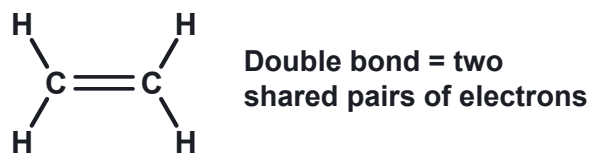
Life is based on carbon compounds. Carbohydrates, lipids, proteins and nucleic acids all have a skeleton of carbon atoms. The reason lies in how carbon bonds.

Covalent bond	A bond formed when two atoms share a pair of electrons. Covalent bonds are strong, so molecules built from them are stable.
Single bond	One shared pair of electrons, e.g. C-C or C-H.
Double bond	Two shared pairs of electrons, e.g. C=C in unsaturated fatty acids or C=O in a carboxyl group.

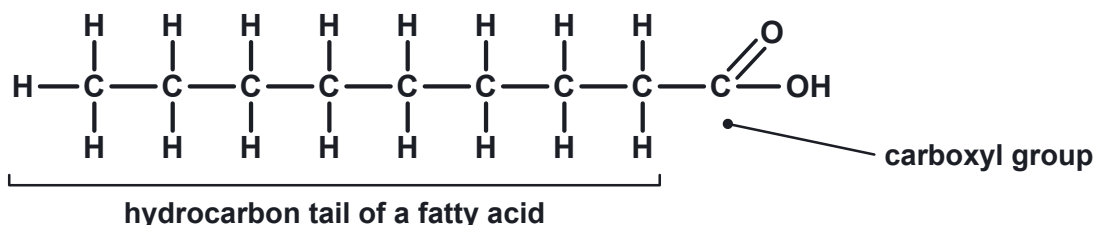
A carbon atom has four electrons in its outer shell, so it can form **up to four covalent bonds**. These can be four single bonds, or a combination of single and double bonds. Carbon can bond to other carbon atoms and to atoms of other non-metallic elements, mainly hydrogen, oxygen, nitrogen, sulfur and phosphorus.

Because carbon atoms bond to each other, they can form a huge range of skeletons. This is why there is **a diversity of carbon compounds** in living things.

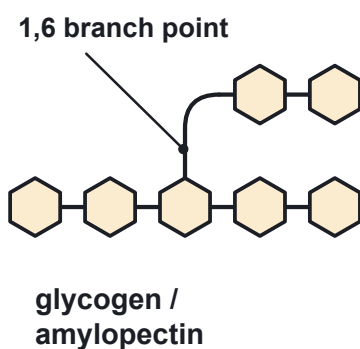
Shapes of carbon skeletons, with examples	
Skeleton	Example in living things
Unbranched chain	The hydrocarbon tail of a fatty acid; amylose in starch
Branched chain	Amylopectin and glycogen, with side branches of glucose
Single ring	Glucose (a six-membered ring); ribose (a five-membered ring)
Multiple rings	Steroids such as testosterone (four fused rings); the double ring of adenine



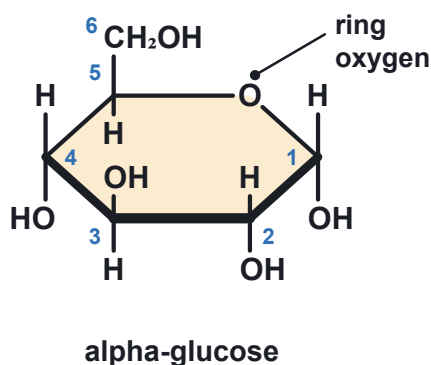
Unbranched chain



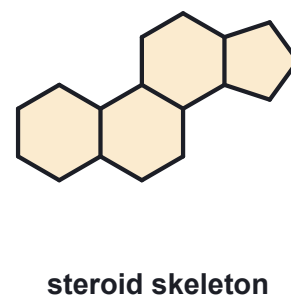
Branched chain



Single ring



Multiple rings



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Carbon forms up to **four covalent bonds**, so it can build unbranched chains, branched chains, single rings and multiple rings.

Maths skill: SI prefixes are agreed internationally, so all scientists use them the same way: kilo (k) = 10^3 , centi (c) = 10^{-2} , milli (m) = 10^{-3} , micro (μ) = 10^{-6} , nano (n) = 10^{-9} . Molecule sizes are usually given in nm.

Converting between SI prefixes

Convert a length of $0.025 \mu\text{m}$ into nm.

- $1 \mu\text{m} = 10^{-6} \text{ m}$ and $1 \text{ nm} = 10^{-9} \text{ m}$, so $1 \mu\text{m} = 1000 \text{ nm}$.
- $0.025 \mu\text{m} \times 1000 = 25 \text{ nm}$.

Answer: 25 nm

Condensation and hydrolysis reactions Spec B1.1.2, B1.1.3

Macromolecules are large molecules built from many small units called monomers. A chain of monomers is a polymer.

Condensation: building polymers

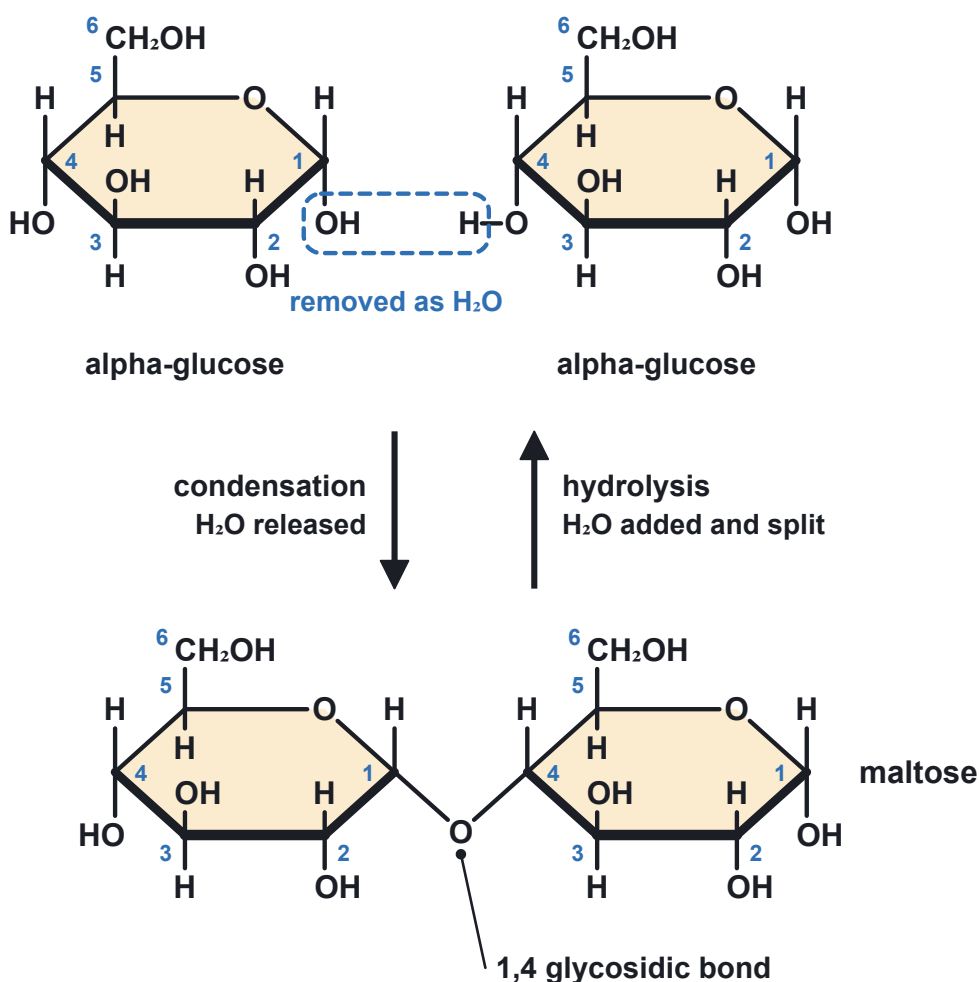
In a **condensation reaction**, two monomers are linked by a covalent bond. An -OH from one monomer and an -H from the other are removed and combine to form **water**. Repeating this links monomers into a polymer. Condensation reactions are catalysed by enzymes and need energy, usually supplied by ATP.

Polymers made by condensation		
Polymer	Monomer	Bond formed
Polysaccharide (starch, glycogen, cellulose)	Monosaccharide (e.g. glucose)	Glycosidic bond
Polypeptide	Amino acid	Peptide bond
Nucleic acid (DNA, RNA)	Nucleotide	Phosphodiester bond

Hydrolysis: digesting polymers

In **hydrolysis**, a water molecule is split. Its $-H$ and $-OH$ groups are added to the two monomers on either side of the bond, so the bond breaks and monomers are released. That is where the name comes from: hydro (water) and lysis (splitting).

Digestion of food in the gut is hydrolysis catalysed by enzymes: amylase hydrolyses starch, proteases hydrolyse polypeptides and lipases hydrolyse triglycerides. Hydrolysis also happens inside cells, for example when glycogen is broken down to release glucose.



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Condensation removes water to form a **1,4 glycosidic bond** in maltose; **hydrolysis** splits a water molecule to break it again.

Common mistake: Water is produced by condensation and used up by hydrolysis. Say that hydrolysis splits a water molecule, not just that it adds water.

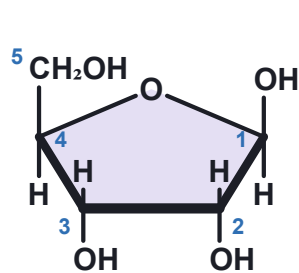
Monosaccharides: form and function Spec B1.1.4

Monosaccharides are the monomers of carbohydrates. In water they mostly exist as rings. You need to recognise two groups from ring diagrams.

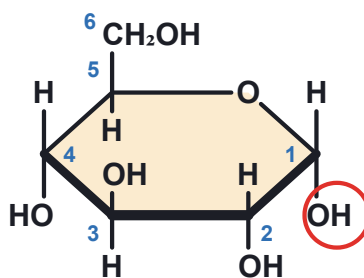
Pentoses and hexoses			
Group	Carbon atoms	Ring	Examples
Pentose	5	Five-membered ring: four carbons and one oxygen; C5 sits outside the ring	Ribose, deoxyribose
Hexose	6	Glucose and galactose: six-membered ring of five carbons and one oxygen, with C6 (CH ₂ OH) outside the ring. Fructose: five-membered ring, with C1 and C6 outside	Glucose, galactose, fructose

Exam tip: To identify a sugar from a diagram, count all the carbon atoms, including any outside the ring. Five means pentose, six means hexose. Fructose is a hexose even though it forms a five-membered ring.

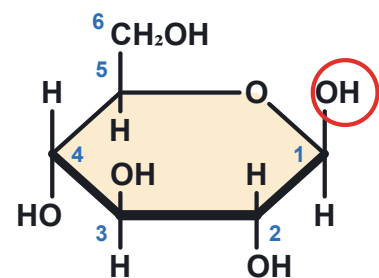
Glucose (C₆H₁₂O₆) exists as **alpha-glucose** and **beta-glucose**. They differ only at carbon 1: in alpha-glucose the -OH on C1 is below the ring; in beta-glucose it is above the ring.



Ribose
pentose: 5 carbons



Alpha-glucose
hexose: -OH on C1 below ring



Beta-glucose
hexose: -OH on C1 above ring

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Hexoses have six carbons, pentoses five. Alpha- and beta-glucose differ only in the position of the **-OH on C1**.

Glucose: properties linked to use

How glucose's properties suit its function		
Property	Reason	Use
Soluble	Polar -OH groups form hydrogen bonds with water	Dissolves in cytoplasm and blood plasma
Transportable	Small and soluble	Carried in blood plasma to every cell
Chemically stable	The ring structure does not react readily	Can be carried and held in cells without unwanted reactions
Yields energy when oxidised	Oxidation releases energy, captured as ATP in cell respiration	The main respiratory substrate in most cells

Its solubility is also a drawback for storage: a high concentration of glucose would draw water into cells by osmosis. So glucose is stored as polysaccharides instead.

Exam tip: Linking question: what are the roles of oxidation and reduction? Oxidising glucose to carbon dioxide and water in respiration releases energy; reducing carbon dioxide in photosynthesis stores it.

Starch, glycogen and cellulose Spec B1.1.5, B1.1.6

Energy storage: starch and glycogen

Plants store glucose as **starch** and animals store it as **glycogen**, mainly in liver and muscle cells. Both are polymers of alpha-glucose linked by glycosidic bonds.

Storage polysaccharides		
Polysaccharide	Organism	Structure
Amylose (part of starch)	Plants	Unbranched chain of alpha-glucose (1,4 bonds) that coils into a helix
Amylopectin (part of starch)	Plants	Chain with branches (1,6 bonds) at intervals
Glycogen	Animals and fungi	Like amylopectin but more highly branched

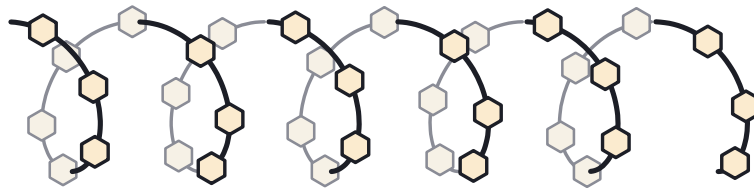
- **Compact:** coiling and branching during polymerisation pack many glucose units into a small space.
- **Relatively insoluble:** the molecules are very large, so they have little osmotic effect and do not leave the cell.
- **Easy to build up or mobilise:** alpha-glucose is added by condensation or removed by hydrolysis. Branches give many chain ends where enzymes can work at the same time, so glycogen can release glucose rapidly.

Structure: cellulose

Cellulose is a polymer of **beta-glucose**. Because the -OH on C1 is above the ring, each monomer is linked in the **alternating orientation**: every second glucose is turned upside down relative to its neighbours. This gives straight, unbranched chains.

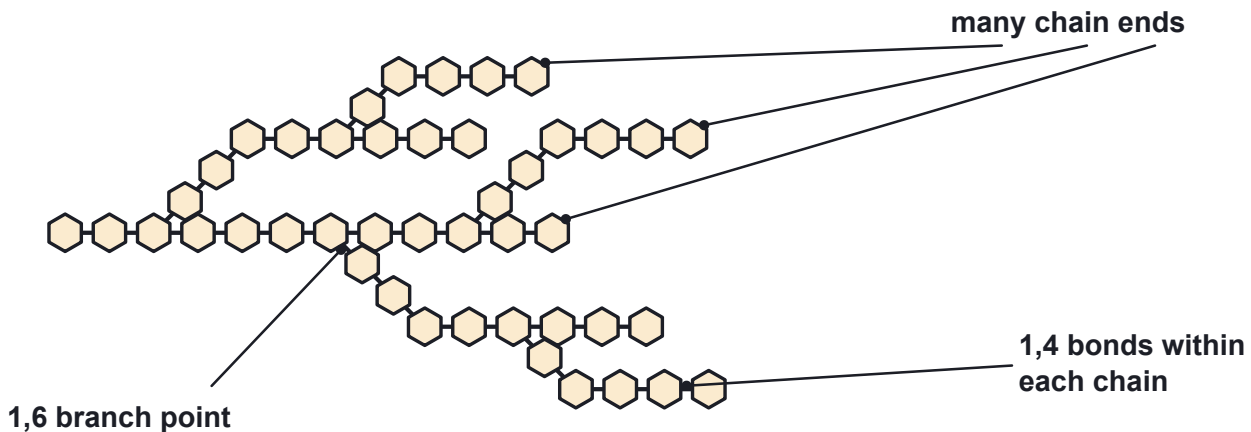
Straight chains lie parallel and are **cross-linked by hydrogen bonds** between their -OH groups. Bundles of chains form microfibrils with very high tensile strength. In plant cell walls these resist the pressure of water inside the cell, so cells become turgid instead of bursting.

Amylose



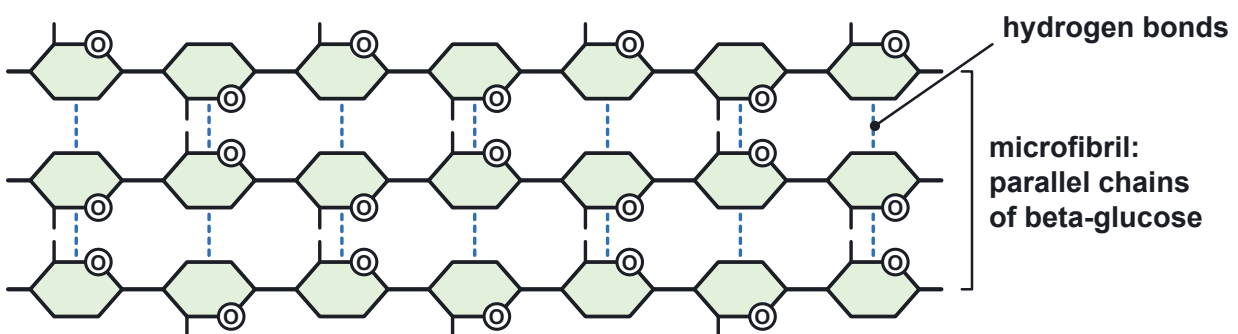
alpha-glucose units
joined by 1,4 glycosidic
bonds, coiled into a helix

Glycogen



Cellulose

every second beta-glucose is inverted, so chains are straight



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Amylose coils into a **helix**, glycogen is **highly branched** with many chain ends, and cellulose forms **straight chains** held in microfibrils by hydrogen bonds.

Exam tip: Linking question: how can compounds made by organisms become carbon sinks? Cellulose is hard to hydrolyse, so in waterlogged soils dead plant matter builds up as peat, locking carbon away.

Glycoproteins and cell-cell recognition Spec B1.1.7

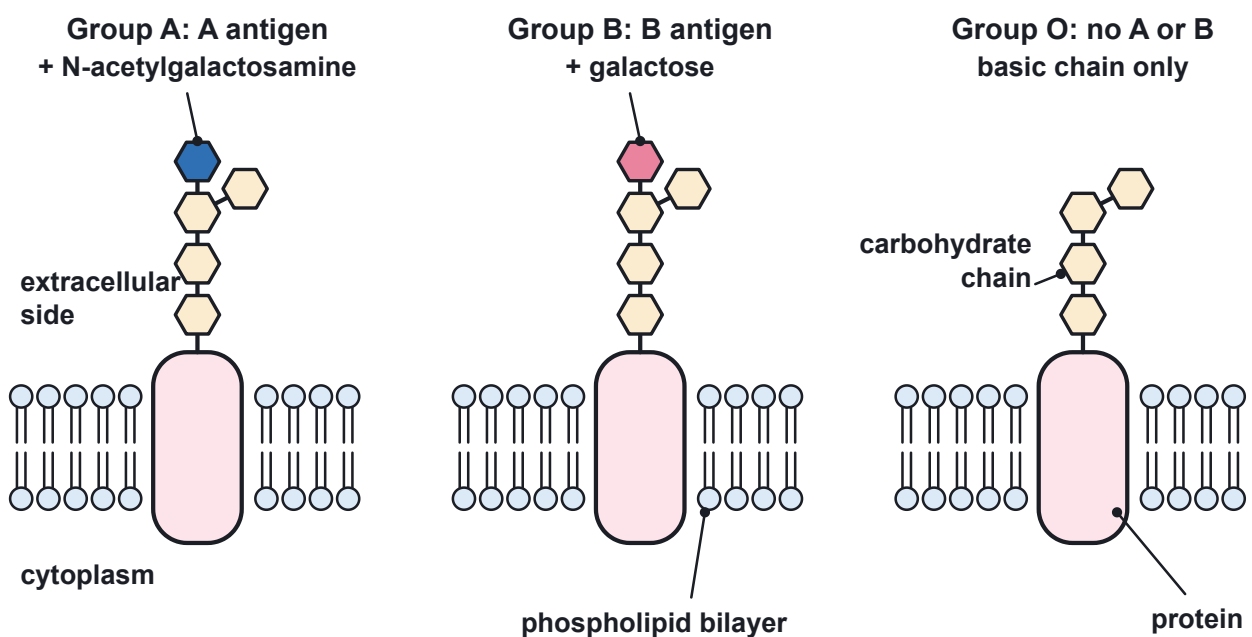
A **glycoprotein** is a protein with one or more carbohydrate chains (short chains of monosaccharides) attached. In the plasma membrane the carbohydrate always faces outwards, into the extracellular fluid. The sequence and branching of the carbohydrate chain is specific to a type of cell, tissue or individual. Other cells, including cells of the immune system, can bind to it. This is **cell-cell recognition**: it lets cells recognise self from non-self and helps cells of the same tissue stick together.

Example: ABO antigens

Red blood cells carry carbohydrate chains on their membrane glycoproteins (and glycolipids) that act as **antigens**. All groups share the same basic chain; groups A and B add one extra sugar to it, a different sugar in each case. The sugar names in the table are for interest only: you need to know that the antigens differ in their carbohydrate chain, not what the sugars are.

ABO antigens on red blood cells		
Blood group	Antigen on red blood cells	Carbohydrate chain
O	Neither A nor B	Basic chain only
A	A antigen	Basic chain + N-acetylgalactosamine
B	B antigen	Basic chain + galactose
AB	A and B antigens	Both forms present

If a person receives red blood cells with an antigen their own cells do not carry, antibodies in their plasma bind to that antigen. The donated cells clump together (agglutination). This is why blood for transfusion must be matched.



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ABO antigens are **carbohydrate chains on glycoproteins**: groups A and B each add a different extra sugar to the same basic chain.

Lipids: hydrophobic properties, triglycerides and phospholipids Spec B1.1.8, B1.1.9

Lipids

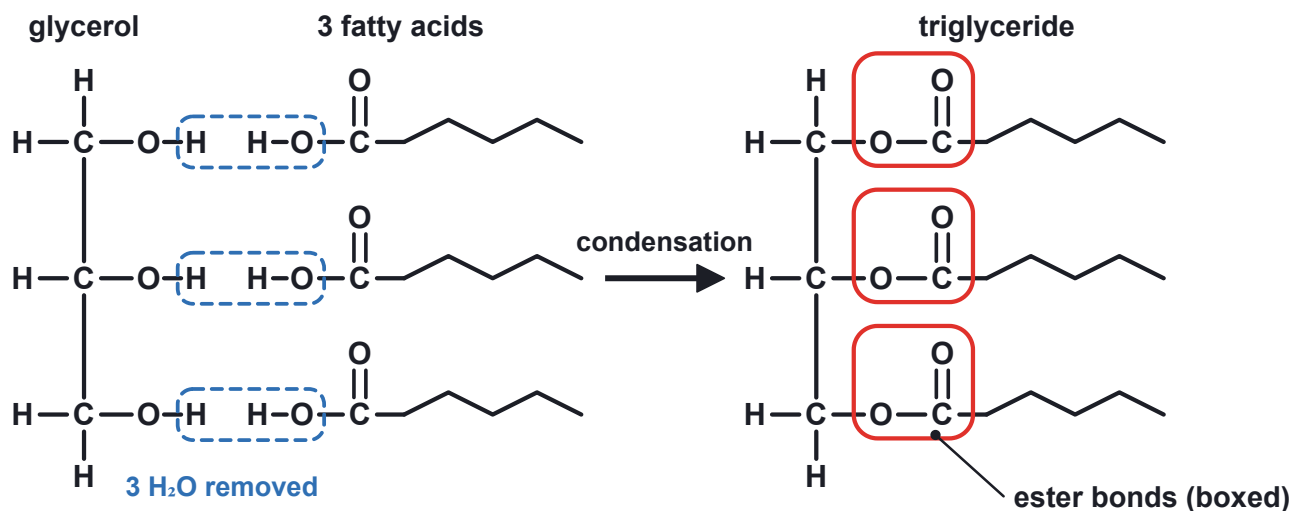
Substances in living organisms that dissolve in non-polar solvents but are only sparingly soluble in aqueous solvents. They include fats, oils, waxes and steroids.

Lipids are mostly hydrocarbon. C-H bonds share electrons almost equally, so they are non-polar and cannot form hydrogen bonds with water. This makes lipids **hydrophobic**: in water, lipid molecules cluster together instead of dissolving.

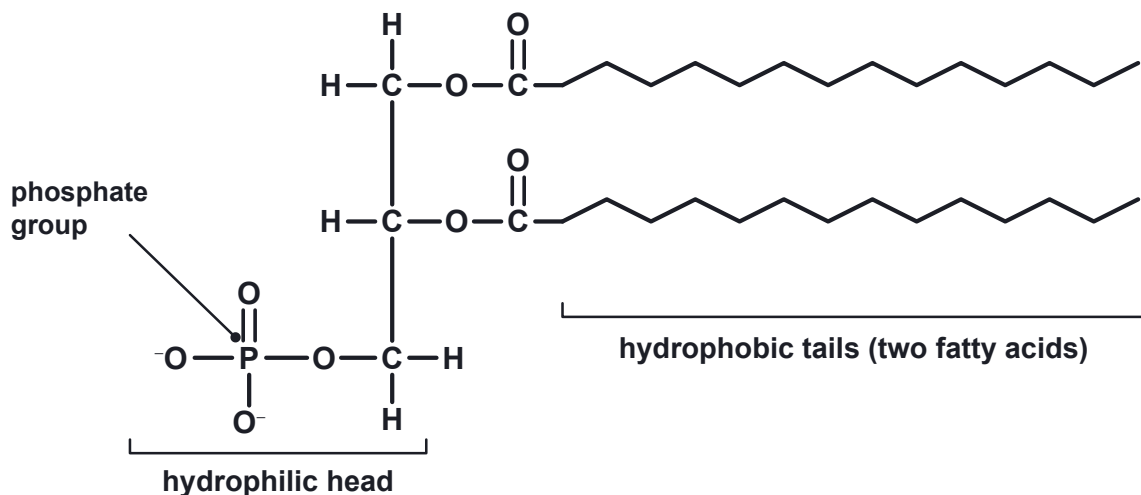
Formation by condensation

Glycerol has three -OH groups. Each can react with the carboxyl (-COOH) group of a fatty acid in a **condensation reaction**, forming an ester bond and releasing water.

Triglycerides and phospholipids		
Feature	Triglyceride	Phospholipid
Made from	One glycerol + three fatty acids	One glycerol + two fatty acids + one phosphate group
Water released	Three molecules, one per ester bond	One per bond formed (three in all)
Polarity	Entirely hydrophobic	Hydrophilic phosphate head, hydrophobic tails
Main role	Energy storage and insulation	Membranes



Phospholipid



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Condensation of glycerol with three fatty acids forms a **triglyceride** with three **ester bonds**; a **phospholipid** has two fatty acids and a phosphate group.

Common mistake: A triglyceride is not a polymer: glycerol and fatty acids are not repeating identical monomers. It is still made by condensation and broken down by hydrolysis.

Fatty acids, energy storage and insulation Spec B1.1.10, B1.1.11

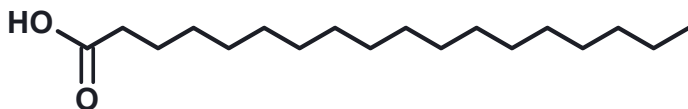
Fatty acids have a carboxyl group at one end of a hydrocarbon chain. They differ in chain length and in the number of double bonds between carbon atoms (C=C).

Types of fatty acid			
Type	C=C double bonds	Chain shape	Melting point
Saturated	None: every carbon holds as many H atoms as possible	Straight	Highest
Monounsaturated	One	One bend at the double bond	Lower
Polyunsaturated	Two or more	Several bends	Lowest

Straight saturated chains pack closely, so the attractions between them are strong and more energy is needed to melt them. A double bond (in the usual cis form) puts a bend in the chain, so chains cannot pack closely and the **melting point** is lower.

This links to where fats and oils are stored. Plants store **oils** rich in unsaturated fatty acids, for example in seeds. Plants are not endotherms, so their tissues are often cool, and low-melting oils stay liquid there. **Endotherms** such as mammals and birds store fats with a higher proportion of saturated fatty acids than plant oils. These fats are solid at room temperature, but the endotherm's warm body keeps them soft enough to store and mobilise.

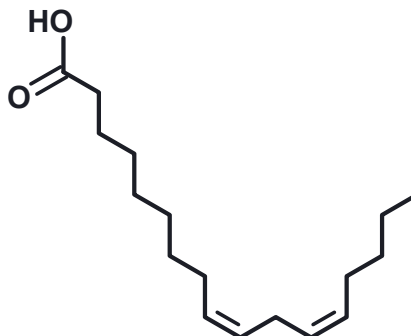
Saturated: no C=C, straight chain



Monounsaturated: one C=C, one bend



Polyunsaturated: two or more C=C, more bends



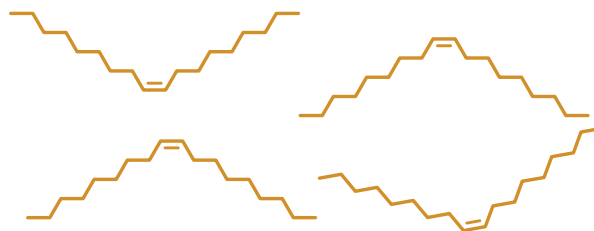
Each chain has 18 carbons; C1 is the carboxyl carbon (–COOH).

Straight chains pack tightly



solid fat (higher melting point)

Bent chains pack loosely



liquid oil (lower melting point)

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Each cis ==C=C double bond puts a bend in the chain, so unsaturated chains pack loosely and have a lower melting point==.

Triglycerides in adipose tissue

Adipose tissue is made of cells filled with triglyceride droplets. It lies under the skin and around organs. Triglycerides are suited to long-term energy storage because:

- They release about twice as much energy per gram as carbohydrates when oxidised (about 37 kJ g⁻¹ compared with about 17 kJ g⁻¹).
- They are insoluble, so they have no osmotic effect and stay in the cells.
- They are stored without water, whereas glycogen is stored bound to water, so the same energy store adds much less mass.
- They are chemically stable, so they can be kept for long periods.

Fat is a poor conductor of heat, so a layer of adipose tissue under the skin acts as thermal insulation. This matters for endotherms, which keep a body temperature above that of their surroundings. The colder the habitat, the more important it is: seals and whales in cold seas have a thick layer of blubber, and animals that hibernate build up adipose tissue as a store for winter.

Exam tip: Guiding question: carbohydrates versus lipids for storage. Glycogen and starch are for short-term storage because glucose is released quickly; triglycerides are for long-term storage because they hold more energy per gram.

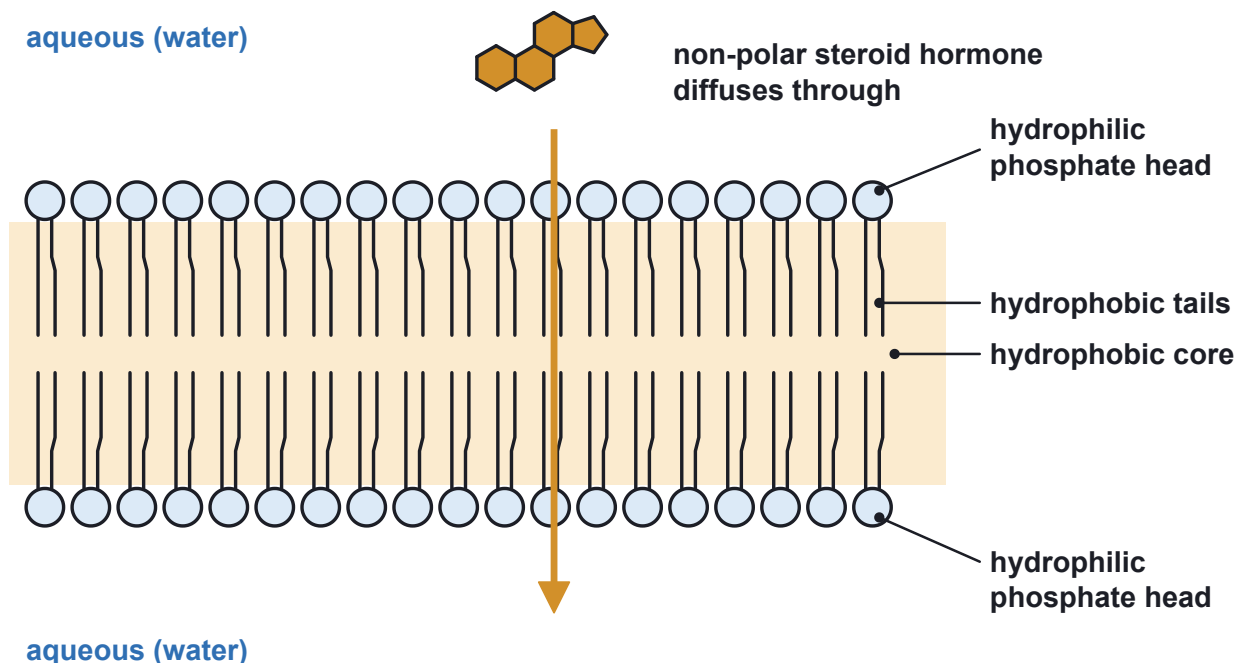
Phospholipid bilayers and steroids Spec B1.1.12, B1.1.13

Amphipathic

Having both a hydrophilic region and a hydrophobic region in the same molecule.

A phospholipid is **amphipathic**. The phosphate group carries a charge, so the head is hydrophilic and attracted to water. The two fatty acid tails are hydrophobic.

In water, phospholipids arrange themselves so that the heads face the water and the tails avoid it. The result is a **phospholipid bilayer**: two layers of molecules, heads outwards on each surface and tails pointing inwards to form a hydrophobic core. This forms spontaneously, because it is the most stable arrangement. The bilayer is the basis of every cell membrane.



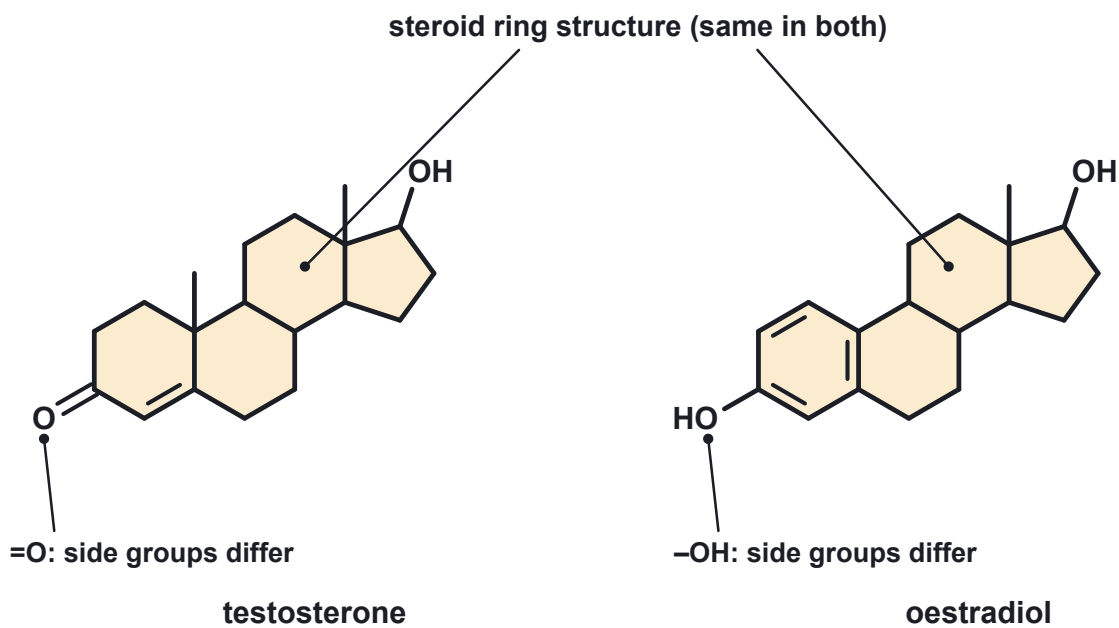
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Phospholipids form a **bilayer** with a hydrophobic core; non-polar **steroid hormones** can diffuse straight through it.

Steroids

Steroids are lipids with a characteristic skeleton of **four fused rings** of carbon atoms: three rings of six carbons and one ring of five. You can identify a steroid from a molecular diagram by this ring pattern; the side groups attached to it differ between steroids.

Steroids are largely non-polar, so they can pass through the hydrophobic core of the bilayer by simple diffusion. The sex hormones **oestradiol** and **testosterone** are steroids. They pass through the plasma membrane of target cells and bind to receptor proteins inside the cell.



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Testosterone and oestradiol share the **steroid ring structure**; only the **side groups** differ.

*Exam tip: Ions and polar molecules cannot easily cross the hydrophobic core, but non-polar steroids can. Use the word **hydrophobic core**, not just **membrane**, in explanations.*

Quick check

1. How many covalent bonds can a carbon atom form?
2. What is released when two monosaccharides are joined by condensation?
3. Which monomer makes up cellulose?
4. What is meant by amphipathic?
5. Name two steroid hormones that pass through the phospholipid bilayer.

Quick check answers

Carbohydrates and lipids

1. Up to four, which can be single bonds or a combination of single and double bonds.
2. A molecule of water.
3. Beta-glucose, linked in alternating orientation.
4. A molecule with both a hydrophilic region and a hydrophobic region, such as a phospholipid.
5. Oestradiol and testosterone.