# Carbohydrates and lipids

B1.1 · SL

# Why can glucose polymers have different functions?

## An element list does not specify the structure

A potato stores starch, a seed stores oil, and a plant cell wall contains cellulose. All contain carbon, hydrogen and oxygen.

B1.1 covers carbon compounds, carbohydrate structure, recognition, lipid structure, storage, insulation, bilayers and steroids. Content is common to SL and HL.

Molecular cartoons simplify three-dimensional structures. Numerical practice values are invented.

# Four bonds allow many carbon skeletons

## Count a double bond twice in valence accounting

Carbon usually forms four covalent bonds: four single bonds, or two single bonds and one double bond, are possible arrangements.

Carbon bonds to carbon and other non-metals, producing unbranched chains, branched chains and rings. Steroids contain fused rings.

A covalent bond involves a shared electron pair. An element list alone does not identify a carbohydrate, lipid or protein.

# Use diagram conventions and metric prefixes

1. **Read atoms.** Unlabelled skeletal corners usually mean carbon; a labelled O means oxygen. Include carbons outside a ring.
2. **Convert.** $1\,\mathrm{mm} = 1000\,\mu\mathrm{m}$ and $1\,\mu\mathrm{m} = 1000\,\mathrm{nm}$. Thus $7\,\mathrm{nm} = 0.007\,\mu\mathrm{m}$.
3. **Check.** A carbon with one double bond and three single bonds has total bond order five, inconsistent with the usual valence here.

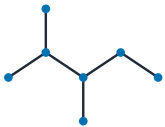
# Carbon skeletons

**unbranched chain**



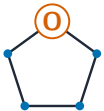
6 carbons in a line

**branched chain**



side branches

**ring**




5 atoms, only 4 carbons

- carbon (a corner or line end)

O a labelled oxygen

H on carbon omitted

Four bonds per carbon allow many shapes

# A large molecule is not always a polymer

| Molecule | Building units and linkage |
|---|---|
| Polysaccharide | Monosaccharide residues joined by glycosidic bonds |
| Polypeptide | Amino-acid residues joined by peptide bonds |
| Nucleic acid | Nucleotide residues joined by phosphodiester links |
| Triglyceride | One glycerol and three fatty acids joined by ester links; not a repeating-monomer polymer |

# Water participates in breaking a linkage

## Distinguish free monomers from incorporated residues

Condensation links units with water released in the simple accounting model. Hydrolysis uses water; H and OH become incorporated into products.

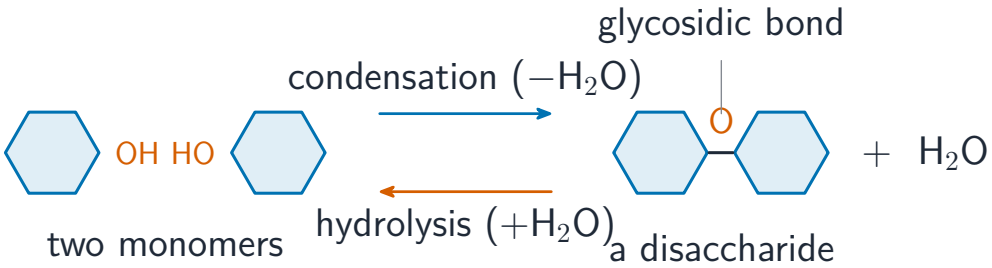
A residue is the part of a unit incorporated into a larger molecule. It need not be identical to the original free monomer.

Digestion can first produce shorter fragments. Complete hydrolysis to monomers requires breaking all relevant links. These models do not show every biosynthetic step.

# Count links before counting water

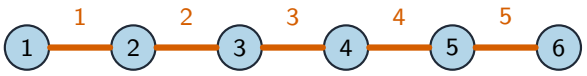
1. **Single chain.** A linear chain of 20 units has $20 - 1 = 19$ links. Complete **hydrolysis** consumes 19 water molecules.
2. **Two chains.** Two ten-unit chains have $9 + 9 = 18$ links initially. Joining their ends adds one link, producing 19 in total.
3. **Interpret.** Forming every link from free monomers and making just the final connection are different calculations.

# Condensation and hydrolysis




**Hydrolysis** adds water to break it

# Counting links in a polymer




6 units, 5 links

$n$ units $\to n-1$ links

forming every link releases $n-1$ water molecules (condensation);
complete hydrolysis uses $n-1$ water molecules

20 units: 19 links, 19 water

So $n-1$ water molecules are released

# Count all carbons, including those outside a ring

## A ring corner may be oxygen

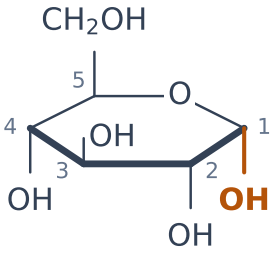
Pentoses contain five carbons, as in ribose; hexoses contain six, as in glucose.

A common glucose ring has five carbons plus one oxygen, with C6 outside. A common ribose ring has four carbons plus one oxygen, with C5 outside.

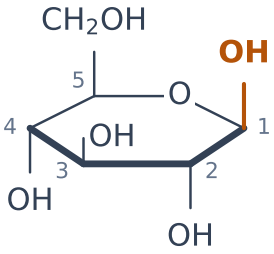
A polygon's number of corners alone cannot identify a pentose or hexose. Read atom labels and side groups.

# Compare relative positions in alpha- and beta-glucose

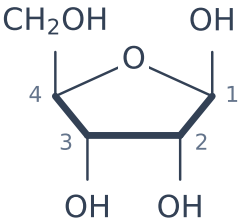
α-D-glucose




β-D-glucose




β-D-ribose




The C1 hydroxyl differs; rotating the whole molecule does not change alpha into beta.

# Glucose properties support transport and controlled use

## Solubility is not itself energy release

Hydroxyl groups interact with water, so glucose dissolves and can be transported in aqueous fluids.

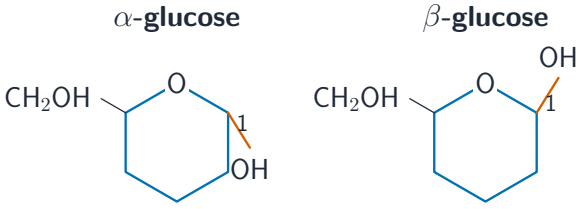
Glucose is sufficiently stable for controlled handling, while enzymes catalyse its reactions. Oxidation during respiration transfers energy to useful processes.

Alpha and beta forms differ in C1 hydroxyl orientation relative to the C5 hydroxymethyl group. Molecular structure, not only formula, affects behaviour.

# Food tests identify chemical features, not complete structures

| Test under stated conditions | Positive result |
|---|---|
| Benedict's reagent with controlled warming | Coloured precipitate for reducing sugars |
| Iodine solution | Blue-black with starch |
| Biuret reagent | Violet with peptide-containing proteins |
| Dissolve in ethanol, then add water | Cloudy emulsion for lipids; keep ethanol away from flames |

# Alpha and beta glucose




only carbon 1 differs: the OH points **down** in $\alpha$, **up** in $\beta$

One small difference: starch or cellulose

# Three storage polymers organize alpha-glucose differently

| Polymer | Organization and storage consequence |
| --- | --- |
| Amylose | Mainly unbranched alpha-1,4 chains coil compactly |
| Amylopectin | Alpha-1,4 chains plus alpha-1,6 branch points |
| Glycogen | More highly branched; many ends provide sites for regulated addition or removal |

# A large store need not mean many dissolved particles

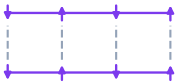
## Relative insolubility helps retention and osmotic control

Coiling and branching pack many glucose residues into a small volume. A branch point is not the same as a free chain end.

Large, relatively insoluble polymers form retained stores rather than many separate dissolved glucose molecules.

Fewer dissolved particles reduce the store's osmotic contribution. This does not eliminate all water movement or the need for regulation. Hydrolysis can mobilize glucose residues.

# Compare storage organization with straight structural chains

| Amylose | Glycogen | Cellulose |
| --- | --- | --- |
|  |  |  |
| Coiled α-glucose chain | Many branch ends | Alternating β-glucose |

Schematic organization, not atomic formulas.
Solid: covalent chain links. Dashed: hydrogen bonds between cellulose chains.

> Cellulose chains are straight, with hydrogen bonds between neighbouring chains.

# Strong bundles depend on two different bond types

## Structure explains tension resistance and enzyme specificity

Beta-1,4 glycosidic bonds connect alternating beta-glucose residues along cellulose chains. Hydrogen bonds help hold neighbouring chains in microfibrils.

Covalent backbones and collective interactions give tensile strength to the plant cell wall. A cell wall is not the cell membrane.

Humans digest suitable starch links but do not produce cellulase for cellulose's beta-1,4 links. Disrupting hydrogen bonds is not complete glycosidic hydrolysis.

# A terminal sugar can alter specific recognition

## ABO antigens are carbohydrate structures on cell surfaces

A glycoprotein has carbohydrate groups attached to a protein. Exposed carbohydrate arrangements can be recognized by specific binding molecules.

A and B antigens differ in terminal carbohydrate structures on membrane glycoproteins and glycolipids.

Group O lacks A and B terminal modifications; it does not lack every surface antigen. Recognition depends on molecular binding, not a cell reading a label.

# Not all lipids have the same structure

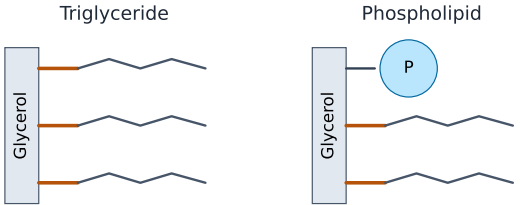
## Hydrocarbon regions interact poorly with water

Fats, oils, waxes and steroids are lipid examples. They generally dissolve poorly in water and more readily in non-polar solvents.

A triglyceride combines glycerol and three fatty acids. A typical glycerophospholipid combines glycerol, two fatty acids and a phosphate-containing head.

A phospholipid is not a triglyceride with phosphate added on top of three tails. Head-group chemistry can vary.

# Distinguish three-tail storage from two-tail membrane components




Orange: ester links. P: phosphate head.
Heads are hydrophilic; tails are hydrophobic.

Triglycerides have three ester-linked tails; a typical glycerophospholipid has two tails.

# Account for all products during condensation

1. **Links.** Three fatty acids esterify three glycerol hydroxyl groups: three ester links and three released waters in the simple model.
2. **Mass.** Use molar masses glycerol 92, fatty acid 256, water 18. Triglyceride $= 92 + 3(256) - 3(18) = 806\,\mathrm{g\,mol^{-1}}$.
3. **Conserve.** Reactants total 860; triglyceride 806 plus water $3(18) = 54$ totals 860. Complete ester **hydrolysis** uses three waters.

# Count carbon–carbon double bonds in the fatty-acid chain

| **Class** | **C=C bonds and comparison** |
|---|---|
| Saturated | Zero C=C bonds in the hydrocarbon chain |
| Monounsaturated | One C=C bond |
| Polyunsaturated | Two or more C=C bonds |
| Important limit | The carboxyl C=O bond does not make a fatty acid unsaturated |

# Cis bends tend to lower melting point

## Compare otherwise similar chains at a stated temperature

Cis double bonds introduce bends that tend to disrupt close packing. Saturated chains pack more closely and often melt at higher temperatures.

Chain length, cis/trans geometry and mixture composition also affect melting. Not every double bond produces the same kink.

Many plant oils are rich in unsaturated fatty acids and many animal fats have larger saturated fractions. These are tendencies, not universal source rules.

# High energy per mass supports long-term storage

## Separate storage properties from immediate availability

Triglycerides have many reduced carbon–hydrogen bonds and a high oxidation energy yield per mass. They are stored with little associated water compared with hydrated carbohydrate stores.

Their hydrophobic nature requires suitable packaging for transport in aqueous fluids. High energy density does not mean free dissolution or instant availability.

Fuel choice also depends on mobilization, oxygen supply and physiology. Carbohydrate stores remain useful.

# Compare equal energy before comparing stored mass

1. **Invented data.** Energy available: lipid $38\,\mathrm{kJ}$ per gram; carbohydrate $17\,\mathrm{kJ}$ per gram. Target: 380 kJ.
2. **Dry masses.** Lipid $380/38 = 10.0$ g; carbohydrate $380/17 = 22.4$ g to three significant figures.
3. **Hydration.** If carbohydrate carries 3 g water per gram dry store, hydrated mass $= 4(380/17) = 89.4$ g. This ratio is a supplied assumption.

# Insulation slows heat transfer; it does not create heat

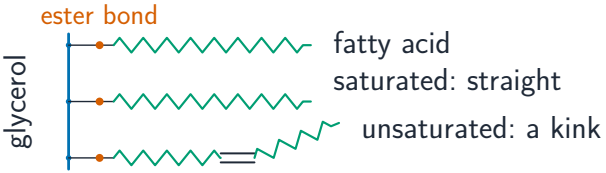
## Relate adipose tissue to body temperature and habitat

Adipose cells store triglycerides. A tissue layer can reduce heat transfer from a warm animal to colder surroundings.

Stored lipid can be metabolized for energy, but the insulating effect itself slows heat loss rather than producing heat.

Body temperature, habitat, fur, feathers and behaviour influence insulation needs. Name the temperature difference.

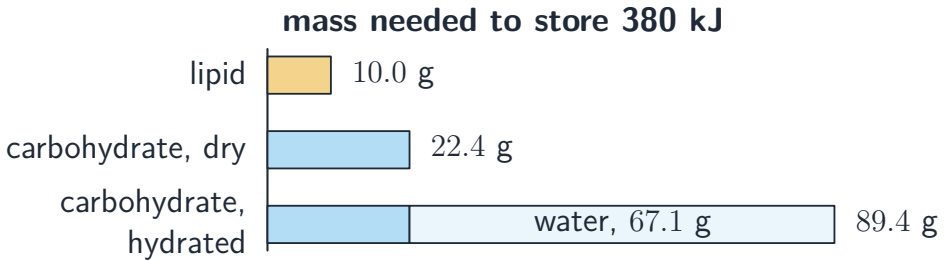
# A triglyceride




3 ester bonds form $\rightarrow 3$ $H_2O$ removed (condensation)

Here two chains are saturated and one unsaturated

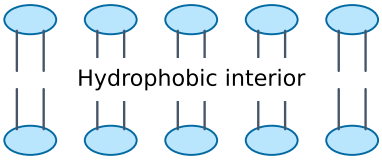
# Why lipid is a compact energy store




Carbohydrate stores water with it

# Orient both surfaces toward water

Water: outside the cell




Water: inside the cell

Blue heads are hydrophilic; tails point inward.
Schematic cross-section; real membranes contain other components.

Hydrophilic heads face water on both sides; hydrophobic tails face inward.

# Both bilayer surfaces meet water

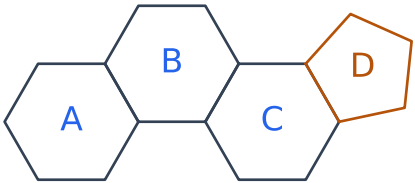
## Amphipathic means hydrophilic and hydrophobic regions

Polar or charged heads interact with water; largely non-polar tails associate away from it. Heads face water on both surfaces and tails face inward.

The hydrophobic interior restricts many ions and polar molecules, but is not impermeable to everything.

Bilayer formation follows molecular interactions, without purpose or choice. Real membranes are dynamic and include proteins and other lipids.

# Recognize fused rings rather than four separate circles




A–C: six atoms each. D: five.

> A steroid nucleus has three six-membered rings and one five-membered ring, fused together.

# Overall lipid solubility permits hormone passage

## A shared skeleton does not mean identical function

Oestradiol and testosterone are steroid hormones with this four-ring framework. Different side groups and bonds distinguish individual steroids.

Their overall lipid solubility permits passage through the bilayer, even though their structures contain oxygen groups.

A charged ion faces a different barrier. A specific response also needs an appropriate receptor and cellular machinery; passage alone is insufficient.

# Try linkage, energy and structure questions

## Pause before the worked reveal

A 35-unit linear sugar chain is completely hydrolysed. How many glycosidic links and water molecules are involved?

Use 38 kJ per gram lipid and 17 kJ per gram carbohydrate to store 190 kJ. Add 3 g water per gram dry carbohydrate.

Explain why cellulose strength, triglyceride storage and phospholipid bilayers depend on different structural features.

# Reveal: use links, unrounded masses and the right interaction

1. **Hydrolysis.** $35 - 1 = 34$ links; 34 water molecules are consumed.
2. **Energy.** Lipid $190/38 = 5.00$ g; dry carbohydrate $190/17 = 11.2$ g; hydrated mass $4(190/17) = 44.7$ g.
3. **Structure.** Cellulose: straight, hydrogen-bonded chains. Triglyceride: energy-rich hydrophobic storage. Phospholipid: polar head plus non-polar tails.

# Check yourself

## Name the structure, property and resulting function

Distinguish glycosidic links along chains from hydrogen bonds between chains; a monomer from a residue; a branch point from a chain end.

Count carbons inside and outside rings. Identify lipid components before naming the molecule. Explain bilayer orientation with water on both sides.

Count links before calculating water or mass. Avoid universal claims about plant oils, animal fats or every large molecule being a polymer.