B1.1 Carbohydrates and Lipids

What to know: structures, functional groups, condensation vs hydrolysis, energy storage, cellulose, glycoproteins/ABO, triglycerides, phospholipids, fatty acid saturation, adipose tissue, steroid hormones.

1. Core ideas at a glance

Area	High-yield point
Carbon chemistry	Carbon forms 4 covalent bonds, including single and double bonds, allowing chains, branches and rings.
Monosaccharides	Small carbohydrate monomers with general formula $C_nH_{2n}O_n$ (for standard monosaccharides).
Condensation	Builds larger molecules from smaller ones and always produces water.
Hydrolysis	Uses water to split covalent bonds, so water is always a reactant.
Energy storage	Carbohydrates are useful for short-term accessible storage; triglycerides store about twice as much energy per gram for long-term storage.
Structure–function	Different glucose linkages produce starch/glycogen for storage and cellulose for structure.
Lipids	Hydrophobic overall; phospholipids are amphipathic and therefore self-assemble into bilayers.

Exam tip

In long-answer responses, always link molecular structure to a property and then to a biological function. Example: many hydroxyl groups → polarity → high solubility → easy transport in blood.

2. Carbon compounds and functional groups

- Life is described as carbon-based because carbohydrates, lipids, proteins and nucleic acids all contain carbon.
- Carbon can form up to four covalent bonds, enabling a huge diversity of organic molecules.
- Carbon skeletons may be unbranched chains, branched chains or rings; they may contain single or double bonds.
- Only a few carbon-containing compounds, such as carbon dioxide, are not classified as organic.

Bonding patterns to remember

Element	Typical number of covalent bonds
Hydrogen	1
Oxygen	2

Nitrogen	3
Carbon	4
Phosphorus	5

Common functional groups

Functional group	Why it matters in biochemistry
Hydroxyl (–OH)	Makes molecules more polar; common in sugars such as glucose.
Amino ($–NH_2$)	Found in amino acids and many nitrogen-containing biomolecules.
Carboxyl (–COOH)	Found in amino acids and fatty acids; involved in condensation reactions.
Phosphate (H_2PO_4 / phosphate group)	Important in nucleotides, ATP and phospholipids; often contributes polarity.

Metric prefixes worth recognizing in biology: kilo = 10^3, centi = 10^{-2}, milli = 10^{-3}, micro = 10^{-6} and nano = 10^{-9}.

3. Condensation and hydrolysis

Macromolecules are usually assembled from smaller monomers. Digestion does the reverse, breaking polymers into absorbable monomers.

Reaction	What happens
Condensation	Two smaller molecules join to form a larger molecule; water is produced.
Hydrolysis	A larger molecule is split into smaller molecules; water is consumed/split.

- Examples of macromolecules made by condensation: polysaccharides, polypeptides and nucleic acids.
- Examples of digestion by hydrolysis: lactose + water → glucose + galactose; protein + water → amino acids.
- Both reaction types require specific enzymes.
- For a polymer of n monomers, n − 1 bonds form; therefore n − 1 water molecules are released in condensation. Example: 443 amino acids form 442 peptide bonds and release 442 water molecules.

Metabolism

Metabolism means the total of all reactions occurring in all cells of an organism, not just digestion or breathing rate.

4. Monosaccharides and glucose

- Monosaccharides are the smallest carbohydrates and the monomers of disaccharides and polysaccharides.
- Pentoses have 5 carbons (for example ribose: $C_5H_{10}O_5$). Hexoses have 6 carbons (for example glucose: $C_6H_{12}O_6$).

- The formula $C_nH_{2n}O_n$ applies to standard monosaccharides, but not to larger carbohydrates such as disaccharides and polysaccharides.

Why glucose is biologically useful

- Stable: covalent bonds do not break spontaneously.
- Water-soluble: many hydroxyl groups make glucose polar.
- Transportable: because it dissolves in water, it can move in blood and tissue fluid.
- High energy yield: oxidation of glucose releases a large amount of chemical energy.
- Versatile precursor: glucose can be polymerized into storage molecules (starch, glycogen) and structural molecules (cellulose).

5. Polysaccharides: storage and structure

Polysaccharide	Monomer / linkage / function
Amylose	Alpha-glucose; $\alpha(1 \rightarrow 4)$ linkages only; unbranched but coils into a helix; compact plant storage.
Amylopectin	Alpha-glucose; $\alpha(1 \rightarrow 4)$ plus $\alpha(1 \rightarrow 6)$ branch points; branched plant storage.
Glycogen	Alpha-glucose; very similar to amylopectin but more highly branched; animal storage in liver and muscle.
Cellulose	Beta-glucose; $\beta(1 \rightarrow 4)$ linkages; straight unbranched chains for plant cell walls.

Why starch and glycogen are good storage molecules

- Compact: coiling and branching pack many glucose units into a small volume.
- Relatively insoluble: large size means they do not dissolve readily, so they do not diffuse away and do not strongly affect osmotic balance.
- Easy to build and mobilize: glucose monomers can be added by condensation and removed by hydrolysis.

Why cellulose is structural instead of storage

- Beta-glucose monomers alternate in orientation, producing straight chains.
- Parallel cellulose chains form many hydrogen bonds, creating strong microfibrils.
- Cellulose is insoluble and mechanically strong, making it ideal for plant cell walls.
- Very few organisms produce cellulase, so cellulose is not generally used as an energy store.

Key distinction

Alpha-glucose polymers (starch, glycogen) are adapted for energy storage; beta-glucose polymer (cellulose) is adapted for strength and support.

6. Conjugated molecules and ABO blood groups

- Conjugated molecules contain more than one biochemical category bonded together.
- Examples: lipoprotein = lipid + protein; glycolipid = carbohydrate + lipid; glycoprotein = carbohydrate + protein.
- Glycoproteins on cell surfaces help with cell signalling, adhesion, transport and self/non-self recognition.

ABO type	Antigen(s) on red cells	Can receive from	Can donate to

A	A	A, O	A, AB
B	B	B, O	B, AB
AB	A and B	A, B, AB, O	AB
O	Neither A nor B	O	A, B, AB, O

Rule to remember: a person cannot safely receive A or B antigens unless they genetically possess that antigen on their own red blood cells.

7. Lipids: properties and formation

- Lipids include fats, oils, waxes and steroids.
- They contain large hydrocarbon regions, so they are non-polar overall and dissolve better in non-polar solvents than in water.
- Their poor solubility in water is described as hydrophobic behaviour.

Triglycerides and phospholipids

Molecule	Composition	Notes
Triglyceride	1 glycerol + 3 fatty acids	Formed by 3 condensation reactions; releases 3 water molecules.
Phospholipid	1 glycerol + 2 fatty acids + 1 phosphate group	Also formed by 3 condensation reactions; releases 3 water molecules.

- Glycerol is a 3-carbon molecule with three hydroxyl groups.
- Each fatty acid has a hydrocarbon chain and a terminal carboxyl group.
- Replacing one fatty acid with a phosphate group changes the polarity of one end of the molecule.

8. Saturated vs unsaturated fatty acids

Type	Number of C=C bonds	General effect on melting point / state
Saturated	0	Highest melting point; usually solid at room temperature; common in animal fats.
Monounsaturated	1	Lower melting point; often liquid oils at room temperature.
Polyunsaturated	More than 1	Low melting point; usually liquid oils at room temperature; common in many plant oils.

- Double bonds introduce bends/kinks, preventing tight packing and lowering melting point.
- Longer fatty acid chains raise melting point; more double bonds lower it.
- Endotherms often store more saturated fats, while many plants store more unsaturated oils.

9. Triglycerides in adipose tissue

- Adipose tissue stores triglycerides in fat cells (adipocytes).

- Triglycerides are ideal for long-term storage because they are insoluble and therefore remain stored rather than diffusing through body fluids.
- They release about twice as much energy per gram as carbohydrates.
- Stored fat can be hydrolysed to glycerol and fatty acids when energy is needed.
- In cold habitats, thick adipose tissue (blubber) acts as thermal insulation in endothermic animals such as whales, walruses and seals.

10. Phospholipid bilayers and steroids

Phospholipid bilayers

- A phospholipid has a hydrophilic phosphate head and hydrophobic fatty acid tails.
- A molecule with both hydrophilic and hydrophobic regions is called amphipathic.
- In water, phospholipids spontaneously arrange into a bilayer with heads facing outward and tails inward.
- This forms the basic fabric of plasma membranes and organelle membranes.

Steroid hormones

- Steroids are derived from cholesterol and can be recognized by four fused carbon rings.
- Examples required: testosterone and oestradiol.
- Because steroids are non-polar, they pass through phospholipid bilayers easily.
- They can enter target cells and even the nucleus, where they influence transcription and mRNA production.

11. Carbohydrates vs lipids as energy stores

Feature	Carbohydrates	Lipids
Typical storage form	Starch in plants; glycogen in animals	Triglycerides in adipose tissue / oils in plants
Best use	Shorter-term, readily mobilized energy	Long-term, compact energy storage
Solubility	Monomers such as glucose are water-soluble	Very low solubility in aqueous fluids
Transport	Glucose is easy to transport in blood and cell fluids	Fatty acids are less easily transported in aqueous environments
Energy per gram	Lower	About twice that of carbohydrates
Osmotic effect of stored form	Polysaccharides are relatively insoluble so osmotic effect is low	Triglycerides are insoluble, so osmotic effect is also low

One-line comparison

Carbohydrates are better for quick access and transport; lipids are better for dense, long-term storage and insulation.

12. Common exam traps

- Do not say all carbohydrates follow $C_nH_{2n}O_n$; that formula is for standard monosaccharides only.
- Do not confuse alpha-glucose with beta-glucose when explaining starch/glycogen vs cellulose.
- Do not say phospholipids are entirely hydrophobic; they are amphipathic.

- Do not forget water in reaction equations: condensation produces it, hydrolysis uses it.
- AB is the universal recipient; O is the universal donor (for the ABO system described here).

13. Worked answers to the textbook exercises

Q1

- Glucose repeatedly contains hydroxyl (–OH) groups.
- Glycine contains an amino ($–NH_2$) group and a carboxyl (–COOH) group.
- ATP contains phosphate, hydroxyl and amino-containing groups (the adenine base contains amino functionality).

Q2

- Triose: $C_3H_6O_3$
- Pentose: $C_5H_{10}O_5$
- Hexose: $C_6H_{12}O_6$

Q3

- A person with blood type A can receive blood from A and O.
- A person with blood type A can donate blood to A and AB.

Q4

- Adding glucose to an existing polysaccharide is a condensation reaction.
- Water is a product of this reaction.

Q5

- Removing glucose from an existing polysaccharide is a hydrolysis reaction.
- Water is a reactant of this reaction.

14. Final recall checklist

- I can explain why carbon forms diverse compounds.
- I can distinguish condensation from hydrolysis and state the role of water.
- I can compare pentoses and hexoses and state the formula for monosaccharides.
- I can relate glucose properties to its biological uses.
- I can compare amylose, amylopectin, glycogen and cellulose.
- I can explain how glycoproteins determine ABO blood groups.
- I can form triglycerides and phospholipids from their subunits.
- I can compare saturated, monounsaturated and polyunsaturated fatty acids.
- I can explain why triglycerides and phospholipids are suited to different roles.
- I can identify a steroid from four fused rings and explain why steroid hormones cross membranes.