Unit 1 · Biomolecules

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Biomolecules and Cell Biology (Units 1–3 together): 9 of 75 marks; with Biology, Microbiology, Biota and Environment and Conservation a combined 21, at least 3 MCQs, 2 short and 1 long from them
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: the right bonding between DNA bases (A = T)
- **MCQ (1 mark)**
  - carbohydrate formula $C_x(H_2O)_y$; a disaccharide; what polysaccharides are
  - glycogen's role; ribose and deoxyribose in RNA, DNA
  - essential amino acids; what tyrosine makes
  - conjugated, fibrous proteins; insulin's job
  - simple lipids; oils liquid; glycolipids; cholesterol → hormones
  - mRNA; ribose; phosphate in both nucleic acids
  - Mg in chlorophyll; iodine and goiter; enzymes specific; water a solvent
- **Short (5 marks, in parts)**
  - define biomolecules, metabolism, aldoses and ketoses; examples
  - oligo- vs polysaccharides; essential vs non-essential amino acids
  - primary and quaternary structure, with examples; thrombin and fibrinogen
  - DNA vs RNA; mRNA's role; phospholipids in membranes; iron's jobs
  - telomeres; autosomes vs sex chromosomes; a balanced lunch
  - name the parts: a β-sheet, an amino acid, a nucleotide

Key terms

Biomolecules: molecules of living things; organic (carbohydrates, proteins, lipids, nucleic acids, hormones, vitamins) or inorganic (water, minerals, ions, O_2, CO_2).

Metabolism: all the chemical reactions of a living thing; **catabolism** breaks down (energy out), **anabolism** builds up.

Cellular pool: all the biomolecules in a cell at a time, in its water.

Micromolecules: small, low mass, soluble (water, gases, sugars, amino acids, nucleotides); **macromolecules**: carbohydrates, lipids, proteins, nucleic acids.

Polymer: chain of **monomers** (all macromolecules except lipids).

Condensation: joining two molecules, water removed; **hydrolysis**: splitting by adding water (digestion).

Aldose: sugar with an aldehyde group –CHO at carbon 1 (glucose); **ketose**: ketone group >C=O at carbon 2 (fructose).

Reducing sugar: reduces Cu^{2+} to Cu^{+}: Benedict's blue → brick-red Cu_2O; all monosaccharides.

Glycosidic bond: C–O–C between two sugars.

Peptide bond: –CO–NH– between –COOH of one amino acid and $–NH_2$ of the next.

Zwitterion: $H_3N^{+}–CHR–COO^{-}$; amino acids are **amphoteric**.

Prosthetic group: the non-protein part of a conjugated protein.

Denaturation: a protein loses its shape (not its peptide bonds) to heat, pH, alcohol, heavy metals; loses its job.

Ester: acid + alcohol, water removed; most lipids.

Nucleoside: base + pentose; **nucleotide**: nucleoside + phosphate.

Enzyme: protein biocatalyst; acts on its **substrate** at its **active site**; lowers the **activation energy**.

Carbohydrates

- C, H, O, H : O = 2 : 1; general formula $\mathbf{C_x(H_2O)_y}$ (a pattern: deoxyribose $C_5H_{10}O_4$ doesn't fit; acetic acid fits but isn't one)
- polyhydroxy aldehydes or ketones; also called **saccharides**

Monosaccharides ($C_nH_{2n}O_n$, n = 3–7): can't be hydrolyzed; white, crystalline, soluble, sweet

- trioses (glyceraldehyde, dihydroxyacetone), tetroses (erythrose), pentoses (**ribose**, ribulose), hexoses (**glucose**, galactose, **fructose**), heptoses (sedoheptulose)
- glucose: aldohexose, most abundant, blood sugar; fructose ketohexose, same formula (**isomers**)
- in water: **rings**; glucose C5–O–C1 (6-membered); fructose C5→C2 and ribose C4→C1 (5-membered); **Haworth** projection

- α (–OH on C1 down) and β (up): starch from α-glucose, cellulose from β

Oligosaccharides (2–10 units, glycosidic bonds)

- $C_6H_{12}O_6 + C_6H_{12}O_6 \longrightarrow C_{12}H_{22}O_{11} + H_2O$ (condensation ⇄ hydrolysis)
- **sucrose** = glucose + fructose, $\alpha 1 \rightarrow \beta 2$, **non-reducing** (both carbonyls used); carried in phloem
- **maltose** = glucose + glucose, $\alpha(1 \rightarrow 4)$, reducing (starch breakdown)
- **lactose** = galactose + glucose, $\beta(1 \rightarrow 4)$, reducing (milk)
- **raffinose** ($C_{18}H_{32}O_{16}$) = galactose + sucrose, $\alpha(1 \rightarrow 6)$; **stachyose** ($C_{24}H_{42}O_{21}$) 2 galactose + glucose + fructose; in legume seeds

Polysaccharides (glycans; > 10 units): not sweet, mostly insoluble, practically non-reducing

- **structural**: cellulose (plant walls), chitin (fungal walls, insects), mannan (yeast), peptidoglycan (bacteria)
- **storage**: starch (plants), glycogen (animals, fungi)
- **homo-**: glucans (starch, glycogen, cellulose), fructans (inulin: garlic, onion)
- **hetero-**: arabinogalactans (gums), hyaluronic acid, peptidoglycan

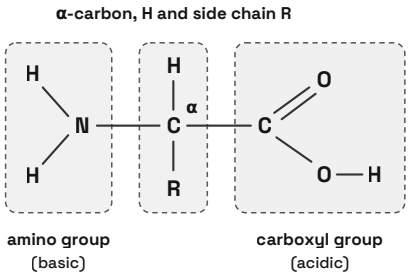
	Bonds	Shape
amylose	$\alpha(1 \rightarrow 4)$	unbranched, helix
amylopectin	$\alpha(1 \rightarrow 4)$ + $\alpha(1 \rightarrow 6)$ branch every 24–30	branched
glycogen	as amylopectin, branch every 8–12	very branched, fast release
cellulose	$\beta(1 \rightarrow 4)$	straight, flat; microfibrils

Functions

- energy: ~17 kJ (4 kcal)/g; $C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$ + ~2870 kJ/mol
- structure: ribose, deoxyribose (RNA, DNA, ATP); cellulose; chitin
- storage: starch; glycogen ("animal starch") in **liver** and **muscles**
- raw material for fats and amino acids
- fats burn fully only with glucose; else **ketone bodies**

Amino acids

- on the α-**carbon**: $-NH_2$ (basic), –COOH (acidic), H, side chain **R** (glycine R = H; alanine $-CH_3$)
- colorless crystalline solids; soluble in water, not in ether; 20 coded



Amino acid: amino group, carboxyl group, H and R on the α-carbon.

- dipeptide → tripeptide → polypeptide; written N-terminus → C-terminus
- **essential (9)**: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine
- **non-essential (11)**: alanine, arginine, asparagine, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, tyrosine

Functions

- build proteins and enzymes
- **tryptophan** → niacin (B_3), serotonin, **IAA** (auxin)
- **tyrosine** → **thyroxine**, **adrenaline**, melanin
- **glycine** → heme (via protoporphyrin)

Proteins

- chains of amino acids in an order set by the **gene**; order → folding → job; over half a cell's dry mass

By make-up

- **simple**: only amino acids: albumins, globulins, histones, protamines
- **conjugated** (+ prosthetic group):
  - glycoprotein: + carbohydrate (mucin of saliva)
  - phosphoprotein: + phosphate (casein, ovovitellin)
  - lipoprotein: + lipid (HDL)
  - nucleoprotein: + nucleic acid (chromatin, ribosomes)
  - chromoprotein: + pigment with Fe, Cu, Mg (hemoglobin, rhodopsin, hemocyanin)
- **derived**: partial hydrolysis: proteoses, peptones (pepsin)

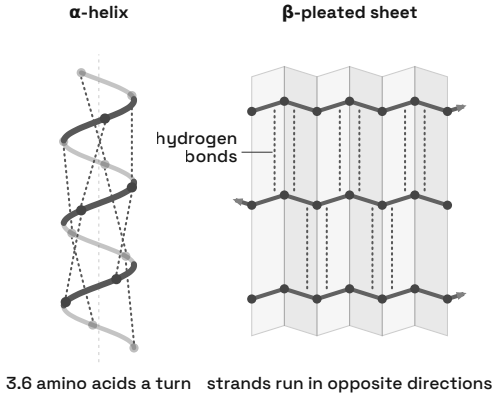
By shape

- **fibrous**: long chains as fibers, tough, insoluble, structural: keratin, collagen, elastin, myosin, fibroin
- **globular**: compact, mostly soluble, in **all** living things: enzymes, insulin, antibodies, hemoglobin, albumins, glutelins

Structure

1. **primary**: amino acid sequence, peptide bonds; insulin (51 amino acids, 2 chains) first sequenced, Sanger 1949–55 (Nobel 1958)
2. **secondary**: H-bonds between backbone C=O and N–H: α-**helix** (right-handed, 3.6 a turn, C=O to N–H 4 along; α-keratin), β-**pleated sheet** (silk fibroin)

3. **tertiary**: whole 3D fold of one chain (globular); ionic, H-bonds, hydrophobic, **disulphide** (–S–S–)
4. **quaternary**: two or more chains (subunits): **hemoglobin** ($2\alpha + 2\beta$), immunoglobulins (2 heavy + 2 light); one-chain ribonuclease, myoglobin: none



Secondary structure: α-helix and β-pleated sheet.

Functions

- structure, repair: collagen, keratin, actin, myosin
- energy: 5.65 kcal/g burned; **4 kcal/g** in the body (N lost as urea)
- enzymes; hormones (**insulin** lowers blood glucose)
- defense: **antibodies**
- clotting: **thrombin** cuts soluble **fibrinogen** → insoluble **fibrin** threads trap cells
- transport: hemoglobin (O_2), membrane carriers

Lipids

- C, H, O, much **less O** (tristearin $C_{57}H_{110}O_6$); insoluble in water, soluble in acetone, ether, chloroform, alcohol
- R–COOH + R′–OH ⇌ R–COO–R′ + H_2O

Fatty acids (R–COOH; even C, 14–22, mostly 16 or 18)

- **saturated**: only single bonds, straight, pack tightly, high m.p., solid: ghee, butter, coconut, palm; palmitic (16 C), stearic (18 C, 69 °C)
- **unsaturated**: C=C (cis, bent), low m.p., liquid oils: oleic (1 C=C, ~13 °C), linoleic (2), linolenic (3)

Group	What it is	Examples
simple	fatty acid + alcohol	glycerides, oils, waxes
complex	+ another group	phospholipids, glycolipids, lipoproteins
derived	from these by hydrolysis	fatty acids, glycerol, steroids

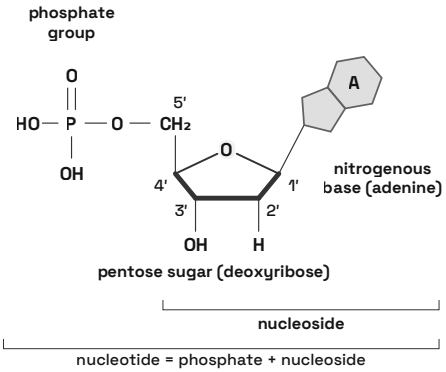
- triglyceride + $3H_2O$ → glycerol + 3 fatty acids (**lipase**)
- **glycerides**: glycerol (3 –OH) + 1, 2, 3 fatty acids = mono-, di-, **triglyceride** (3 H_2O removed)
- **oils**: rich in unsaturated; **hydrogenation** (H_2, Ni) → vanaspati, margarine; **trans fats** raise LDL, lower HDL
- **waxes**: long-chain fatty acid + long-chain alcohol (not glycerol); waterproof: cuticle, beeswax, lanolin; paraffin is a hydrocarbon, not a lipid
- **phospholipids**: glycerol + 2 fatty acids + phosphate–choline; hydrophilic head, hydrophobic tails → **lipid bilayer**; lecithin, cephalin, plasmalogens
- **glycolipids**: sugar head; myelin (white matter): cerebrosides, gangliosides
- **lipoproteins**: carry fats and cholesterol in blood: chylomicrons, VLDL, LDL, HDL
- **steroids**: four carbon rings; **cholesterol** (a sterol) → steroid hormones (progesterone, testosterone, estrogen, cortisol, aldosterone), **vitamin D** (7-dehydrocholesterol + UV), **bile acids**; too much LDL cholesterol → plaque

Functions

- stored food; ~9 kcal (37 kJ)/g, over twice carbohydrate
- insulation; cushions organs; adipose triglycerides the main reserve
- carry vitamins **A, D, E, K**
- membranes (phospholipids, glycolipids); bile salts emulsify fat
- lipoproteins carry fats, bind endotoxins; waxes waterproof

Nucleic acids

- C, H, O, N, P; polymers of **nucleotides** (polynucleotides)
- nucleotide = **pentose** (ribose / deoxyribose: no –OH on 2′) + **base** (on C1′) + **phosphate** (on C5′); ATP is a nucleotide
- **purines** (2 rings): adenine, guanine; **pyrimidines** (1 ring): cytosine, thymine (DNA only), uracil (RNA only)
- **A=T** (2 H-bonds), **G≡C** (3); RNA: A–U
- **phosphodiester bond**: phosphate joins C5′ of one sugar to C3′ of the next → sugar–phosphate backbone



Nucleotide: phosphate on C5′, base on C1′ of the pentose.

DNA (Watson and Crick, 1953)

- two strands, **right-handed double helix**, **antiparallel** (5′→3′, 3′→5′)
- backbones outside, bases inside; H-bonds between complementary bases
- **2 nm** wide; base pairs **0.34 nm** apart; turn **3.4 nm**, ~10 bp
- **Chargaff**: A = T, G = C (human ~30% A, 30 T, 20 G, 20 C); 18% G → C 18%, A = T 32%

- functions: genetic material; replication; crossing over → variation; mutation; transcription; DNA → RNA → protein (**central dogma**)

RNA: single strand, ribose, A, G, C, **U**; 3′–5′ phosphodiester bonds

- **mRNA**: carries the gene's code to ribosomes; few %, short-lived; 5′ cap
- **rRNA**: in ribosomes; ~80%, stable; joins amino acids
- **tRNA**: adapter; brings one amino acid, pairs with the codon
- reverse transcriptase: mRNA → cDNA; genetic material of some viruses (influenza, polio, coronavirus)

DNA	RNA
double helix	usually one strand
deoxyribose	ribose
A, G, C, **T**	A, G, C, **U**
nucleus (some in mitochondria, chloroplasts)	made in nucleus, works in cytoplasm
stable	less stable
copies itself	copied from DNA
stores information	uses it to make protein

Chromosome ends and kinds (exercise)

- **telomeres**: repeated sequence (TTAGGG) at the ends; cap and protect; lost instead of genes in copying; a division clock (aging); rebuilt by **telomerase** (stem cells, cancer cells)
- **autosomes**: 22 pairs, don't decide sex, alike in both sexes; **sex chromosomes**: 1 pair (XX, XY), decide sex, carry sex-linked genes

Minerals

- ~4% of body mass; ~25 elements needed
- **macro** (> ~100 mg a day): Ca, P, K, S, Na, Cl, Mg (and N for plants)
- **micro/trace**: Fe, Zn, Cu, Mn, I, Se, Mo, Co, Cr, F
- **Ca**: bones, teeth, shells ($CaCO_3$); clotting, muscle; middle lamella
- **Mg**: center of **chlorophyll**; ATPases
- **K**: **membrane potential**, nerve impulses; stomata
- **S**: cysteine, methionine; keratin's –S–S–; coenzyme A
- **Na**: nerve impulses; ion and water balance
- **N**: proteins, nucleic acids, ATP, chlorophyll
- **P**: nucleic acids, ATP, phospholipids; bones
- **Cl**: plasma anion; stomach HCl; chloride shift
- **Cu**: cytochrome oxidase, plastocyanin; melanin
- **Fe**: **hemoglobin**, myoglobin, cytochromes; lack → **anemia**
- **I**: **thyroxine**; lack → **goiter**, cretinism
- **Mn**: respiration, photosynthesis (splits water)
- **Mo**: **nitrogenase**, nitrate reductase
- **Zn**: 300+ enzymes (carbonic anhydrase)

Enzymes

- **exoenzymes** work outside the cell (amylase, pepsin); **endoenzymes** inside (Krebs cycle)
- lower the **activation energy**; same energy given out, same equilibrium

Characteristics

1. proteins, mostly globular; may need a metal ion or **coenzyme** (from a vitamin)
2. hydrophilic; a colloid (hydrosol)
3. **specific**: one substrate or bond, one reaction
4. reversible in principle
5. efficient: catalase breaks millions of H_2O_2 a second
6. speed up only; don't start impossible reactions
7. made from its gene
8. denatured by heat, wrong pH, heavy metals (Hg, Pb, Ag), radiation

Importance: almost every reaction, at body temperature, each at its own pH (pepsin acid, trypsin alkaline); need for homeostasis

Water

- 60–70% of body, 70–90% of protoplasm (jellyfish 95%)
- H–O–H at 104.5°; **polar**, a dipole (O $\delta-$, H $\delta+$); **hydrogen bonds** to up to 4 others; ice an open lattice, floats
- **functions**: best **solvent**; hydrolysis, ions; high heat of evaporation (~2.4 kJ/g): sweating cools; steady temperature; **cohesion**, surface tension → xylem columns; transport (plasma, phloem); habitat (lakes freeze from top); removes wastes (homeostasis)

COMMON MISTAKES

✗ histone is a nucleoprotein
✓ a histone alone is simple; with DNA (chromatin) a nucleoprotein.

✗ fibrous proteins only in animals, globular in plants
✓ both kinds everywhere; they differ in shape and job.

✗ sucrose is a reducing sugar
✓ non-reducing: its bond uses both carbonyl groups.

✗ 28% A, 24% G, 20% C, 28% T in DNA
✓ G must equal C, A must equal T.

✗ cellulose is made of α-glucose
✓ β-glucose, $\beta(1\rightarrow4)$; starch is α.

✗ paraffin wax is a lipid
✓ a mixture of hydrocarbons, no ester.

✗ protein gives 5.65 kcal/g in the body
✓ 4 kcal/g; its nitrogen leaves as urea.

✗ denaturation breaks the peptide bonds
✓ only the shape is lost.