Biomolecules

The complex molecules that build & sustain all living organisms are called biomolecules. They run every cellular process — energy, growth, ~~digestion~~ heredity, repair, immunity.

Main Classes

1. Carbohydrates — fuel + structure
   (sugars, starch, cellulose)
2. Proteins — builders & enzymes
   (made from 20 alpha-amino acids)
3. Nucleic acids — heredity & code
   (DNA stores, RNA expresses)
4. Vitamins — micro-nutrients, required in tiny amounts
5. Hormones — chemical messengers
   (insulin, adrenaline, thyroxine)

Life = C, H, O, N, P, S + H2O

<- six key elements

Biomolecules are mostly polymers built from smaller repeating units called monomers. Hydrolysis breaks them, condensation joins them.

Carbohydrates

Polyhydroxy aldehydes or ketones, or compounds that yield these on hydrolysis. General formula $C_n(H_2O)_n$ (so the old name 'hydrate of C').

Classification

Based on hydrolysis behaviour:

1. Monosaccharides — cannot be hydrolysed further. Examples:
   glucose, fructose, galactose,
   ribose, 2-deoxyribose, mannose.
2. Disaccharides — give 2 monosaccharides on hydrolysis. e.g. sucrose, maltose, lactose.
3. Oligosaccharides (2 to 10 units).
4. Polysaccharides — give many units, e.g. starch, cellulose, glycogen.

Aldose vs Ketose

Aldose : carries a -CHO group (e.g. glucose, ribose).

Ketose : carries a >C=O inside chain (e.g. fructose).

Reducing vs Non-reducing

Reducing : free -CHO or -C=O group can reduce Tollens' / Fehling. Non-reducing : both functional groups locked in glycosidic bond (e.g. sucrose).

Glucose (aldohexose)

Molecular formula : $C_6H_{12}O_6$ (IUPAC : D-(+)-glucose

Most abundant monosaccharide; called blood sugar.

Made by photosynthesis : $6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6$

Open-chain (Fischer)

CHO	(C1)
H - C - OH	(C2)
HO - C - H	(C3; OH then ~~sally~~ right-like)
H - C - OH	(C4)
H - C - OH*	(C5) <-=> D - series
CH_2OH	(C6)

Cyclic Haworth forms

C1 -CHO reacts with C5 -OH internally to give a 6-membered ring -> ~~furanose~~ pyranose ring.

New chiral centre at C1 is called the anomeric C.

Constants :

alpha - D - glucopyranose : m.p. = 419 K *

$[\alpha]_D$ = + 112

beta - D - glucopyranose : m.p. = 423 K

$[\alpha]_D$ = + 19 de

Mutarotation

Slow inter-conversion of alpha <-> beta via open chain.

Equilibrium $[\alpha]_D$ = + 52.7 deg (in water).

Fructose (ketohexose)

Same formula $C_6H_{12}O_6$ but with a keto group
→ C = O at C2 (NOT -CHO at C1 like glucose).
IUPAC : D - (-) - fructose, $[\alpha]_D$ = - 92.4 deg

Cyclic form

C2 keto reacts with C5 -OH → 5-membered ring
called α - D - fructofuranose / beta - D - fructofuranose.
(Note: 5-ring = furanose, 6-ring = pyranose.)

Anomers

Cyclic sugars that differ ONLY in the configuration
of the anomeric carbon (C1 in aldoses, C2 in ketoses).
e.g. α - D - glucose & beta - D - glucose
— anomers at C1.

Epimers

Diastereomers that differ in configuration at ONLY
ONE of several chiral carbons (not the anomeric one).

Examples :
Glucose & mannose → ~~C1~~ C2 epimers
Glucose & galactose → C4 epimers

Anomer : ONE C, the anomeric one (C1 / C2)

Epimer : ONE C, but some OTHER chiral C

Disaccharides

Two monosaccharides joined by an oxide / glycosidic bond (- O -) ; loss of one water molecule.

Sucrose (table sugar)

α - D - glucose + beta - D - fructose
joined by α (1 -> beta 2) glycosidic linkage.
Both anomeric C's are locked -> ~~reducing~~ NON-reducing.
Hydrolysis (acid / invertase enzyme) gives
equimolar glucose + fructose = invert sugar.
$[\alpha]_D$: + 66.5 deg -> - 20 deg (rotation flips !)

Maltose

α - D - glucose + α - D - glucose
joined by α (1 -> 4) glycosidic bond.
C1 of second glucose is FREE -> REDUCING sugar.

Lactose (milk sugar)

beta - D - galactose + beta - D - glucose
joined by beta (1 -> 4) glycosidic bond.
Free anomeric C on glucose -> REDUCING sugar.

Reducing : maltose , lactose

Non-reducing : sucrose

Polysaccharides

Long polymeric chains of monosaccharide units.
Mostly non-sweet, non-reducing (free anomeric C is negligible vs total chain).

Starch (plant storage)

Two components :

a) Amylose 20 % -> LINEAR chain
of α - D - glucose joined α (1 -> 4).
Soluble in hot water.

b) Amylopectin 80 % -> BRANCHED chain
main bonds α (1 -> 4)
branch bonds α (1 -> 6) every 25 - 30 units.
Insoluble in water.

Cellulose

Linear polymer of beta - D - glucose
joined by beta (1 -> 4) glycosidic bonds.
Structural in plant cell walls. ~~Animals digest it~~ Humans cannot digest cellulose — we lack cellulase.

Glycogen (animal storage)

Polymer of α - D - glucose ; α (1 -> 4) + α (1 -> 6) branches — MORE branched than amylopectin.
Stored mainly in liver & skeletal muscle.
Called 'animal starch'.

Amino Acids

Building blocks of proteins. 20 standard
~~beta~~ alpha - amino acids occur naturally.
General structure :

$H_2N - CH(R) - COOH$	<- R = side <- chain

Classification by R

(a) Acidic : side -COOH group
Asp (D), Glu (E).

(b) Basic : side -NH2 / amide / imidazole
Lys (K), Arg (R), His (H).

(c) Neutral : non-polar / polar non-charged
Gly, Ala, Ser, Thr, ...

(d) Aromatic : ring R group
Phe (F), Tyr (Y), Trp (W).

(e) Sulphur : -SH or -S-CH3 in R
Cys (C), Met (M).

Essential 9 (PVT TIM LH)

Body cannot synthesise — must come from diet.

Phe , Val , Thr , Trp , Met* ,	<- 9 essentials <- for adults
Leu , Ile , Lys , His	<- (His added <- in growth)

Zwitterion & pI

In aqueous solution, an amino acid does NOT exist as a neutral molecule. The -COOH donates H+ to the -NH2, giving the dipolar ion (zwitterion):

$$H_3N^{(+)} - CH(R) - COO^{(-)}$$

<- internal salt

Net charge depends on pH : in acid -> cation, in base -> anion. The pH at which the molecule carries zero net charge is the isoelectric point :

$$pI = (pKa1 + pKa2) / 2$$

<- neutral AA only

Peptide Bond

Formed by condensation between the -COOH of one amino acid and the -NH2 of another, losing H2O.

$$-CO-NH-$$ (the peptide bond)

Special features

1. Planar (the 6 atoms C, N, O, H, C(alpha) x 2 lie in one plane).
2. 40 % double-bond character because of resonance $-C(=O)-N- \leftrightarrow -C(-O-)=N+-$.
3. Restricted rotation about C - N.
4. Trans configuration is preferred (less steric).
5. Provides H-bond donor (N-H) & acceptor (C=O).

Protein Structure

Primary (1 deg)

Linear sequence of amino acids joined by peptide bonds. This sequence is dictated by the gene (DNA). A single mis-placed AA can destroy function (e.g. sickle-cell HbS = Val replaces Glu at pos 6).

Secondary (2 deg)

Local folding stabilised by H-bonds (between N-H and C=O of the backbone). Two main motifs:

(a) alpha - HELIX : right-handed coil
3.6 residues per turn, pitch 5.4 A°
rise 1.5 A° per residue. (e.g. keratin)

(b) beta - PLEATED sheet : extended strands
parallel or antiparallel ; H-bonds
between strands. (e.g. silk fibroin)

Tertiary (3 deg)

Full 3-D fold of one polypeptide chain.
Stabilised by disulphide (- S - S - between Cys), salt bridges, hydrophobic & H-bonding interactions.

Quaternary (4 deg)

Two or more polypeptide subunits assembled together :
Haemoglobin : 2 α + 2 beta chains (tetramer)
Insulin : A chain (21 AA) + B chain (30 AA
2 inter-chain S-S + 1 intra-A S-S.

Denaturation

Loss of biological activity caused by disruption of the higher-order structure of a protein.

What breaks

Denaturation breaks the WEAK interactions :

- hydrogen bonds
- hydrophobic clusters
- salt bridges
- some disulphide links

What survives

Primary structure (peptide bonds) = intact

i.e. the AA sequence is preserved ; only the folded shape (2 deg / 3 deg / 4 deg) is lost.

Common causes

Heat , pH change , detergents , heavy metals , alcohol , UV radiation , mechanical agitation.

Everyday examples

- Egg-white turns opaque on heating
  (albumin denatures, traps air -> coagulates).
- Milk curdles in lemon juice
  (casein denatures at low pH).

Enzymes

Biological catalysts — almost all enzymes are globular proteins (exception : ribozymes = RNA).
Names usually end in '-ase' (maltase, urease).

Key properties

1. Lower the activation energy Ea ;
   do NOT change delta G of reaction.
2. Highly SPECIFIC to substrate & reaction.
3. Work at mild T & pH ; denature easily.
4. Catalytic — turn-over number is high.

Models of specificity

Lock-and-key (Emil Fischer) : active site is rigid and exactly fits one substrate.
Induced fit (Koshland) : active site is flexible and reshapes around the substrate.

Inhibitors

(a) Competitive : binds the same active site as substrate ; reversed by raising [S].
(e.g. ~~methanol~~ malonate vs succinate dehydrogenase.)

(b) Non-competitive : binds an allosteric site ; changes enzyme shape ; often irreversible (e.g. heavy metals Hg^{2+}, Pb^{2+}).

Increasing [S] does NOT relieve non-competitive.

Vitamins - Fat soluble

Organic micro-nutrients ; needed in small amounts for normal metabolism. Two big groups based on solubility :

Fat-soluble : A , D , E , K

Water-soluble : B group , C

FAT-soluble (stored in liver / fat tissue)

Vit	Name	Deficiency disease
A	Retinol	Night-blindness , xerophthalmia <- carotene <- source
D	Calciferol	Rickets (child) , osteomalacia (adult) <- sunlight <- synth
E	Tocopherol	Sterility , muscular dystrophy
K	Phylloquinone	Blood clotting failure (haemorrhage)

Why stored ?

Being non-polar they dissolve in body fat and stay for weeks -> daily intake NOT essential.

BUT ~~more~~ hyper-vitaminosis is possible (toxic).

Water - soluble Vitamins

Polar molecules — excess is excreted in urine, so NOT stored. Daily dietary intake is essential.

Vit	Name	Deficiency	
B1	Thiamine	Beriberi	
B2	Riboflavin	Cheilosis, glossitis	
B3	Niacin	Pellagra	
B5	Pantothenic acid	Burning - feet syndrome	
B6	Pyridoxine	Convulsions	
B7	Biotin	Dermatitis, hair loss	
B9	Folic acid	Megaloblastic anaemia	
B12	Cobalamin (Co)	Pernicious anaemia	<- only B12 has <- a metal (Co
C	Ascorbic acid	Scurvy	

Nucleic Acids (DNA / RNA)

Polymers that store & transmit hereditary info.
Watson & Crick proposed the double-helix in 1953.

Components

Each nucleic acid is built from three parts :

1. Pentose sugar
   - DNA : 2 - deoxy - D - ribose
   - RNA : D - ribose
2. Phosphate group (-O - P(=O)(OH) - O -)
3. Nitrogenous base
   - Purines : Adenine (A), Guanine (G)
     ~~monocyclic~~ bicyclic 9-atom ring
   - Pyrimidines : Cytosine (C), Thymine (T), Uracil (U) - monocyclic 6-atom r

Base pairing (DNA)

A = T (2 H - bonds) <- Chargaff's <- rule

G triple-bond C (3 H - bonds)

DNA dimensions (B - form)

- Two strands are ANTIPARALLEL (5'-73' vs 3'-75')
- 10 base pairs per turn
- Pitch (one full turn) = 3.4 nm
- Rise per base pair = 0.34 nm
- Helix diameter = 2 nm (20 A)

RNA

Single - stranded ; U replaces T ; sugar = ribose.

Nucleotides & Function

Nucleoside vs Nucleotide

Nucleoside = sugar + base

Nucleotide = sugar + base +	PO_4

e.g. adenosine (nucleoside) -> AMP / ADP / ATP

Nucleotides connect by phosphodiester bonds
(5' phosphate of one -> 3' OH of next).

Backbone direction is 5' -> 3'.

Types of RNA

- mRNA (messenger) - carries gene code from DNA to ribosome
- tRNA (transfer) - anticodon ; brings the matching amino acid
- rRNA (ribosomal) - structural part of the ribosome

Central dogma

DNA -> RNA -> Protein

<- transcription
<- + translation

Hormones (brief)

Chemical messengers secreted by endocrine glands.

Three chemical types :

1. Steroid : cortisol , testosterone , estrogen
2. Peptide : insulin , glucagon , oxytocin
3. Amine : adrenaline , thyroxine (T4)