

Chemistry Option B: Human Biochemistry

(HL & SL)

1/1/2014

Chapter B: Human Biochemistry

B.1 Energy

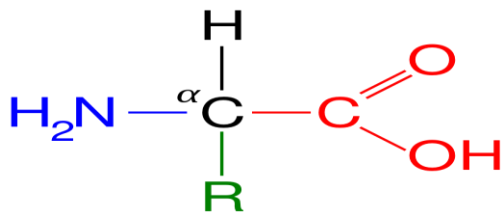
B.1.1 Calculate the energy value of a food from enthalpy of combustion data.

Energy value = $MC\Delta T$

B.2 Proteins

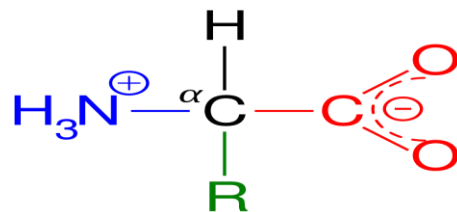
B.2.1 Draw the general formula of 2-amino acids.

①



General structure of unionised 2-aa

②

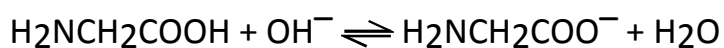
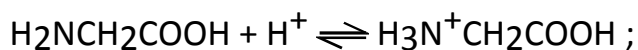


General structure of zwitterions

B.2.2 Describe the characteristic properties of 2-amino acids (3m)

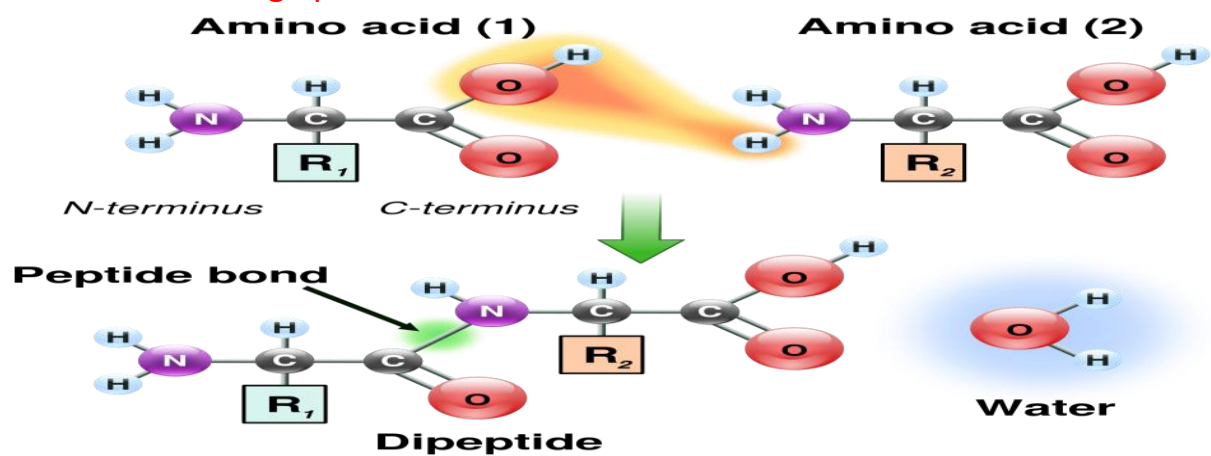
- general formula $\text{HOCCRRH}_2\text{NH}_2$;
- At isoelectric point;
- zwitterion/forms neutral ion when H^+ transfers from COOH to NH_2 ;
- buffer action/can accept H^+ and OH^- ;

Eg: Glycine acting as a buffer



B.2.3 Describe the condensation reaction of 2-amino acids to form polypeptides.

Reactions involving up to three amino acids will be assessed.



B.2.4 Describe and explain the primary, secondary (α -helix and β -pleated sheets), tertiary and quaternary structure of proteins. Include all bonds and interactions (both intramolecular and intermolecular) responsible for the protein structure.

Structure	Definition	Interactions
Primary	(linear) sequence/order of amino acids	<ul style="list-style-type: none"> • covalent bonds
Secondary	way in which chain of amino acids folds itself / way in which sequence is kept together by hydrogen bonding between atoms in sequence	<ul style="list-style-type: none"> • hydrogen bonding
Tertiary	made up of 2-amino acid residues such as serine and cysteine, are the result of interactions between amino acids; secondary structures fold to give a three-dimensional shape	<ul style="list-style-type: none"> • van der Waals attraction between non polar groups; • ionic bonding between charged groups/NH_3^+ and COO^-; • hydrogen bonding between H bonded to O or N with another O or N; • disulfide bridges/bonds between two S atoms (in cysteine); • peptide linkages/bonds between $-\text{COOH}$ and $-\text{NH}_2$ groups;

B.2.5 Explain how proteins can be analysed by chromatography and electrophoresis. (5m)

- add hydrochloric acid/HCl / hydrolyse to convert protein into amino acid mixture / (successively) release amino acids;
- mixture/amino acids spotted/placed on paper/gel;
Can be shown with diagram.
Do not accept protein placed/spotted on paper/gel.
- use of buffer solution;
- apply voltage/potential difference;
Can be shown with diagram.
Do not allow "pass current/electricity through mixture".
- amino acids move in different directions (depending on their isoelectric points);
- develop with ninhydrin/triketohydrindane hydrate/
2,2-dihydroxyindane-1,3-dione/organic dye;
- measure distances moved / compare with known samples / measure isoelectric points (and compare with data);

B.2.6 List the major functions of proteins in the body.

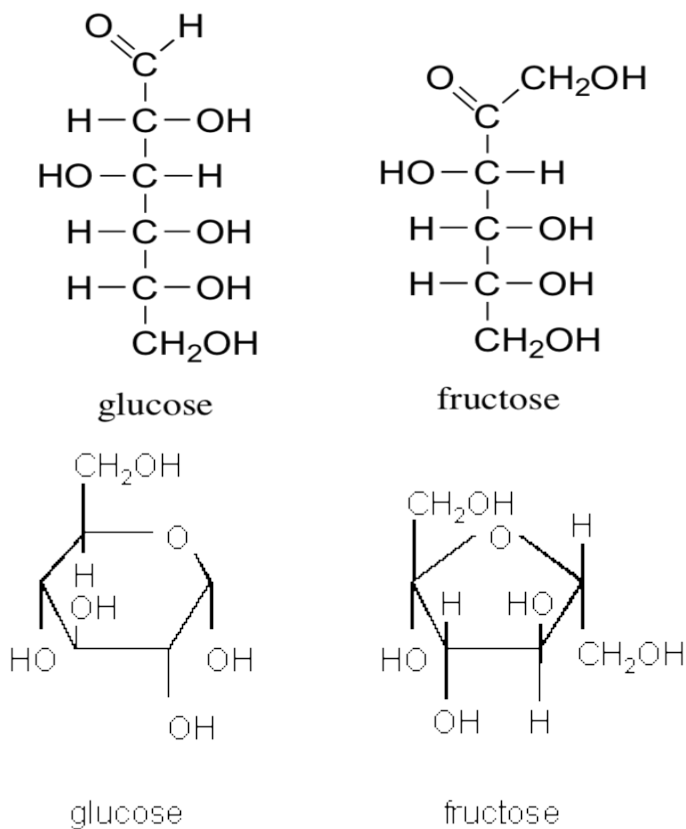
- structural proteins (for example, collagen),
- enzymes, hormones (for example, insulin),
- immunoproteins (antibodies),
- transport proteins (for example, hemoglobin)
- an energy source.

B.3 Carbohydrates

B.3.1 Describe the structural features of monosaccharides.

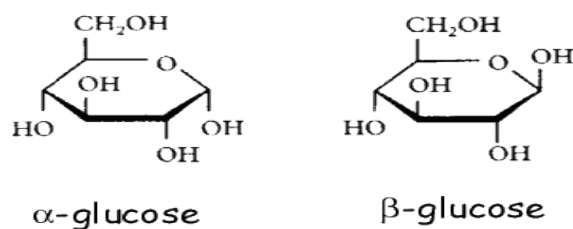
- Monosaccharides contain a carbonyl group (C=O)
- at least two –OH groups
- have the empirical formula CH₂O.

B.3.2 Draw the straight-chain and ring structural formulas of glucose and fructose. Students should be made aware of the structural difference between α and β isomers.



Distinguish between the structures of α - and β -glucose.

- the OH on carbon-1/C-1 is inverted / difference in position of OH on carbon-1/C-1;



Explain why **two** cyclic isomers are formed from the straight-chain glucose and name both isomers.

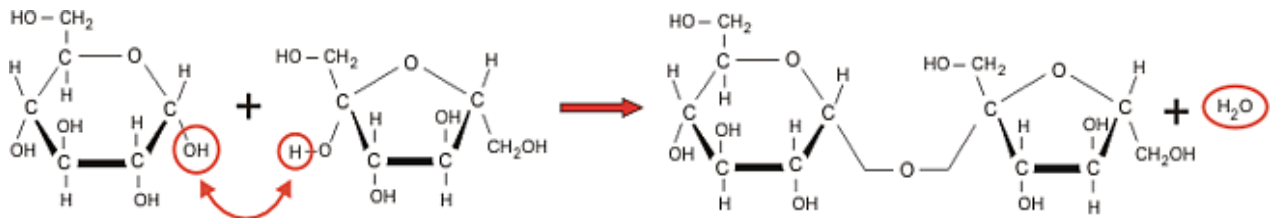
- C1 is asymmetric/chiral/has four different groups;
- forming two isomers where the OH-group is on a different side (of C1/ring);
- α -glucose **and** β -glucose;

B.3.3 Describe the condensation of monosaccharides to form disaccharides and polysaccharides.

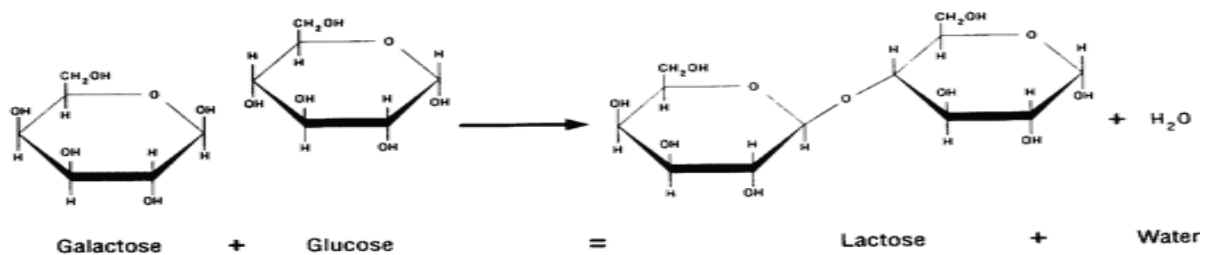
Examples include:

- disaccharides :

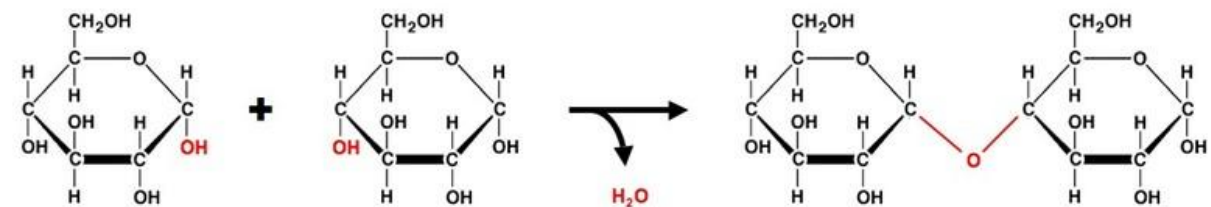
Sucrose



Lactose



Maltose



- polysaccharides:

Starch (α -glucose) made of amylose and amylopectin

Glycogen (α -glucose)

Cellulose (β -glucose)

B.3.4 List the major functions of carbohydrates in the human body.

- energy source (glucose),
- energy reserves (glycogen)
- precursors for other biologically important molecules.

B.3.5 Compare the structural properties of starch and cellulose, and explain why humans can digest starch but not cellulose. (3-4m)

- both are polymers of glucose;
- starch has two forms: amylose a straight chain polymer with $\alpha - 1, 4$ linkages;
- and amylopectin a branched polymer with $\alpha - 1, 4$ and $\alpha - 1, 6$ linkages;
- cellulose has $\beta - 1, 4$ linkages;

Both are polymers of glucose units. Starch has two forms: amylose, which is a straight-chain polymer (α -1,4 linkage), and amylopectin, which is a branched structure with both α -1,4 and α -1,6 linkages. Cellulose has a β -1,4 linkage; this can be hydrolysed by the enzyme cellulase, which is absent in most animals, including mammals.

B.3.6 State what is meant by the term dietary fibre. (1m)

- Dietary fibre is mainly plant material that is not hydrolysed by enzymes secreted by the human digestive tract but may be digested by microflora in the gut.
- Examples include cellulose, hemicellulose, lignin and pectin.

B.3.7 Describe the importance of a diet high in dietary fibre.

Dietary fibre may be helpful in the prevention of conditions such as

- diverticulosis
- irritable bowel syndrome
- constipation
- obesity
- Crohn's disease
- hemorrhoids
- diabetes mellitus.

B.4 Lipids

B.4.1 Compare the composition of the three types of lipids found in the human body.

- triglycerides (fats and oils),
- phospholipid (lecithin) - contains C, H, O, P and N
- steroids (cholesterol)- composed of C, H and O steroidal backbone/4 ring/tetra cyclic carbon structure skeleton

B.4.2 Outline the difference between High Density Lipoprotein (HDL) and Low Density Lipoprotein (LDL) cholesterol and outline its importance. (2m)

- LDL is (a) larger (molecule) than HDL;
- LDL transports cholesterol to arteries **and** HDL removes cholesterol from arteries;
- LDL produced from saturated fats/trans fatty acids;
- LDL increases the risk of heart disease/problems;
- HDL has a higher proportion/percentage of proteins/LDL has a lower proportion of proteins

B.4.3 Describe the difference in structure between saturated and unsaturated fatty acids.

- Saturated fatty acids have only C-C single bonds (109.5)
- Mono unsaturated fatty acids have 1 C=C double bond (120)
- Poly unsaturated fatty acids have more than 1 C=C double bond

*Most naturally occurring fats contain a mixture of saturated, mono-unsaturated and poly-unsaturated fatty acids and are classified according to the predominant type of unsaturation present.

B.4.4 Compare the structures of the two essential fatty acids linoleic (omega-6 fatty acid) and linolenic (omega-3 fatty acid) and state their importance.(3m)

Similarities:

- both have 18 carbon atoms;
- both have carboxyl/COOH;

Differences :

linoleic (omega-6 fatty acid)	linolenic (omega-3 fatty acid)
linolenic acid (will have higher iodine value);	
first double bond after the 6 th C atom	first double bond after the 3 rd C atom from the end of the CH ₃ group
2 double bonds	3 double bonds

Note: When compared to stearic acid

- C=Cs in linoleic acid cause the chain to be more uneven/kinked;
- linoleic acid cannot pack as closely as stearic acid;
- intermolecular/van der Waals'/London/dispersion forces weaker in linoleic acid;

Importance:

- essential fatty acids / cannot be synthesized in body;
- lowers LDL cholesterol level / lowers risk of heart disease / affects inflammation / conversion to important molecules;

EG: Deduce whether the fatty acid obtained in part (a) will have a higher or lower melting point compared to oleic acid, CH₃(CH₂)₇CH=CH(CH₂)₇COOH. Outline your reason. (2m)

- higher (melting point);
- saturated fatty acids / no unsaturation / no C=C bonds;
- *Accept appropriate reason such as close packing, no kink in molecule, stronger van der Waals' forces, larger surface area of contact.*

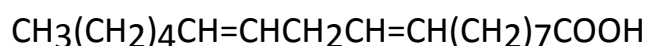
B.4.5 Define the term *iodine number* and calculate the number of C=C double bonds in an unsaturated fat/oil using addition reactions.

- Iodine number: The number of moles of I₂ reacting with one mole of fat/oil indicates the number of double bonds present in the fat/oil molecule.

OR

- the number of grams/mass of iodine that add to/react with 100 g of the fat/lipid/oil;

EG: Linoleic acid ($M_r = 281$) has the following formula.



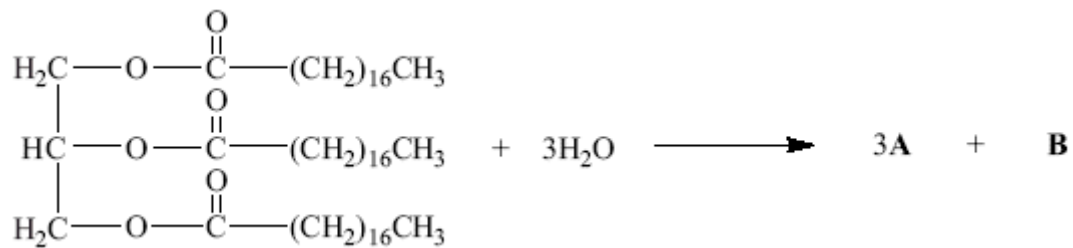
Calculate the volume of 1.00 mol dm⁻³ iodine solution required to react exactly with 1.00 g of linoleic acid.

- amount of linoleic acid = $\frac{1}{281} = 0.00356$ (mol);
- amount of I₂ required = $2 \times 0.00356 = 0.00712$ (mol);
- volume of 1.00 mol dm⁻³ solution = $7.12 \text{ cm}^3 / 0.00712 \text{ dm}^3$;

OR

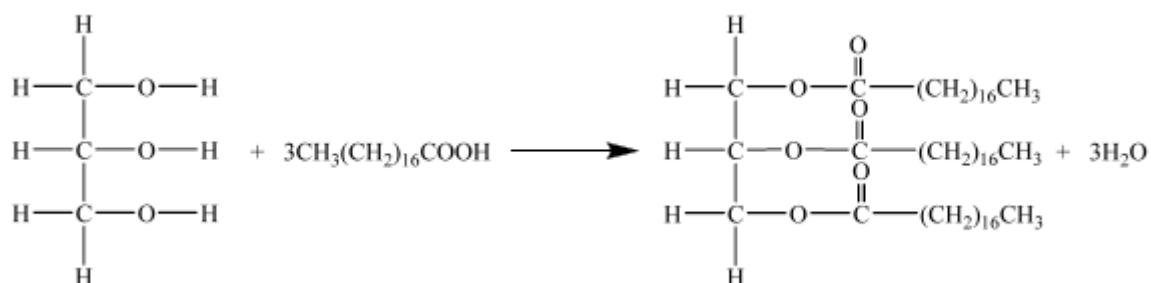
- 281 g of acid require 507.6 g of iodine;
- 1 g of acid requires 1.806 g/0.00712 mol of iodine;
- volume of 1.00 mol dm⁻³ solution = $7.12 \text{ cm}^3 / 0.00712 \text{ dm}^3$;

B.4.6 Describe the condensation of glycerol and three fatty acid molecules to make a triglyceride.



A: $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$; B: $\text{CH}_2\text{OHCHOHCH}_2\text{OH}$;

State the equation for the reaction between glycerol and stearic acid to form a triglyceride.



correct structure of glycerol **and** correct formula of stearic acid;
 correct structure of triglyceride;
 $3\text{H}_2\text{O}$ **and** coefficient of 3 on stearic acid;

B.4.7 Describe the enzyme-catalysed hydrolysis of triglycerides during digestion.

B.4.8 Explain the higher energy value of fats as compared to carbohydrates.(1m)

- fats contain less oxygen than carbohydrates / are in a less oxidized state (so more energy is released);

B.4.9 Describe the important roles of lipids in the body and the negative effects that they can have on health.

Important roles include:

- energy storage
- insulation and protection of organs
- steroid hormones
- structural component of cell membrane
- omega-3 poly-unsaturated fatty acids reduce the risk of heart disease
- poly-unsaturated fats may lower levels of LDL cholesterol.

Negative effects include:

- increased risk of heart disease from elevated levels of LDL cholesterol and *trans* fatty acids;

the major source of LDL cholesterol is saturated fats, in particular lauric (C12), myristic (C14) and palmitic (C16) acids

- obesity.

B.5 Macronutrients and Micronutrients

B.5.1 Outline the difference between micronutrients and macronutrients.

Micronutrients	Macronutrients
<ul style="list-style-type: none">• substances required in very small amounts (<0.005% body weight).• mainly function as a co-factor of enzymes	<ul style="list-style-type: none">• that are required in relatively large amounts (>0.005% body weight).
<ul style="list-style-type: none">• Fe,• Cu,• F,• Zn,• I,• Se,• Mn,• Mo,• Cr,• Co• B.	<ul style="list-style-type: none">• fats,• carbohydrates• minerals (Na, Mg, K, Ca, P, S and Cl)

B.5.2 Compare the structures of retinol (vitamin A), calciferol (vitamin D) and ascorbic acid (vitamin C).

Use data booklet

B.5.3 Deduce whether a vitamin is water- or fat-soluble from its structure. (2m)

- water-soluble—vitamins B and C
- fat-soluble—vitamins A, D, E and K.

vitamin A: not water-soluble because it has only one OH / is not very/less polar / contains long hydrocarbon group;

vitamin C: water-soluble because it has 4/many OH (and 1 C=O)/extensive hydrogen bonding;

vitamin E: fat soluble as long non-polar/hydrocarbon chain; with few polar groups; cannot form hydrogen bonds with water;

B.5.4 Discuss the causes and effects of nutrient deficiencies in different countries and suggest solutions.

Micronutrients Deficiencies	Macronutrient Deficiencies
<ul style="list-style-type: none">• iron—anemia• iodine—goitre• retinol (vitamin A)—xerophthalmia, night blindness• niacin (vitamin B3)—pellagra• thiamin (vitamin B1)—beriberi• ascorbic acid (vitamin C)—scurvy• calciferol (vitamin D)—rickets.	<ul style="list-style-type: none">• protein—marasmus and kwashiorkor.

Solutions include:

- providing food rations that are composed of fresh and vitamin- and mineral-rich foods
- adding nutrients missing in commonly consumed foods
- genetic modification of food
- providing nutritional supplements
- providing selenium supplements to people eating foods grown in selenium-poor soil.

B.6 Hormones

B.6.1 Outline the production and function of hormones in the body.

- chemical messenger;
- secreted directly into the blood by endocrine glands;

Note: Hormones are chemical messengers. They are secreted directly into the blood by endocrine glands.

Examples include ADH, aldosterone, estrogen, progesterone and testosterone, insulin, epinephrine (adrenaline) and thyroxine.

B.6.2 Compare the structures of cholesterol and the sex hormones.

Stress the common steroid backbone but the difference in functional groups (alkene/ketone/carboxyl).

B.6.3 Describe the mode of action of oral contraceptives. (3m)

- prevent release of hormones/FSH/LH (from hypothalamus/pituitary gland);
- prevent/suppress ovulation/egg release;
- prevent attachment of egg to uterus;
- prevent sperm from reaching egg / thickens the cervical mucus;
- mimics the action of progesterone during pregnancy / fools the reproductive system that the body is pregnant;

B.6.4 Outline the use and abuse of steroids. (2m)

Medical use:

- recovery from injury/surgery/starvation/illness/disease/treating hormone disorders;
- treating testes / increase sperm production;
- treating breast cancer;
- induce male puberty;
- gain weight / building tissue (following illness);
- sex change to male;
- stimulation of bone marrow;
- asthma inhalers;
- treatment of female-to-male gender changes;
- treatment of inflammation;

Non-medical use:

- increase in muscle mass / enhances performance/strength;
- build up depleted muscle due to lack of activity;

Abuse:

- muscle/strength build up for an unfair advantage in sport by athletes;

B.7 Enzymes

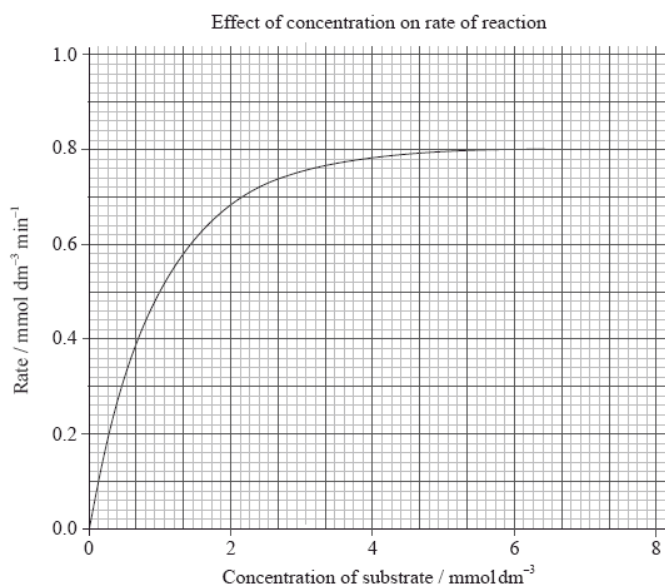
B.7.1 Describe the characteristics of biological catalysts (enzymes)(2m).

- enzymes are proteins;
- enzyme activity depends on tertiary and quaternary structure/the nature of the active site/specifivty of enzyme action;
- lock and key/induced fit hypothesis;

B.7.2 Compare inorganic catalysts and biological catalysts (enzymes) (2m).

Enzymes (biological catalysts)	Inorganic catalysts
denatured by high temps/temp above 40 °C	can be used at high temps/are less affected by conditions
very specific	often catalyse several reactions/non specific
function within a narrow pH range	Unaffected by pH

B.7.3 Describe the relationship between substrate concentration and enzyme activity.(2m)



- As [S] increases, more enzyme molecules can link with substrate molecules (and rate increases);
- once all enzyme molecules are occupied/enzyme sites used up, rate cannot increase any more/has no effect;

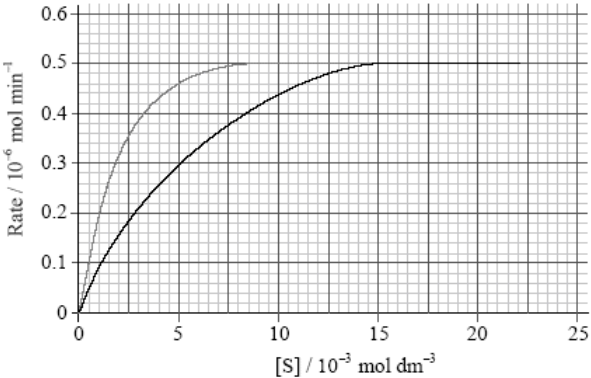
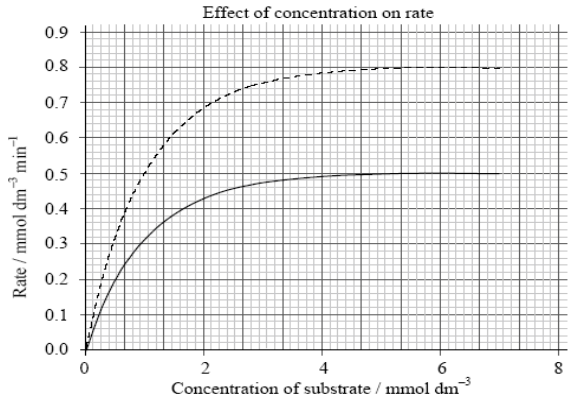
B.7.4 Determine V_{max} and the value of the Michaelis constant (K_m) by graphical means and explain its significance.

- (K_m) is the substrate concentration which is equal to half its maximum value (V_{max})

B.7.5 Describe the mechanism of enzyme action, including enzyme substrate complex, active site and induced fit model. (3m)

- binding on the active site / lock and key / formation of substrate enzyme complex; *Do not allow bind to enzyme.*
- active site depends on tertiary/quaternary structures (of the enzyme);
- (as substrate binds) chemical bonds are broken and the products are released, (allowing another substrate molecule to bind);

B.7.6 Compare competitive inhibition and non-competitive inhibition (5m).

Competitive	Non-competitive
is a similar shape to the substrate and so fits inside active site instead of substrate / <i>OWTTE</i> ;	binds to enzyme away from active site and changes shape of active site so substrate no longer fits / <i>OWTTE</i> ;
K_m higher and V_{max} the same;	K_m unchanged and V_{max} lower;
line on graph showing reduced gradient but same final V_{max} ; 	curve on graph levelling off below original line; 
*Similarity - initial rates reduced;	

B.7.7 State and explain the effects of heavy metal ions, temperature changes and pH changes on enzyme activity.

Heavy-metal ions:

- react (irreversibly) with –SH group / replaces hydrogen atom with heavy-metal atom/ion; *Accept heavy-metal binding to active site. Accept poisons enzymes.*
- decrease activity/rate;

Temperature changes:

- increase in temperature increases (initial) activity/rate;
- more reactants possess (minimum) activation energy;
- at high temperature enzymes become less effective / above 40 °C activity/rate decreases / denatured / *OWTTE*;
- for both (heavy-metal ions and temperature changes) (tertiary) structure disrupted / change of shape means active site stop working / *OWTTE*;

B.8 Nucliec Acids

B.8.1 Describe the structure of nucleotides and their condensation polymers (nucleic acids or polynucleotides).

- Nucleic acids are polymers made up of nucleotides.
- A nucleotide contains a phosphate group, a pentose sugar and an organic nitrogenous base.
- Nucleic acids are joined by covalent bonds between the phosphate of one nucleotide and the sugar of the next, resulting in a backbone with a repeating pattern of sugar–phosphate–sugar– phosphate.
- Nitrogenous bases are attached to the sugar of the backbone.

Note: Students should recognize, but do not need to recall, the structures of the five bases: adenine (A), cytosine (C), guanine (G), thymine (T) and uracil (U).

B.8.2 Distinguish between the structures of DNA and RNA (3m).

DNA	RNA
Deoxyribose	Ribose
lacks an oxygen atom (on C2) has only H	has an OH group on second carbon in ring
contains thymine	contains uracil
is a double-strand nucleic acid	is a single-strand nucleic acid

B.8.3 Explain the double helical structure of DNA.

nucleotides are linked together to form polynucleotides by

- the nucleotides condense/form a phosphodiester bond;
- between the C₃ of the sugar and a neighbouring phosphate group;

bases form a part of nucleotide in DNA by

- bases are covalently bonded to deoxyribose/pentose sugar;
- bond via a condensation reaction with the sugar / N from the thymine bonds to C on the sugar;

hydrogen bonds formed between the different strands/bases;

- thymine/T bonds to adenine/A and cytosine/C bonds to guanine/G;

Note: The structure has two nucleic acid strands that spiral around an axis. Students should describe the hydrogen bonding between specific pairs of nucleotide bases.

B.8.4 Describe the role of DNA as the repository of genetic information, and explain its role in protein synthesis. (3m)

- coded information lies in sequence of bases;
- each sequence of three bases represents one amino acid/triplet code;
- triplet code allows for (64) permutations/codons;
- represents 20 naturally occurring amino acids
- DNA is transcribed to RNA;
- the complete sequence for all bases is known as a genome;
- human genome / complete sequence of bases in human DNA;

Note: DNA is the genetic material that an individual inherits from its parents. It directs mRNA synthesis (transcription) and, through mRNA, directs protein synthesis (translation) using a triplet code.

B.8.5 Outline the steps involved in DNA profiling and state its use. (6m)

Steps involved in DNA profiling:

- restriction enzymes used to break DNA into small fragments;
- fragments are subjected to electrophoresis;
- portions of DNA placed on gel;
- electric field/voltage applied;
- negatively charged portions of DNA migrate to positive electrode;
- DNA portions separated by size / small portions of DNA travel further through the gel;
- DNA sequences stained;
- observed under UV light;

Use: forensic and paternity cases.

Role of restriction enzymes:

- restriction enzymes break down the DNA into smaller fragments/minisatellites;
- splits occur in the regions where there are no codons;
- restriction enzymes have the ability to find a certain sequence;
- the different lengths of the sequences are unique to an individual;

B.9.1 Compare aerobic and anaerobic respiration of glucose in terms of oxidation/reduction and energy released.

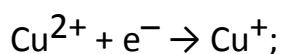
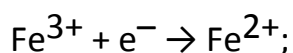
	Aerobic respiration	Anaerobic Respiration
Oxygen	Yes	No
Products	carbon dioxide and water	lactate in human beings; ethanol and carbon dioxide
Reaction	Oxidation half reaction: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} \rightarrow 6\text{CO}_2 + 24\text{H}^+ + 24\text{e}^-;$ Reduction half reaction: $6\text{O}_2 + 24\text{H}^+ + 24\text{e}^- \rightarrow 12\text{H}_2\text{O};$ Overall reaction: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O};$	Overall reaction: $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{CH}_3\text{CH}(\text{OH})\text{COOH};$
Similarity	Glucose undergoes oxidation and is converted into pyruvate. Overall, glucose undergoes oxidation and oxygen undergoes reduction.	

B.9.2 Outline the role of copper ions in electron transport and iron ions in oxygen transport.

Cytochromes are electrons transport carriers.

They contain a prosthetic group containing a metal ion

Either Fe or Cu



In hemoglobin the uptake of oxygen is not accompanied by a change in oxidation number of the Fe which remains at +2

Oxygen is bound in its molecular form by a conformational change in the protein.

Hemoglobin is oxygenated not oxidized