Option B Human Biochemistry

IB CHEMISTRY SL

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B.1 Introduction to biochemistry

Understandings:

- The diverse functions of biological molecules depend on their structures and shapes.
- Metabolic reactions take place in highly controlled aqueous environments.
- Reactions of breakdown are called catabolism and reactions of synthesis are called anabolism.
- Biopolymers form by condensation reactions and are broken down by hydrolysis reactions.
- Photosynthesis is the synthesis of energy-rich molecules from carbon dioxide and water using light energy.
- Respiration is a complex set of metabolic processes providing energy for cells.

Applications and skills:

- Explanation of the difference between condensation and hydrolysis reactions.
- The use of summary equations of photosynthesis and respiration to explain the potential balancing of oxygen and carbon dioxide in the atmosphere.

Guidance:

- Intermediates of aerobic respiration and photosynthesis are not required.
- International-mindedness:
- Metabolic reactions in the human body are dependent on the supply of nutrients through a regular balanced diet. Globally there are significant differences in the availability of nutritious food, which have major and diverse impacts on human health.

Introduction to biochemistry

- Biochemistry is the study of chemical reactions that occur in living organisms.
- These chemical reactions are known as metabolism.
- The chemical reactions involved in metabolism are organised into metabolic pathways.
- Each chemical reaction is controlled by a specific catalyst called an enzyme, and occurs in a controlled aqueous environment.

Catabolism and anabolism

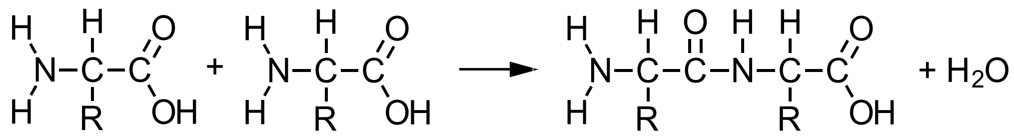
- Catabolism is the breaking up of large molecules to form smaller molecules (energy is released).
- An example of catabolism is cellular respiration. In cellular respiration, glucose is broken down into smaller molecules (CO_2 and H_2O) and energy is released.

glucose + oxygen ⟶ carbon dioxide + water (ΔH is negative)

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

- The energy released in catabolic reactions is used in anabolic reactions.

- Anabolism is the building up of smaller molecules to form larger molecules (energy is required).
- An example is the synthesis of proteins from amino acids.



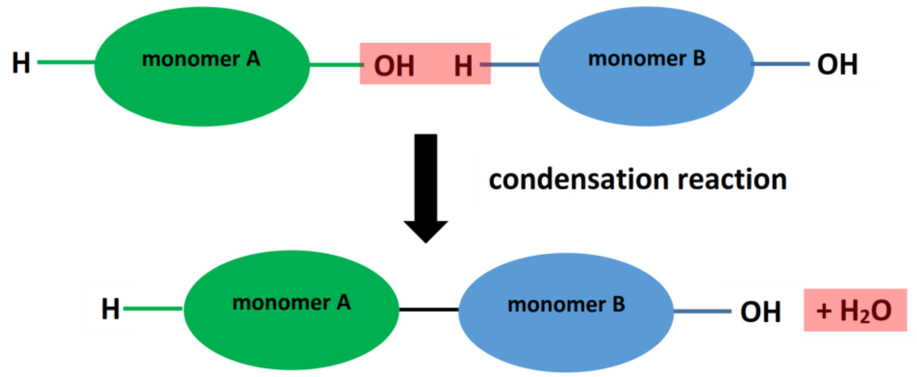
Exercises:

1. Using examples, describe the difference between anabolism and catabolism.

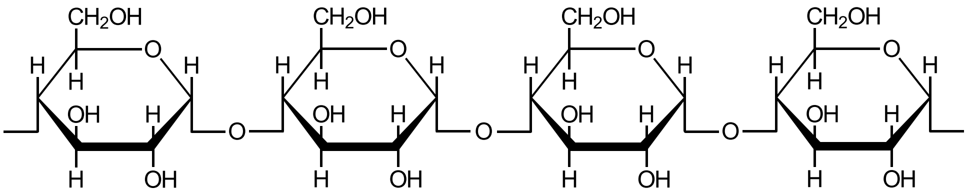
2. Classify catabolic and anabolic reactions as exothermic or endothermic.

Condensation and hydrolysis reactions

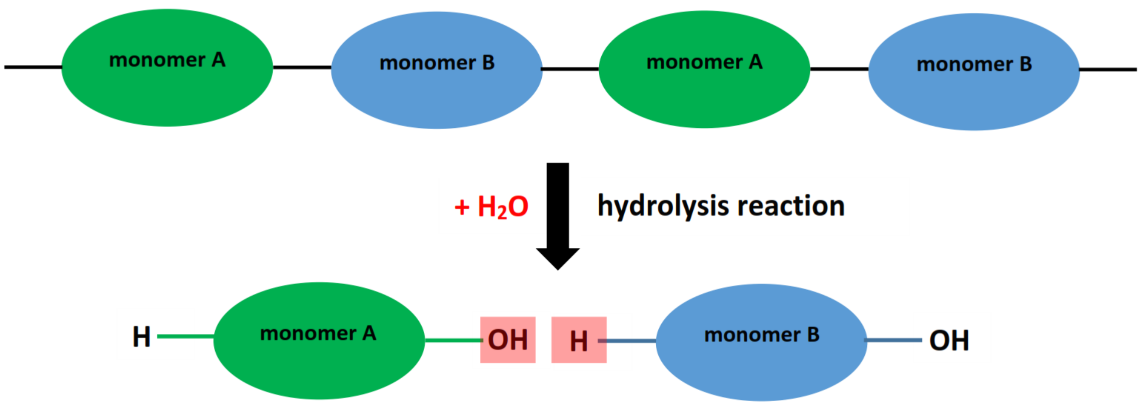
- A condensation reaction is a chemical reaction in which two molecules react to form a larger molecule with the loss of a small molecule (usually water) forming a covalent bond.



- Biopolymers are long chain molecules formed in condensation reactions.
- Each molecule (monomer) must have two reactive functional groups.



- A hydrolysis reaction is a chemical reaction in which a water molecule reacts with a large molecule breaking the covalent bond and forming two smaller molecules.

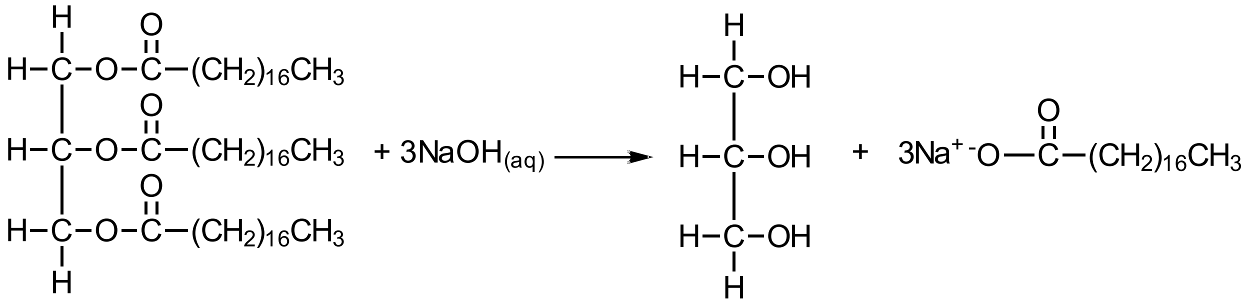


- Hydrolysis reactions are catalysed by enzymes in the human body.
- They also take place in the presence of an acid or an alkali (such as NaOH).

Exercises:

1. Outline the differences between condensation and hydrolysis reactions.

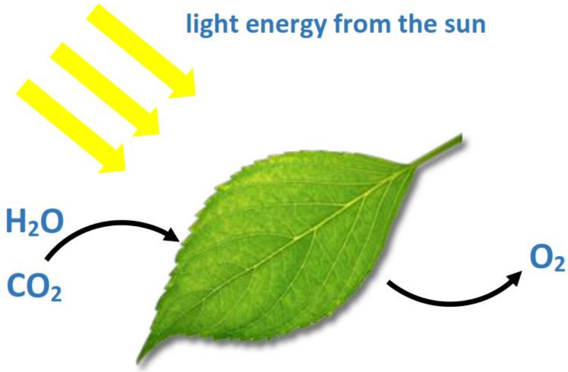
2. In a saponification reaction, a triglyceride is broken down to form glycerol and 3 smaller molecules (see below). Explain why this can be classified as a hydrolysis reaction.



3. Suggest a reason why a monomer must have two reactive functional groups to form a biopolymer.

Photosynthesis and respiration

Photosynthesis



- Photosynthesis is the process by which plants synthesize energy rich molecules such as carbohydrates (anabolism).
- The process occurs in green plants in the presence of a light absorbing pigment called chlorophyll.

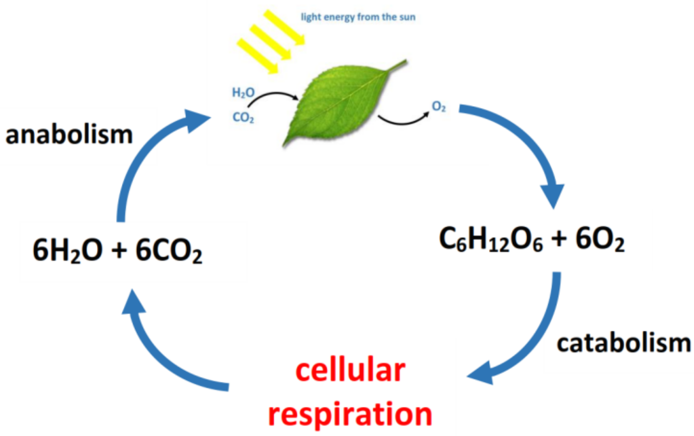
$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 \quad \Delta H \text{ positive}$$

Respiration

- Cellular respiration is a process that occurs in the cells of living organisms.
- Energy rich molecules such as carbohydrates are broken down to produce carbon dioxide and water, releasing energy in the process (catabolism).

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O \quad \Delta H \text{ negative}$$

- The products of cellular respiration are the reactants in photosynthesis (and vice versa).



B.2 Proteins and enzymes

Understandings:

- Proteins are polymers of 2-amino acids, joined by amide links (also known as peptide bonds)
- Amino acids are amphoteric and can exist as zwitterions, cations and anions.
- Protein structures are diverse and are described at the primary, secondary, tertiary and quaternary levels.
- A protein's three-dimensional shape determines its role in structural components or in metabolic processes.
- Most enzymes are proteins that act as catalysts by binding specifically to a substrate at the active site.
- As enzyme activity depends on the conformation, it is sensitive to changes in temperature and pH and the presence of heavy metal ions.
- Chromatography separation is based on different physical and chemical principles.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation reactions of amino acids, and hydrolysis reactions of peptides.
- Explanation of the solubilities and melting points of amino acids in terms of zwitterions.
- Application of the relationships between charge, pH and isoelectric point for amino acids and proteins.
- Description of the four levels of protein structure, including the origin and types of bonds and interactions involved.
- Deduction and interpretation of graphs of enzyme activity involving changes in substrate concentration, pH and temperature.
  Explanation of the processes of paper chromatography and gel electrophoresis in amino acid and protein separation and identification.

Guidance:

- The names and structural formulas of the amino acids are given in the data booklet in section 33.
- Reference should be made to alpha helix and beta pleated sheet, and to fibrous and globular proteins with examples of each.
- In paper chromatography the use of R_f values and locating agents should be covered.
- In enzyme kinetics K_m and V_{max} are not required.

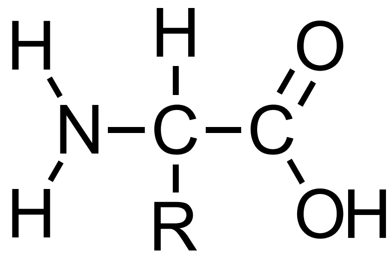
Introduction to proteins

- Proteins are found in such foods as meat, fish, and eggs.
- Proteins are important biological molecules (composed of amino acids) and are used for many different purposes in the human body.
- Hair and finger nails are made of keratin which is a structural protein.
- Enzymes (biological catalysts) are made of proteins that have specific 3D structures.
- Transport molecules such as haemoglobin are also made of proteins.

Amino acids

- Proteins are composed of amino acids.
- The structure of an amino acid can be seen below.

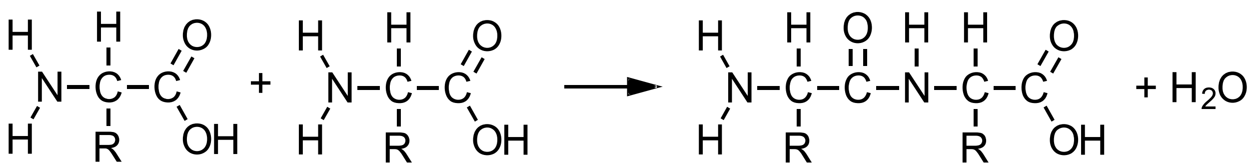
amino group (NH_2)



carboxyl group (COOH)

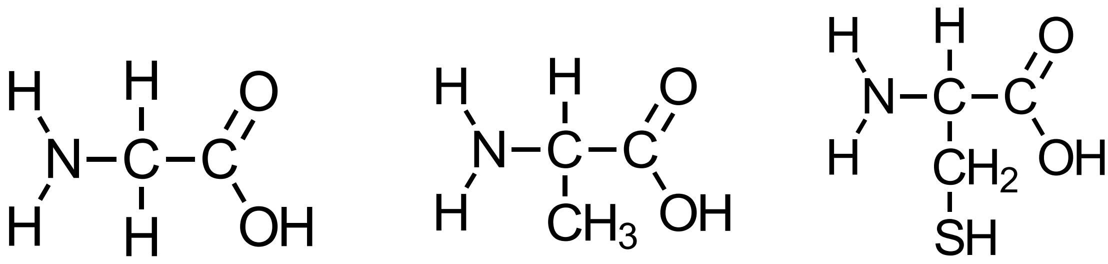
- Amino acids have an amino group (NH_2) and a carboxyl group (COOH).
- The R represents a side chain, which is different for every amino acid.

Amino acids bond in condensation reactions



- The bonding of amino acids produces dipeptides, tripeptides, and polypeptides (proteins).

Exercise: draw the structure a tripeptide that is produced in the reaction of the 3 amino acids below.



How many different tripeptides could be produced from 3 amino acids?

Structure of proteins

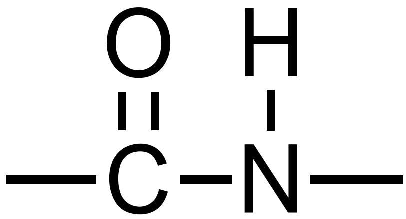
- Proteins are long chain molecules (polymers) composed of amino acids (monomers).
- The three structures of proteins are primary, secondary, tertiary and quaternary.

Primary structure

- The primary structure of a protein refers to the sequence of amino acids in the polypeptide chain, which can be seen in the diagram below).

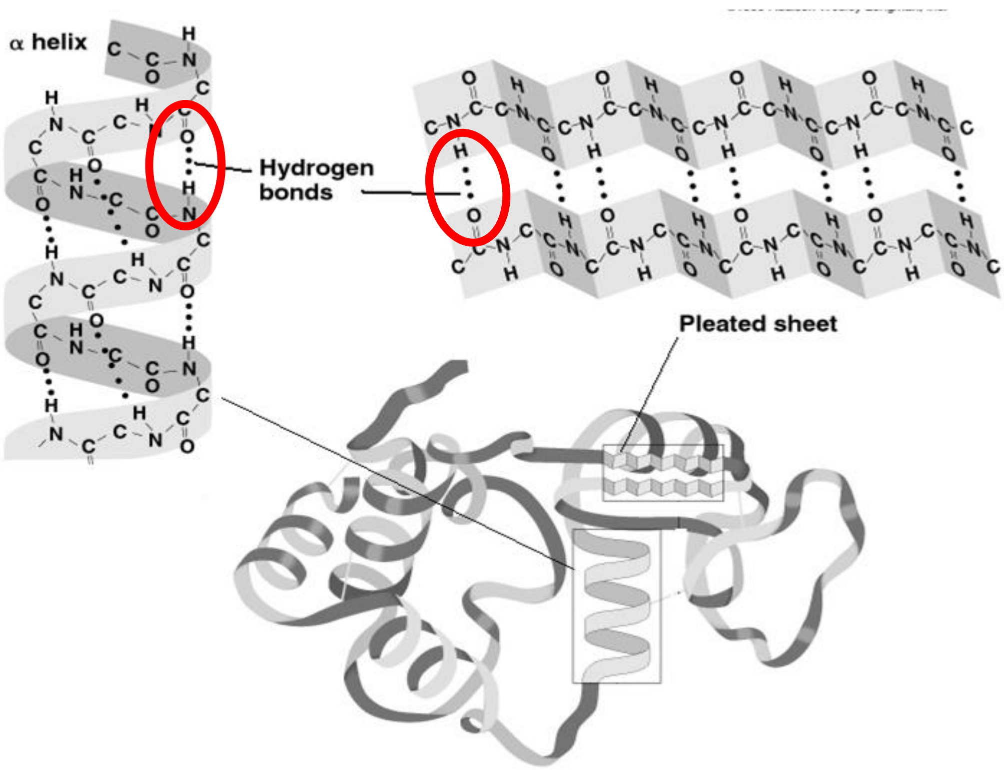
H—Ala—Leu—Pro—Glu—Arg—Thr—Gln—Val—Asn—Met—Asp—Glu—Leu—OH

- The bond responsible for the primary structure is the peptide bond (or amide link).



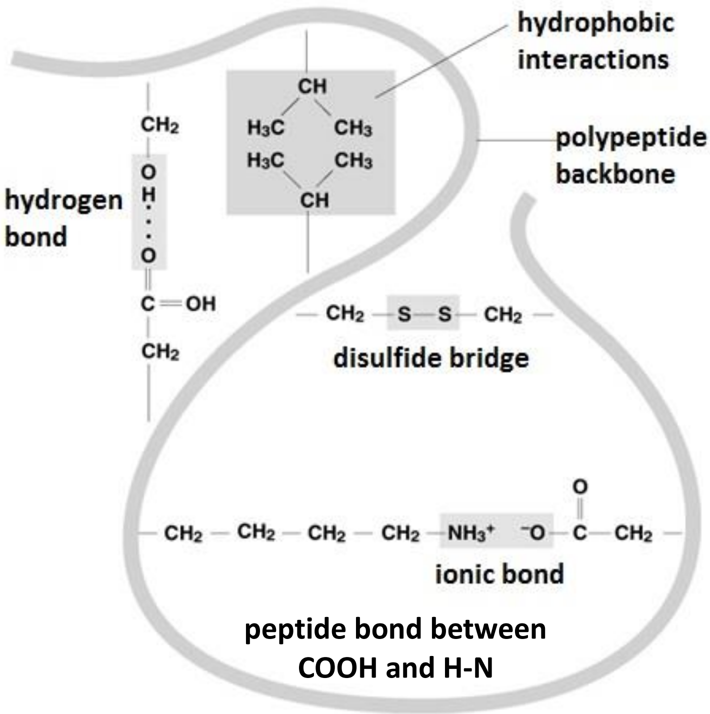
Secondary structure

- The secondary structure of a protein refers to the folding of the polypeptide chain as a result of hydrogen bonding.
- The two types of secondary structure are the α-helix and the β-pleated sheet.



Tertiary structure

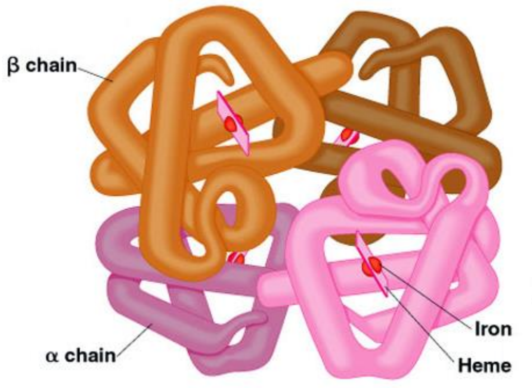
- The tertiary structure of proteins refers to the twisting and folding of the secondary structure to form a specific 3D shape (as a result of interactions between the side chains).



- Hydrophobic interactions (London dispersion forces) between non-polar side chains.
- Hydrogen bonding between polar side chains.
- Ionic bonding between charged side chains.
- Disulfide bridges (covalent bonds) between the side chains of cysteine which contain a sulfhydryl group (CH_2-SH).
- Peptide bonds between COOH and N-H.

Quaternary structure

- The quaternary structure of proteins refers to the interactions between polypeptide chains.
- An example is hemoglobin that has a quaternary structure composed of four polypeptide chains.



Exercises:

1. State the type of bonding that is responsible for the primary and secondary structures of proteins.

   Primary:

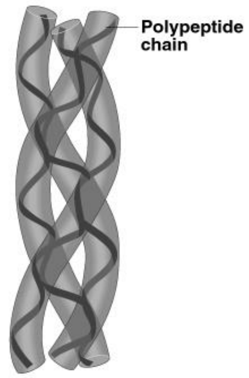
   Secondary:

2. Describe and explain the tertiary structure of proteins. Include in your answer all (5) of the bonds and interactions responsible for the tertiary structure.

Fibrous and globular proteins

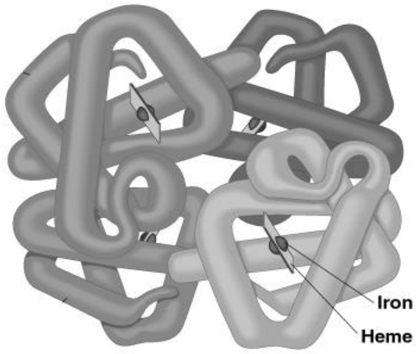
- Fibrous proteins are elongated molecules in which the secondary structure (α-helix or β pleated sheets) forms the dominant structure. They are insoluble in water, and form structural components in the body.
- Globular proteins are spherical molecules that are soluble in water. All have tertiary structures and some have quaternary structures.

fibrous protein



Collagen

globular protein

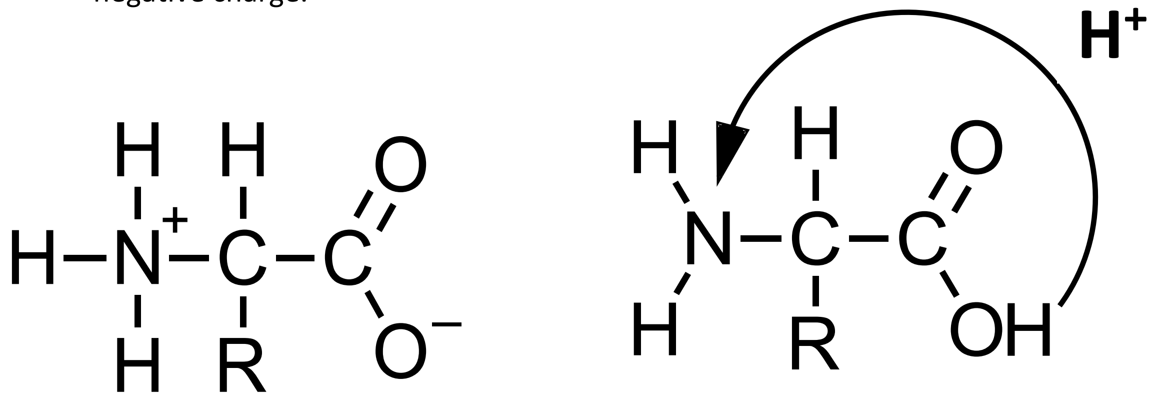


Hemoglobin

Properties	Fibrous proteins	Globular proteins
Shape	long and narrow	rounded/spherical
Role	structural (strength and support)	functional (catalysts and transport)
Solubility in water	mostly insoluble	mostly soluble
Sequence of amino acids	repetitive amino acid sequence	irregular amino acid sequence
Stability	less sensitive to changes in heat and pH	more sensitive to changes in heat and pH
Examples	collagen, keratin	hemoglobin, insulin, catalase

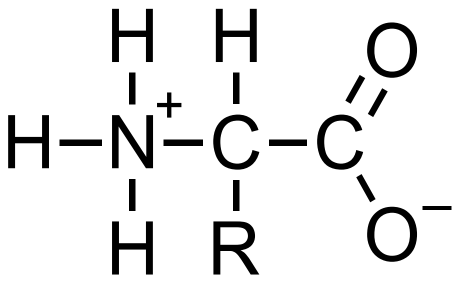
Acid-base properties of amino acids

- Amino acids form zwitterions – electrically neutral molecules with a positive and negative charge.



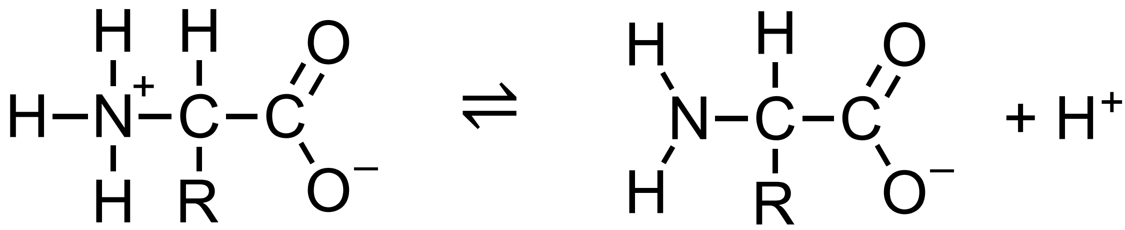
- Amino acids are amphoteric (amphiprotic); they can act as Bronsted – Lowry acids or bases by donating a proton (H^+) or accepting a proton (H^+).

A proton (H^+) can be a donated by the NH_3^+



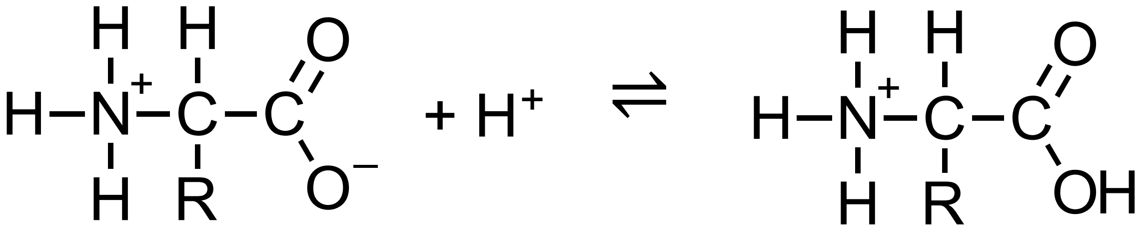
A proton (H^+) can be accepted by the COO^-

- Donating a proton (Brosnted-Lowry acid)



$$NH_3^+CH_2COO^- \rightleftharpoons NH_2CH_2COO^- + H^+$$

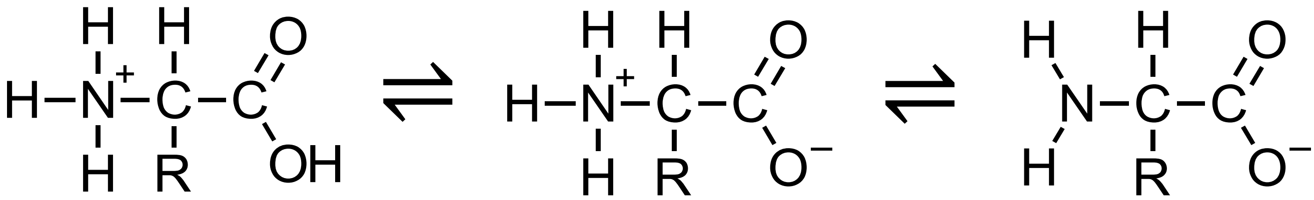
- Accepting a proton (Bronsted-Lowry base)



$$NH_3^+CH_2COO^- + H^+ \rightleftharpoons NH_3^+CH_2COOH$$

Isoelectric points of amino acids

- The charge on an amino acid depends on the pH.
- The isoelectric point is the pH at which the amino acid has no overall charge.



pH < pH of isoelectric point positively charged

Isoelectric point no overall charge

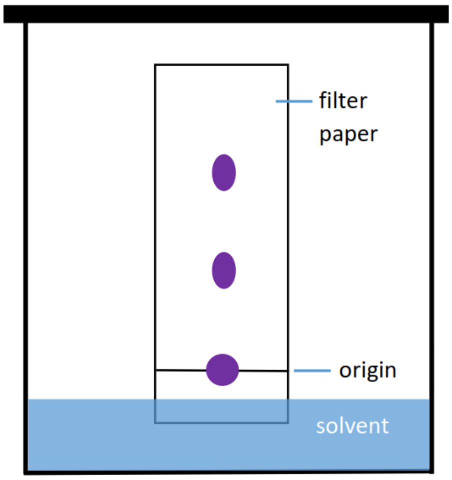
pH > pH of isoelectric point negatively charged

Exercise:
The pH of the isoelectric point of glycine is 6.0. Draw the structure of glycine at pH 3.0 and pH 9.0

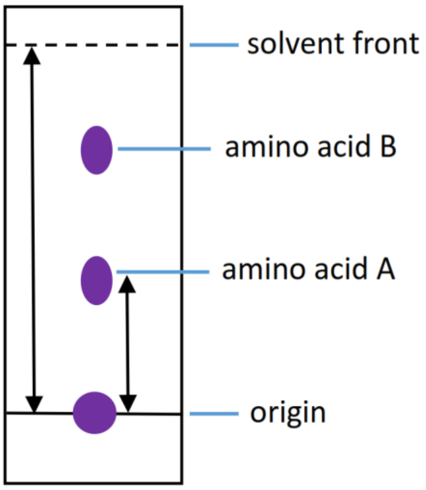
Protein analysis

- The two methods of protein analysis are gel electrophoresis and paper chromatography.
- Before proteins can be analysed, they must be broken down into their component amino acids in a hydrolysis reaction.
- In the hydrolysis reaction with concentrated hydrochloric acid, the peptide bonds between the amino acids are broken.

Paper chromatography



- A small sample of the amino acid mixture is spotted near the bottom of the filter paper (the origin).
- The filter paper is suspended in a solvent with the spot above the level of the solvent.
- As the solvent rises up the filter paper by capillary action, the amino acids in the mixture will distribute themselves between 2 phases – the stationary phase (the filter paper) and the mobile phase (the solvent).
- The different amino acids separate according to how strongly they adsorb onto the stationary phase versus how readily they dissolve in the mobile phase.

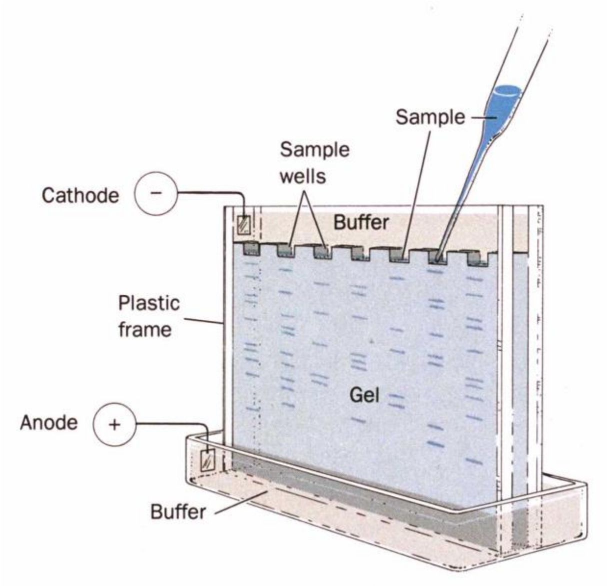


- Once the paper is removed, it is sprayed with ninhydrin (a locating reagent – organic dye).
- Most amino acids will take a purple colour and can be distinguished as separate spots on the paper.
- The position of each amino acid can be expressed as a R_f value and compared with known R_f values.
- Finally, the amino acids in the mixture can be identified.

$$R_f = \frac{distance\ moved\ by\ amino\ acid}{distance\ moved\ by\ solvent\ front}$$

Gel electrophoresis

- Electrophoresis is a technique for the analysis and separation of a mixture based on the movement of charged particles in an electric field.
- Amino acids carry different charges depending on the pH and therefore can be separated when placed in a buffer solution.

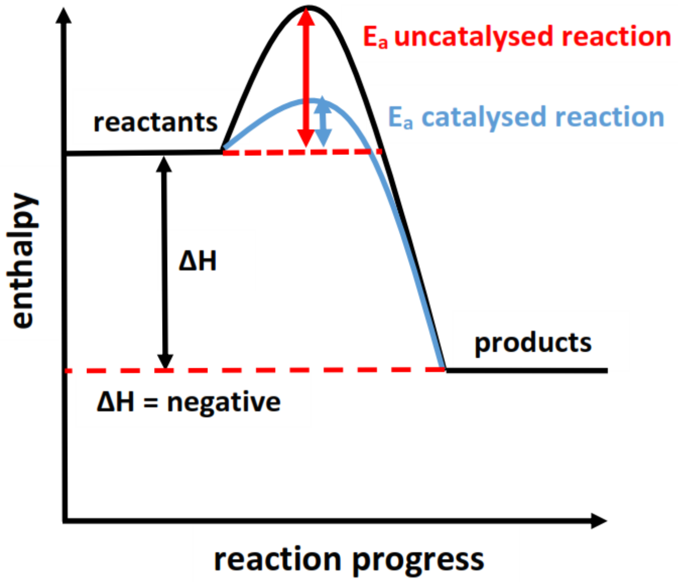


- The amino acid mixture is placed in the centre of a gel (usually polyacrylamide).
- A potential difference is applied.
- Depending on the pH of the buffer solution, the amino acids will move at different rates towards the oppositely charged electrodes.
- After separation, the amino acids are sprayed with a locating agent (ninhydrin – an organic dye).
- The amino acids are identified by measuring the distance travelled and comparing with known samples.

Exercise: Outline the processes of protein analysis in chromatography and gel electrophoresis.

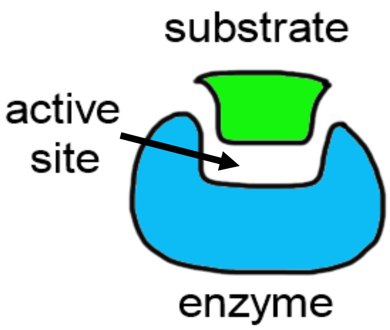
Enzymes

- Enzymes are protein molecules that function as biological catalysts.

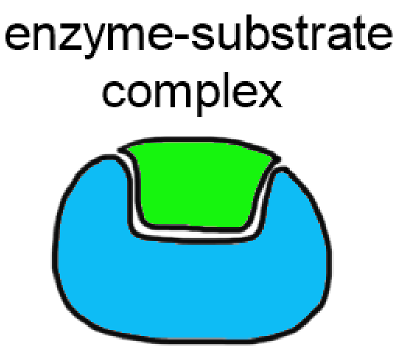


Enzymes increase the rate of a reaction by providing an alternative route for a chemical reaction with lower activation energy (E_a).

How enzymes catalyse reactions



- The substrate enters the active site, which changes shape to fit the substrate.

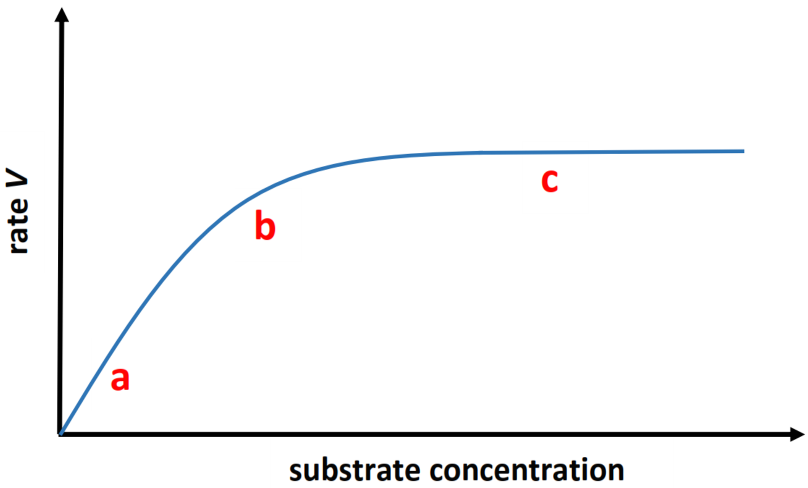


- The substrate binds at the active site forming an enzyme-substrate complex.

- The catalysed reaction takes place and the products leave the active site. The active site is available for the next substrate molecule.

- Enzymes are highly specific for the reaction that they catalyse.
- The action of an enzyme depends on its specific 3D structure (conformation).
- Factors that affect an enzyme's conformation affect its ability to bind with the substrate; changes in temperature, pH, and presence of heavy metal ions.

Enzyme activity and substrate concentration



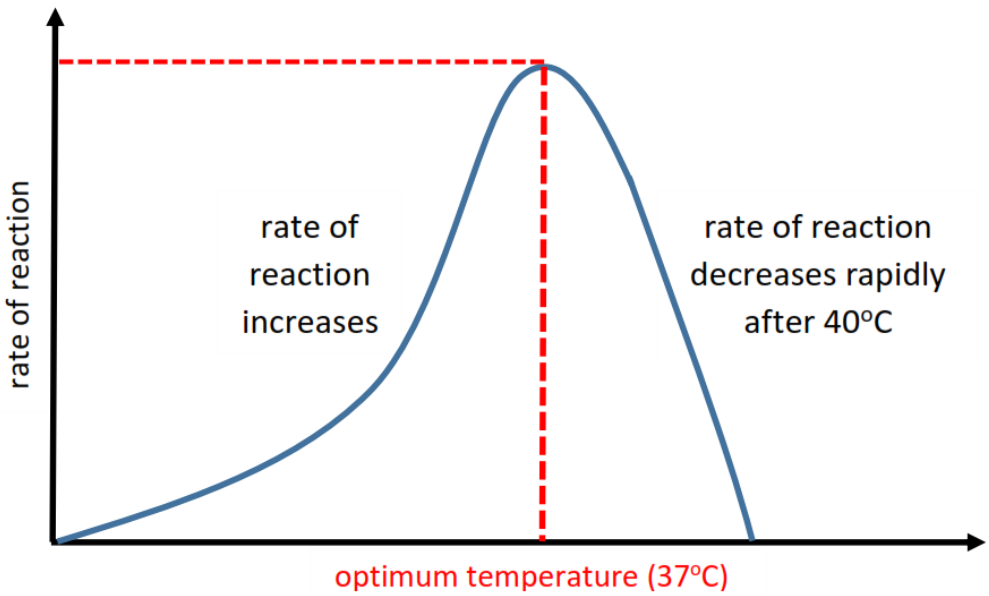
- a - at low substrate concentration, the rate of reaction is proportional to the substrate concentration - there are plenty of active sites available to bind to the substrate.
- b - as the substrate concentration increases, the rate of reaction decreases and is no longer proportional to the substrate concentration - some of the active sites are occupied by substrate.
- c - at high substrate concentration, the rate of reaction is constant and independent of the substrate concentration - the enzyme is saturated with substrate (point of saturation).

Factors that affect enzyme activity

- The activity of an enzyme depends on its tertiary structure (conformation).
- Any factor that disrupts the tertiary structure of an enzyme will affect the ability of the enzyme to catalyse a specific reaction.
- If the tertiary structure of an enzyme is disrupted, the substrate can no longer bind to the active site.
- Loss of the tertiary structure is known as denaturation (irreversible).
- The factors that can disrupt an enzyme's tertiary structure are temperature, pH, and the presence of heavy metal ions.

Temperature

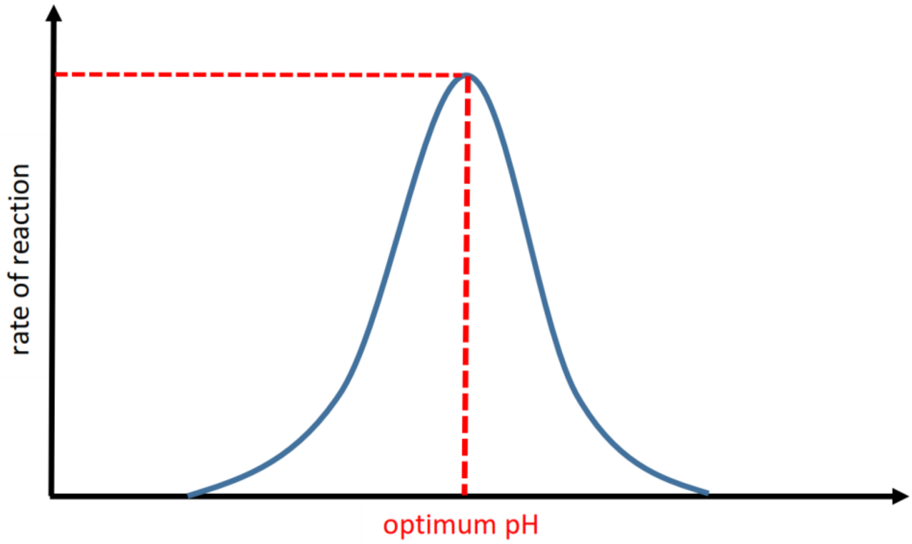
- The optimum temperature is the temperature corresponding to the maximum rate of reaction for an enzyme.



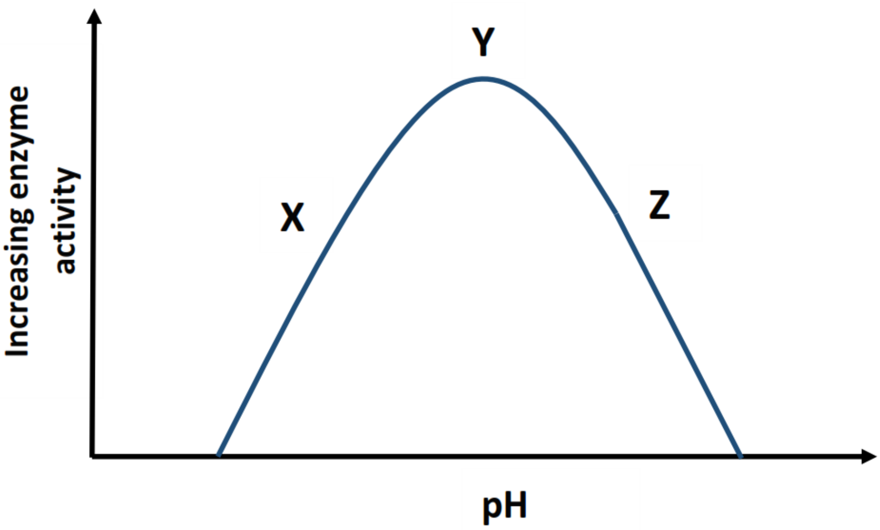
- Beyond the optimum temperature, the bonds and interactions that maintain the enzyme's tertiary structure are disrupted.
- The substrate is no longer able to bind at the active site (rate of reaction decreases).
- If the tertiary structure of an enzyme is disrupted, the substrate can no longer bind to the active site.
- Loss of the tertiary structure is known as denaturation (irreversible).
- The factors that can disrupt an enzyme's tertiary structure are temperature, pH, and the presence of heavy metal ions.
- Lowering the temperature deactivates the enzyme and is reversible.
- The activity of the enzyme decreases but the tertiary structure is maintained.
- This explains why keeping food in the refrigerator prevents it from spoiling (going bad).

pH

- The optimum pH is the pH at which the enzyme is most active (maximum rate of reaction).

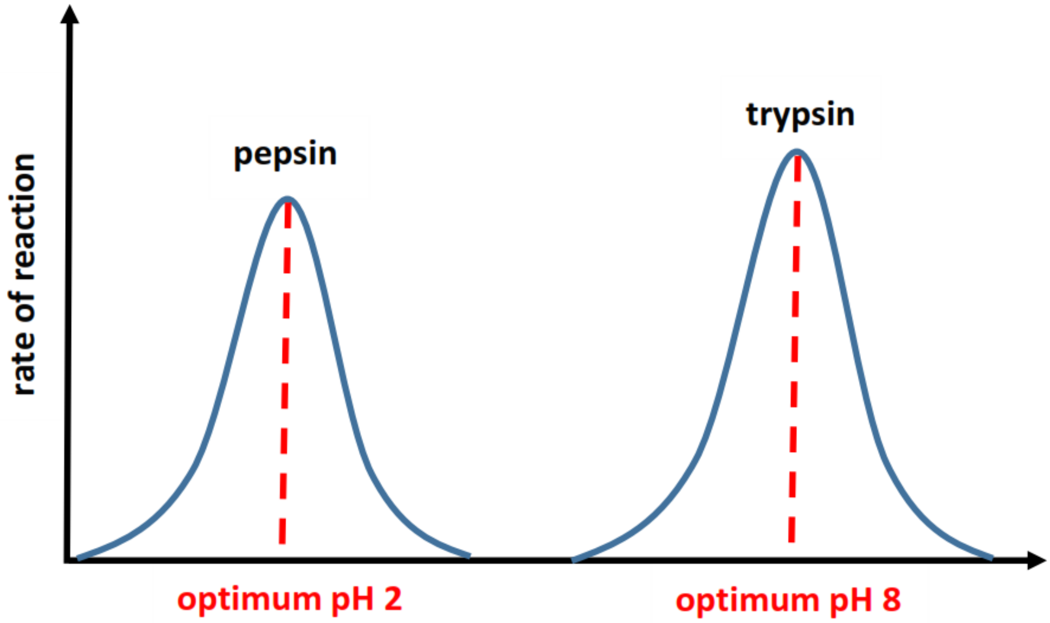


- Above or below the optimum pH, the charges on the acidic (COOH) and basic (NH_2) groups change.
- The enzyme's tertiary structure is disrupted and the shape or charge of the substrate can also be affected so that it cannot bind to the active site.



- At point X (low pH), the enzyme is protonated (has a positive charge), therefore the substrate is unable to bind effectively at the active site.
- At point Y (optimum pH), the substrate is able to bind effectively at the active site.
- At point Z (high pH), the enzyme is deprotonated (has a negative charge), therefore the substrate is unable to bind effectively at the active site.

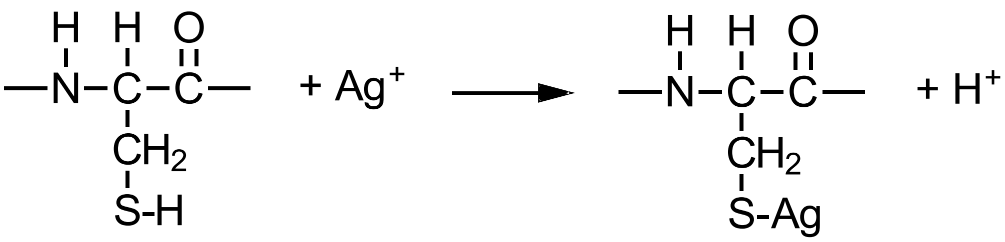
- Pepsin is more active in the stomach where pH is low. Trypsin is more active in the intestine where the pH is higher (alkaline).



- Changes in pH can denature an enzyme in the same way as temperature by disrupting the bonds and interactions that are responsible for the tertiary structure.

Heavy metal ions

- Heavy metal ions (Ag^+) can react with the sulfhydryl group on cysteine, replacing the hydrogen atom with a heavy metal ion.



- The tertiary structure is disrupted and the substrate is no longer able to bind at the active site.

B.3 Lipids

Understandings:

- Fats are more reduced than carbohydrates and so yield more energy when oxidized.
- Triglycerides are produced by condensation of glycerol with three fatty acids and contain ester links. Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Phospholipids are derivatives of triglycerides.
- Hydrolysis of triglycerides and phospholipids can occur using enzymes or in alkaline or acidic conditions.
- Steroids have a characteristic fused ring structure, known as a steroidal backbone.
- Lipids act as structural components of cell membranes, in energy storage, thermal and electrical insulation, as transporters of lipid soluble vitamins and as hormones.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation and hydrolysis reactions between glycerol and fatty acids and/or phosphate.
- Prediction of the relative melting points of fats and oils from their structures.
- Comparison of the processes of hydrolytic and oxidative rancidity in fats with respect to the site of reactivity in the molecules and the conditions that favour the reaction.
- Application of the concept of iodine number to determine the unsaturation of a fat.
- Comparison of carbohydrates and lipids as energy storage molecules with respect to their solubility and energy density.
- Discussion of the impact of lipids on health, including the roles of dietary high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, saturated, unsaturated and *trans*-fat and the use and abuse of steroids.

Guidance:

- The structures of some fatty acids are given in the data booklet in section 34.
- Specific named examples of fats and oils do not have to be learned.
- The structural differences between *cis*- and *trans*-fats are not required.

Introduction to lipids

- Lipids are organic molecules with long hydrocarbon chains that are soluble in non-polar solvents.

Lipids and their functions

lipid	function
triglycerides	energy storage thermal insulation
phospholipids	components of cell membranes electrical insulation in nerves
steroids	hormones in the human body

- Lipids are also involved in the transportation of fat soluble vitamins (A, D, E and K).

Energy content of fats and carbohydrates

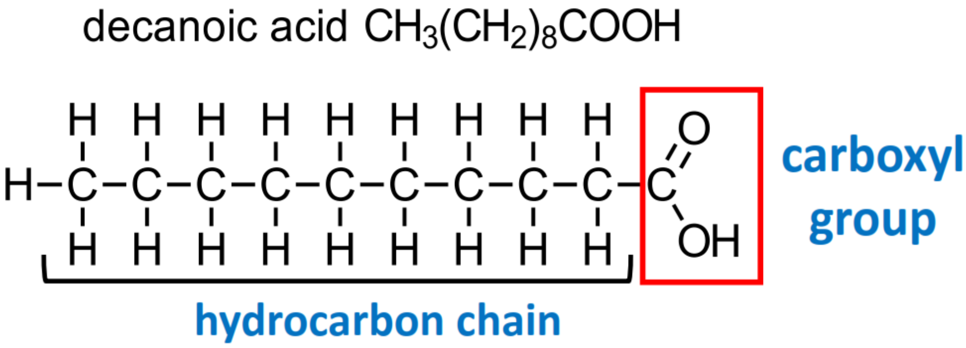
- Carbohydrates and lipids are both used for energy storage in the human body.
- Gram for gram, lipids provide more energy than carbohydrates.
- In lipids, the ratio of H to O is greater than in carbohydrates (they are more reduced).
- When oxidized, lipids release more energy.

Solubility of carbohydrates and fats

- Glucose is soluble in water - it has polar OH groups that form hydrogen bonds with water molecules.
- Fats are insoluble in water - they have non-polar hydrocarbon chains.
- Because they are soluble in water, carbohydrates are more rapidly transported in the body and are used for short term energy supply.
- Because they are insoluble in water, fats are more slowly transported in the body and are used as long term energy storage.
- Lipids provide more energy than carbohydrates because they are more reduced and insoluble in water.

Fatty acids

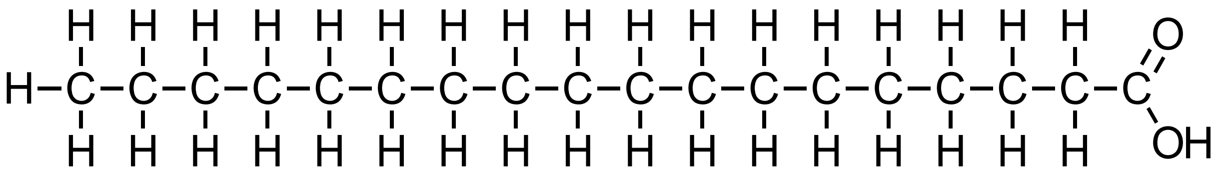
- Fatty acids are carboxylic acids with a long hydrocarbon chain.



- Fatty acids can be saturated, unsaturated or polyunsaturated, depending on the number of carbon to carbon double bonds in the molecule.

Saturated fatty acids

- Carbon to carbon single bonds.
- 109.5° bond angle between carbon atoms (tetrahedral arrangement).

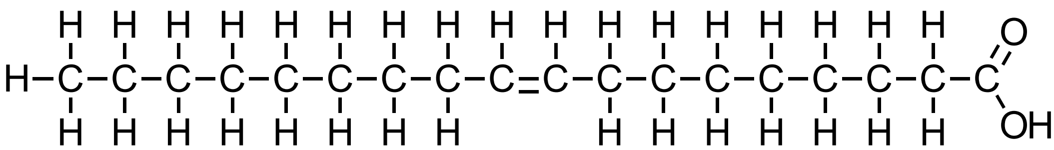


Stearic acid $C_{18}H_{36}O_2$

- Saturated fatty acids have carbon to carbon single bonds with 109.5° bond angles which allow the molecules to pack closely together.
- This leads to stronger London dispersion forces between molecules and a higher melting point.
- Triglycerides composed of saturated fatty acids have higher melting points and are solids at room temperature (fats e.g. butter).

Monounsaturated fatty acids

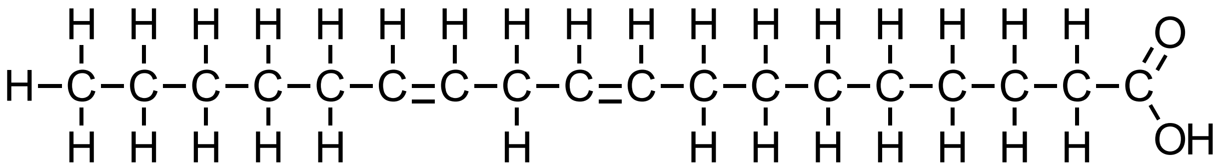
- Carbon to carbon double bond.
- 120° bond angle between carbon atoms in double bond (trigonal planar arrangement).



Oleic acid $C_{18}H_{34}O_2$

Polyunsaturated fatty acids

- Multiple carbon to carbon double bonds.
- 120° bond angle between carbon atoms in double bonds (trigonal planar arrangement).



Linoleic acid $C_{18}H_{32}O_2$

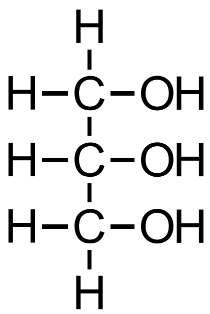
- Unsaturated fatty acids have carbon to carbon double bonds with 120° bond angles (kink) meaning the molecules cannot pack closely together.
- This leads to weaker London dispersion forces between molecules and a lower melting point.
- Triglycerides composed of unsaturated fatty acids have lower melting points and are liquids at room temperature (oils e.g. olive oil).

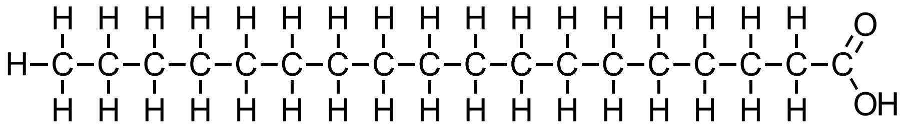
Triglycerides

- Triglycerides are produced in condensation (esterification) reactions between a molecule of glycerol and 3 fatty acids.

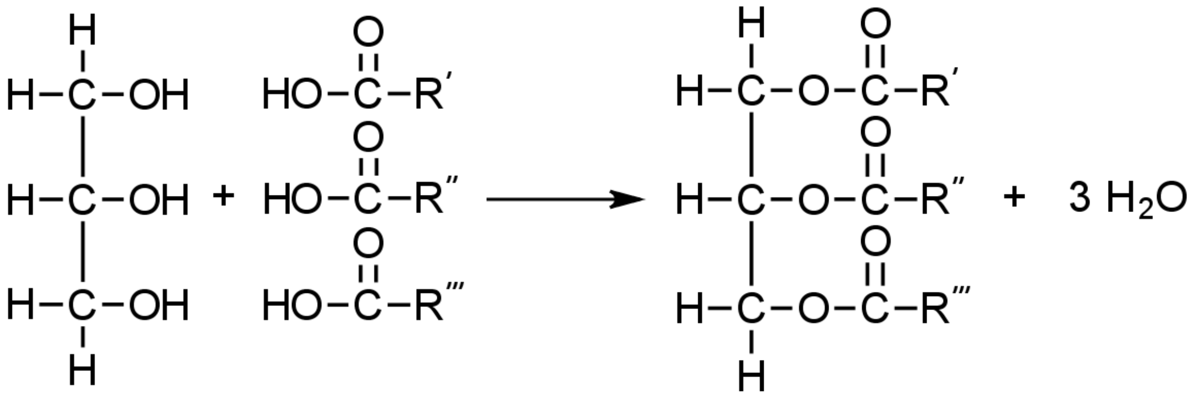
glycerol (propane-1,2,3-triol

fatty acid (stearic acid $C_{18}H_{36}O_2$)





- The glycerol and 3 fatty acids react in a condensation (esterification) reaction to form a triglyceride and 3 molecules of water.



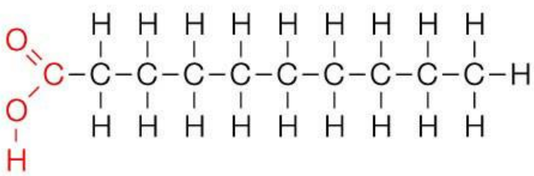
glycerol + 3 fatty acids ⟶ triglyceride + water

- An ester link (COOC) is formed between the glycerol molecule and the 3 fatty acids.

Melting points of triglycerides

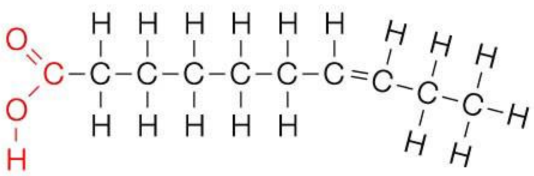
- Saturated fatty acids (fats) have higher melting points than unsaturated fatty acids (oils).
- The kink resulting from the C=C bond prevents the chains from packing close together and weaker London dispersion forces between molecules.

Saturated



Saturated fatty acids - close packing of molecules, stronger London dispersion forces between molecules, higher melting point.

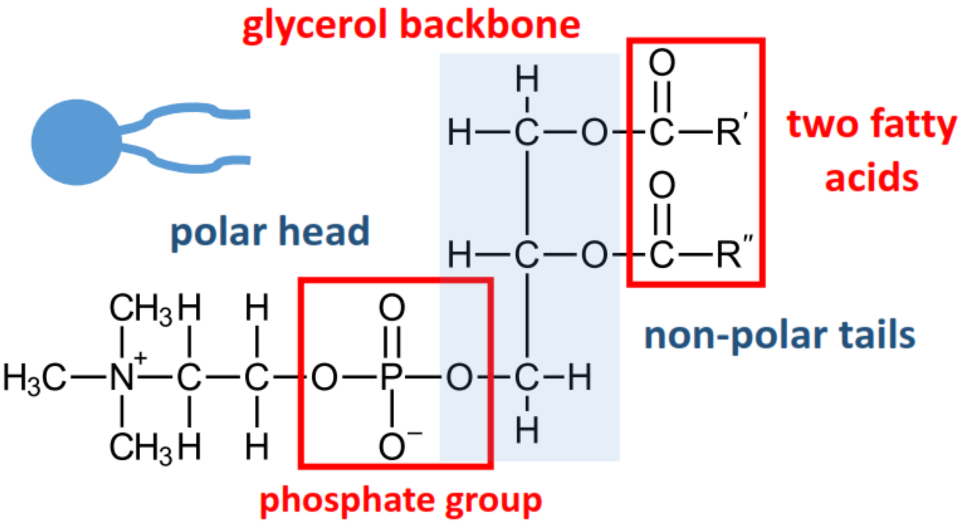
Unsaturated



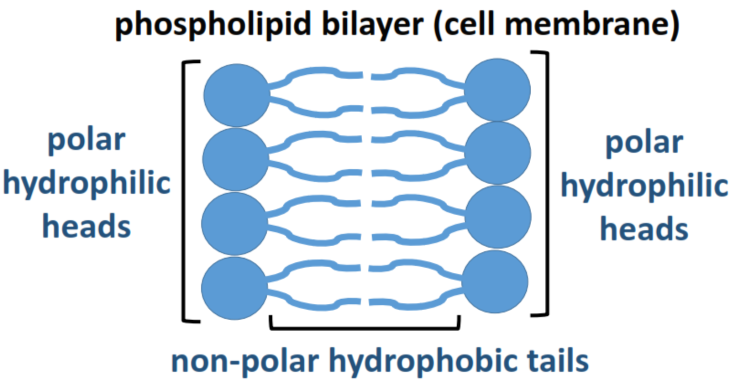
Unsaturated fatty acids - kink in chain prevents close packing of molecules.
Weaker dispersion forces between molecules, lower melting point,

Phospholipids

- A phospholipid is composed of a glycerol backbone with two fatty acids and a phosphate group bonded in condensation reactions.

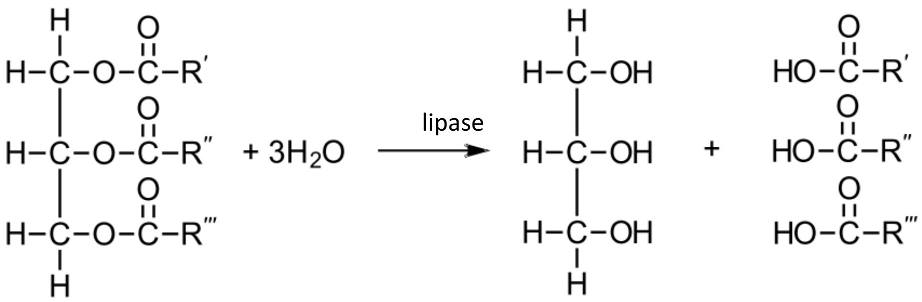


- Phospholipids are found in cell membranes where they form a phospholipid bilayer.



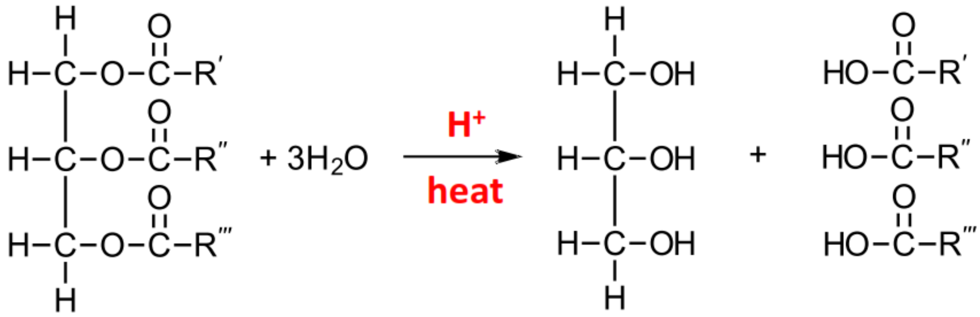
Hydrolysis of lipids

- Fats and oils are hydrolysed in the human body by the enzyme lipase.

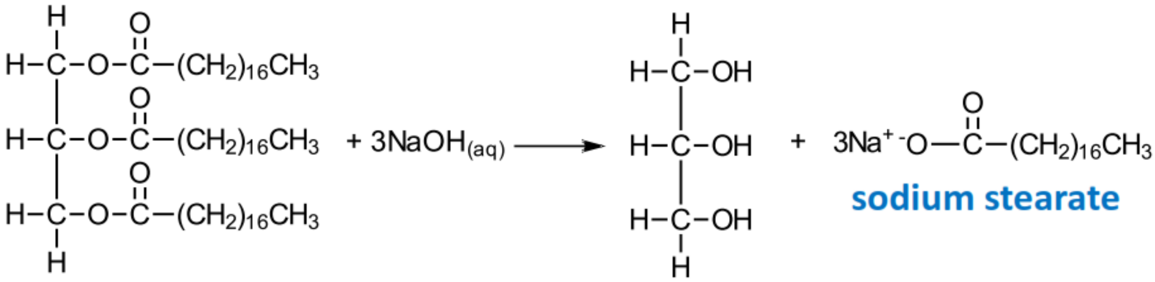


triglyceride + water ➔ glycerol + 3 fatty acids

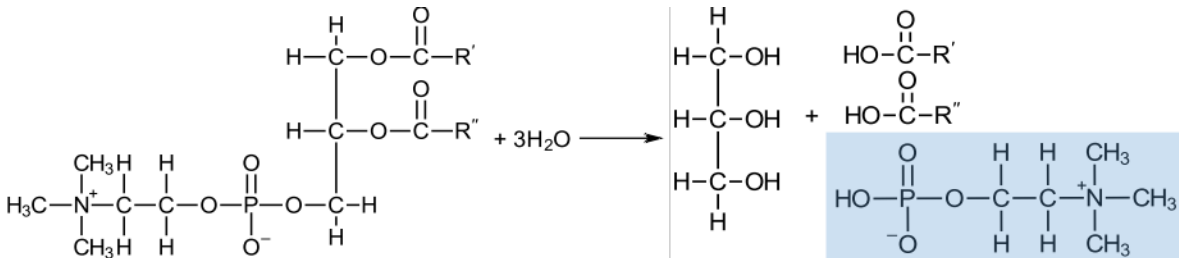
- Acid hydrolysis - triglycerides can be hydrolysed in a hot aqueous solution of strong acid.



- Alkaline hydrolysis produces the salt of the fatty acid (soaps). This is known as saponification.



- Phospholipids are also hydrolysed in the human body.



phospholipid + water ➔ glycerol + 2 fatty acids

Summary:

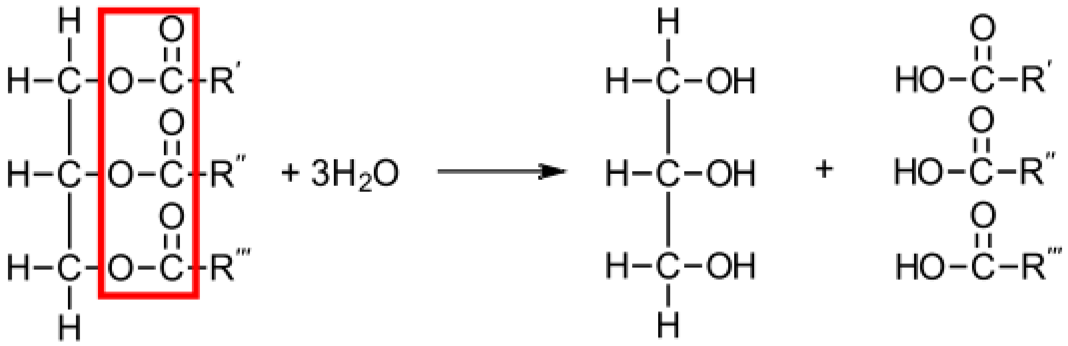
- Triglycerides and phospholipids are broken down in hydrolysis reactions to form their component molecules.
- The reactions use water and can occur in alkaline or acidic conditions.
- Alkaline hydrolysis produces soaps (saponification).
- The digestion of triglycerides and phospholipids in the human body involves the use of enzymes.

Rancidity of fats

- Rancidity of fats and oils causes a disagreeable smell, texture or appearance.
- The two types of rancidity are hydrolytic and oxidative.

Hydrolytic rancidity

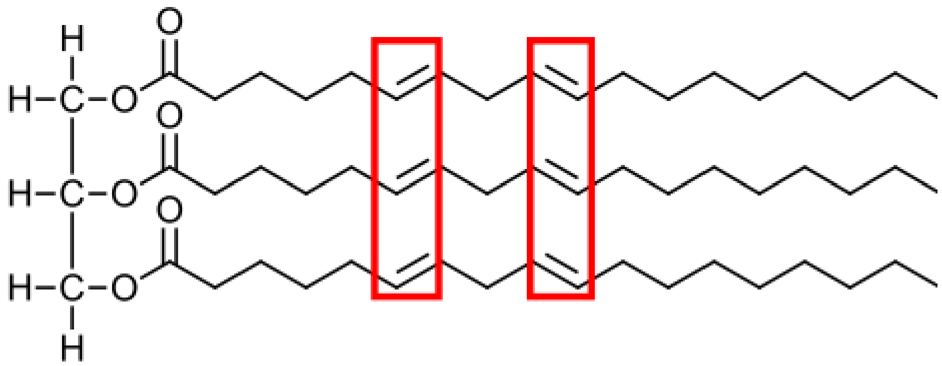
- The sites of reactivity are the ester linkages in the triglyceride.



- This reaction occurs more quickly in the presence of heat and moisture.
- It is catalyzed by the enzyme lipase.
- The rancid smell is due to the release of fatty acids.
- Hydrolytic rancidity can be reduced by refrigeration.

Oxidative rancidity

- Oxidative rancidity (auto oxidation) occurs when oxygen is added across a carbon to carbon double bond.
- The sites of reactivity are the carbon to carbon double bonds.

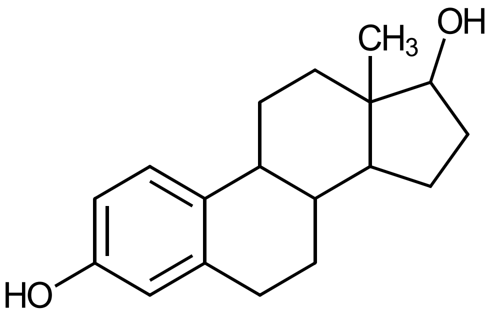


- The reaction is catalyzed by light, enzymes or metal ions.
- It occurs in oils with a high proportion of carbon to carbon double bonds.
- Hydrolytic rancidity can be controlled with anti-oxidants.

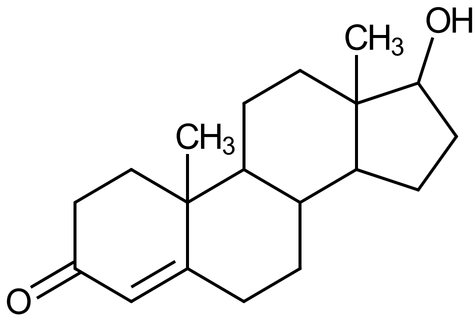
Steroids

- Steroids are lipids with a structure consisting of 4 fused hydrocarbon rings (steroidal backbone).
- The male and female sex hormones are examples of steroids.

female sex hormone (estrogen)



male sex hormone (testosterone)



Uses of steroids:

- Female steroid hormones are used in the oral contraceptive pill and hormone replacement therapy (HRT).
- Steroids are also used to build up depleted muscle due to lack of activity and to assist in recuperation from an illness.

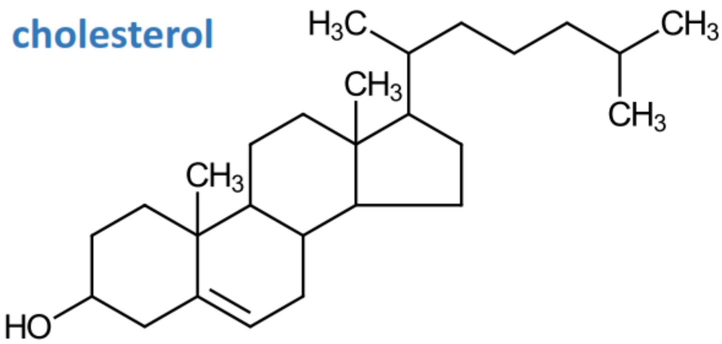
Abuses of steroids:

- Anabolic steroids are sometimes used by athletes to increase muscle and strength for an unfair advantage in sport.

Cholesterol

- Cholesterol has a steroidal backbone (4 fused hydrocarbon rings).

cholesterol

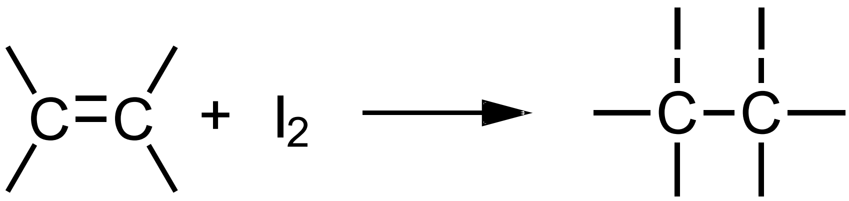


- Cholesterol is transported around the body by lipoproteins.
- LDL (low density lipoprotein) transports cholesterol to the arteries where it leads to thickening of the walls of the arteries (atherosclerosis).
- The main sources of LDL cholesterol are saturated fats; lauric acid, myristic acid and palmitic acid.

- HDL (high density lipoprotein) removes cholesterol from the walls of the arteries.

Iodine number

- The addition of iodine (I_2) to unsaturated fats can be used to determine the number of carbon to carbon double bonds in the fat.
- The iodine number is defined as the number of grams of iodine that reacts with 100g of fat.
- One mole of double bonds reacts with one mole of I_2, according to the equation below.



Exercises:

1. Calculate the mass of iodine that reacts with the following: (M I_2 = 254 $gmol^{-1}$)

(i) One mol of a monounsaturated fatty acid (one mol of carbon to carbon double bonds).

(ii) One mol of a fatty acid with two mol of carbon to carbon double bonds.

(iii) One mol of a fatty acid with three mol of carbon to carbon double bonds.

2. Linolenic acid (M = 278 $gmol^{-1}$) has the following formula.

$$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$$

(i) Determine the number of carbon to carbon double bonds in linolenic acid.

(ii) Determine the mass of iodine (I_2) that reacts with 278 g (one mol) of linolenic acid.

(iii) Calculate the iodine number of linoleic acid (the mass of iodine that reacts with 100g of fat)

3. Linoleic acid (*M* = 281) has the following formula.

$$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$$

Calculate the volume of 1.00 mol dm^{-3} iodine solution required to react exactly with 1.00 g of linoleic acid.

(i) Determine the number of carbon to carbon double bonds in linoleic acid

(ii) Calculate the mass of iodine that reacts with one mol of linoleic acid (M I_2 = 254 $gmol^{-1}$)

(iii) Calculate the mass of iodine that reacts with 1.00 g of linoleic acid and therefore the amount in mol, using the equation n=m/M.

(iv) Use the equation V=n/C to calculate the volume of 1.00 $moldm^{-3}$ iodine solution that reacts with 1.00 g of linoleic acid.

B.4 Carbohydrates

Understandings:

- Carbohydrates have the general formula $C_x(H_2O)_y$.
- Haworth projections represent the cyclic structures of monosaccharides.
- Monosaccharides contain either an aldehyde group (aldose) or a ketone group
- (ketose) and several –OH groups.
- Straight chain forms of sugars cyclize in solution to form ring structures containing an ether linkage.
- Glycosidic bonds form between monosaccharides forming disaccharides and polysaccharides.
- Carbohydrates are used as energy sources and energy reserves.

Applications and skills:

- Deduction of the structural formulas of disaccharides and polysaccharides from given monosaccharides.
- Relationship of the properties and functions of monosaccharides and polysaccharides to their chemical structures.

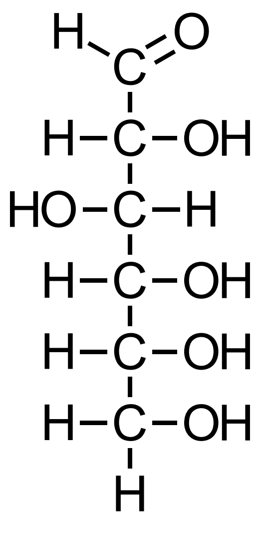
Guidance:

- The straight chain and α-ring forms of glucose and fructose are given in the data booklet in section 34.
- The component monosaccharides of specific disaccharides and the linkage details of polysaccharides are not required.
- The distinction between α- and β- forms and the structure of cellulose are not required.

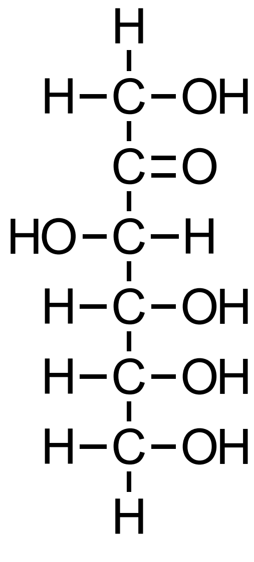
Monosaccharides

- Monosaccharides have a carbonyl group and at least 2 hydroxyl groups.
- The empirical formula of monosaccharides is CH_2O
- Glucose and fructose are examples of hexose sugars (6 carbon atoms $C_6H_{12}O_6$).

glucose (aldose sugar)

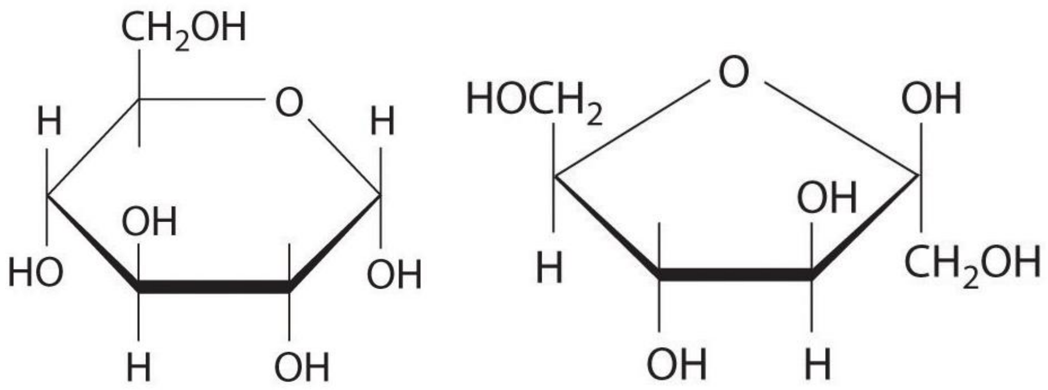


fructose (ketose sugar)



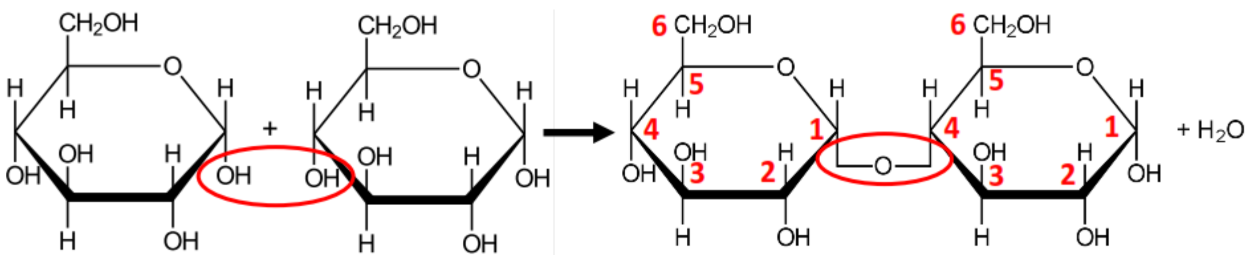
- In aqueous solutions, straight chain sugars form ring structures with an ether linkage.

α-glucose β-fructose



Disaccharides

- Disaccharides are formed from monosaccharides in condensation reactions.
- The bond between glucose monomers is a 1,4 glycosidic link.

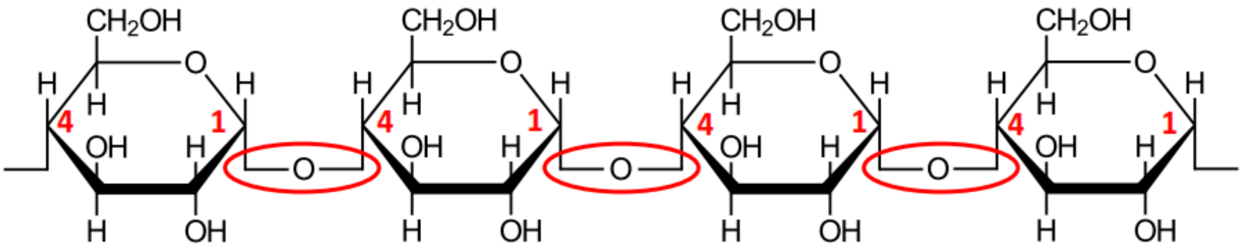


α-glucose + α-glucose → maltose + water
$C_{12}H_{22}O_{11}$

- Disaccharides are formed from monosaccharides in condensation reactions.
- A molecule of water is eliminated as an OH group from each sugar molecule reacts together.
- The bond between sugar molecules in a disaccharide is called a glycosidic link.
- Disaccharides are soluble molecules that can be hydrolyzed into monosaccharides by acid hydrolysis or enzyme catalyzed reactions.

Polysaccharides

- Polysaccharides are composed of long chains of monosaccharides bonded by glycosidic links.



- Starch is a polysaccharide composed of α-glucose with 1,4 glycosidic links between molecules.
- Polysaccharides are used for energy storage.
- Starch is used as carbohydrate storage in plants.
- Glycogen is used as carbohydrate storage in humans.
- Cellulose is used as structural material in plants and as dietary fiber as part of a balanced diet.

B.5 Vitamins

Understandings:

- Vitamins are organic micronutrients which (mostly) cannot be synthesized by the body but must be obtained from suitable food sources.
- The solubility (water or fat) of a vitamin can be predicted from its structure.
- Most vitamins are sensitive to heat.
- Vitamin deficiencies in the diet cause particular diseases and affect millions of people worldwide.

Applications and skills:

- Comparison of the structures of vitamins A, C and D.
- Discussion of the causes and effects of vitamin deficiencies in different countries and suggestion of solutions.

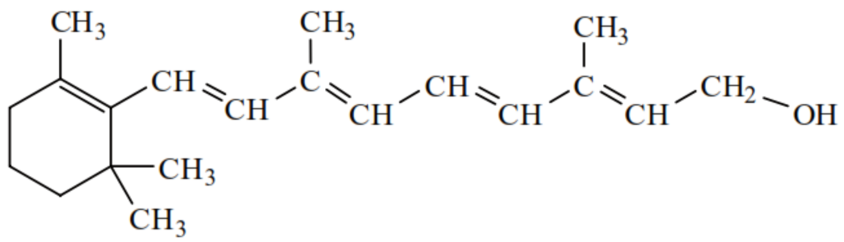
Guidance:

- The structures of vitamins A, C and D are provided in the data booklet section 35
- Specific food sources of vitamins or names of deficiency diseases do not have to be learned.

Vitamins

- Vitamins are organic micro-nutrients (substances needed in small amounts in the human body <0.005% of body mass).
- They are not made in the human body (except vitamin D) so must be obtained from the diet.
- Vitamins can be classified as fat soluble or water soluble.

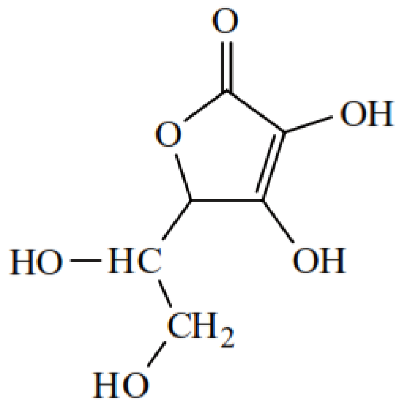
Vitamin A



retinol (vitamin A)

- Fat soluble – non-polar hydrocarbon chain and ring.
- Vitamin A is important for low-light vision.
- A lack of vitamin A causes night blindness.

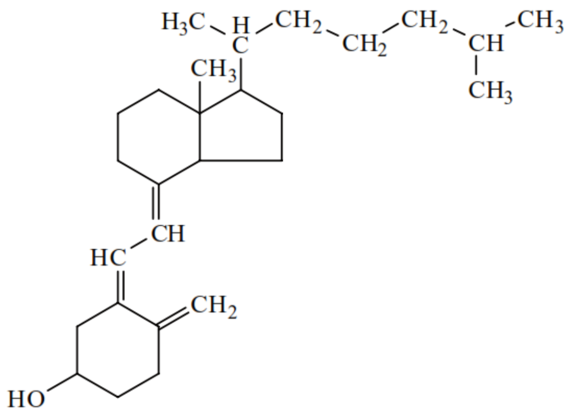
Vitamin C



ascorbic acid (vitamin C)

- Water soluble – large number of polar OH groups which are able to form hydrogen bonds with water molecules.
- A lack of vitamin C causes scurvy.
- Due to its solubility in water, it is not retained by the body for long periods.
- The carbon to carbon double bond and OH groups in vitamin C are readily oxidized (by air and light).
- Keeping food containing vitamin C in the refrigerator slows down this process.
- Water soluble vitamins such as vitamin C are sensitive to heat and are destroyed by cooking.

Vitamin D



vitamin D

- Fat soluble – non-polar hydrocarbon chains and rings.
- Vitamin D stimulates the uptake of calcium ions, important for healthy bones and teeth.
- A lack of vitamin D can cause rickets. Vitamin D is made in the body by the action of sunlight on the skin.

Vitamin deficiencies

- Millions of people worldwide suffer from a lack of vitamins in their diet (malnutrition).

Common vitamin deficiencies and their causes.

Disease	Deficiency
Night blindness	lack of vitamin A
Pellagra	lack of vitamin B3
Scurvy	lack of vitamin C (found in citrus fruit)
Rickets	lack of vitamin D (produced during exposure to sunlight)

Causes of vitamin deficiencies:

- Lack of distribution of global resources
- Depletion of nutrients in the soil
- Lack of education about balanced diets
- Over-processing foods

Solutions to vitamin deficiencies:

- Fortifying staple foods with micronutrients
- Taking nutritional supplements
- Genetically modifying foods to increase nutrient content
- Educating people about balanced diets

B.6 Biochemistry and the environment

Understandings:

- Xenobiotics refer to chemicals that are found in an organism that are not normally present there.
- Biodegradable/compostable plastics can be consumed or broken down by bacteria or other living organisms.
- Host–guest chemistry involves the creation of synthetic host molecules that mimic some of the actions performed by enzymes in cells, by selectively binding to specific guest species, such as toxic materials in the environment.
- Enzymes have been developed to help in the breakdown of oil spills and other industrial wastes.
- Enzymes in biological detergents can improve energy efficiency by enabling effective cleaning at lower temperatures.
- Biomagnification is the increase in concentration of a substance in a food chain.
- Green chemistry, also called sustainable chemistry, is an approach to chemical research and engineering that seeks to minimize the production and release to the environment of hazardous substances.

Applications and skills:

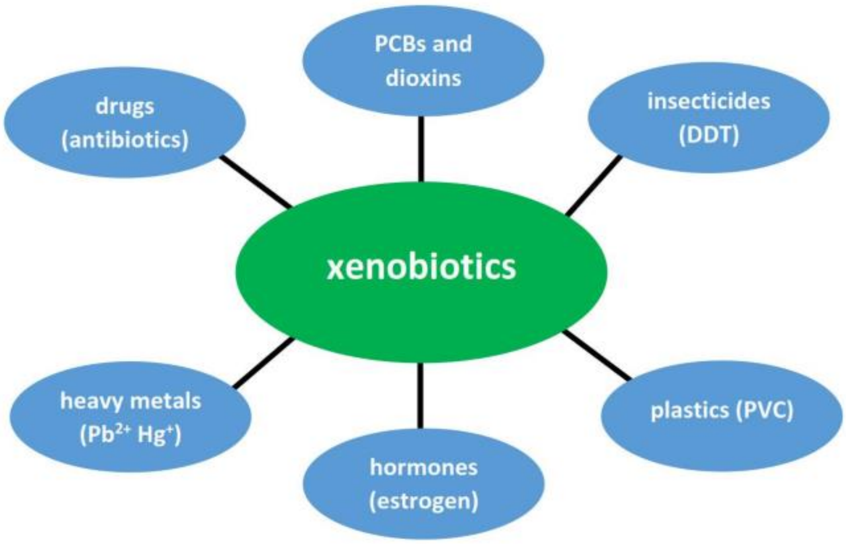
- Discussion of the increasing problem of xenobiotics such as antibiotics in sewage treatment plants.
- Description of the role of starch in biodegradable plastics.
- Application of host–guest chemistry to the removal of a specific pollutant in the environment.
- Description of an example of biomagnification, including the chemical source of the substance. Examples could include heavy metals or pesticides.
- Discussion of the challenges and criteria in assessing the “greenness” of a substance used in biochemical research, including the atom economy.

Guidance:

- Specific names of “green chemicals” such as solvents are not expected.
- The emphasis in explanations of host–guest chemistry should be on non- covalent bonding within the supramolecule.

Xenobiotics

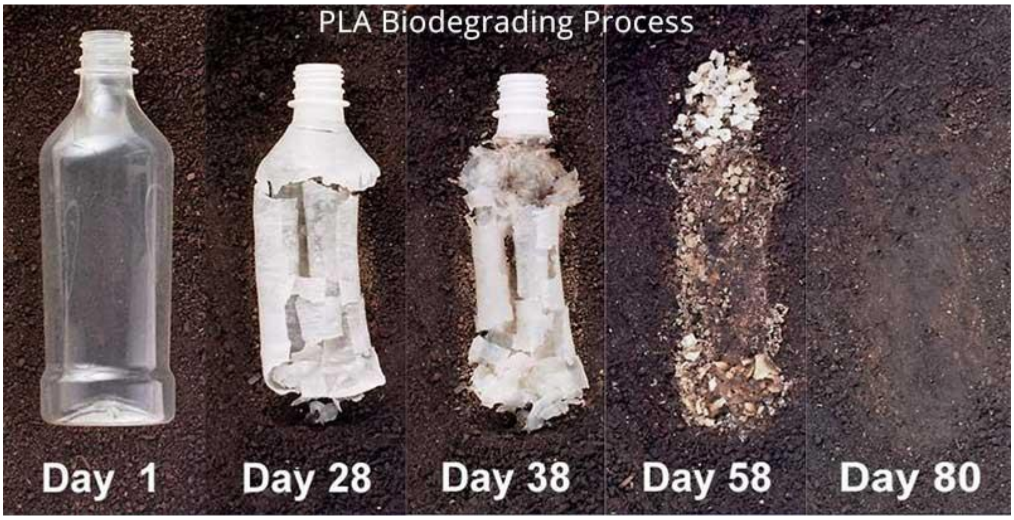
- Xenobiotics are chemical substances found within an organism that are not naturally produced by or expected to be present within that organism.



- Antibiotics are xenobiotics in animals – they are not produced by animals, nor are they part of a normal diet.
- Certain bacteria can become resistant to antibiotics. Sewage treatment plants can promote the spread of antibiotic resistance between bacteria.
- Water discharged into lakes and rivers from sewage treatment plants can contain significant concentrations of the genes that make bacteria antibiotic resistant.
- Dioxins and polychlorinated biphenyls (PCBs) are toxic chemicals that persist in the environment.
- Once dioxins enter the body, they accumulate due to their chemical stability and also their ability to be absorbed by fatty tissue.
- Long term exposure to these substances causes a range of adverse effects on the nervous, immune, and endocrine systems. They may also be carcinogenic (cancer causing).

Biodegradable plastics

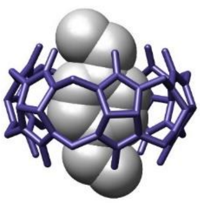
- Biodegradable (compostable) plastics can be consumed or broken down by bacteria or other living organisms.
- PLA (polylactide) is a biodegradable plastic derived from renewable resources such as corn starch.



- The breakdown of starch based plastics (bioplastics) produces carbon dioxide and water.
- Bioplastics can be broken down in hydrolysis reactions due to the the presence of ester linkages or glycosidic links (requires heat and moisture).
- When some biodegradable plastics decompose in landfills, they produce methane gas which is a very powerful greenhouse gas (anaerobic conditions).

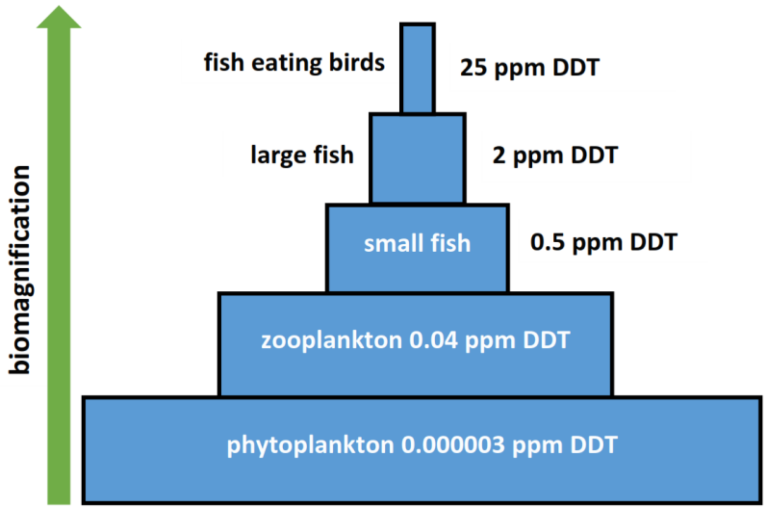
Host-guest chemistry

- The host selectively binds a guest in order to produce a host-guest complex (supramolecule) through non-covalent interactions.
- The four types of non-covalent interactions between the host and guest are: hydrogen bonds, ionic bonds, van der Waal's forces and hydrophobic interactions.
- Host-guest chemistry can be applied to the removal of xenobiotics in the environment.
- The binding between a xenobiotic and a host produces a supramolecule.
- Examples of xenobiotics in the environment are radioactive cesium-137, and aromatic amines which are known to be carcinogenic.



Biomagnification

- Biomagnification is the increase in concentration of a xenobiotic in a food chain.



- DDT is an insecticide that was used to control mosquito populations that spread diseases such as malaria and typhus.
- DDT is readily soluble in fat and does not break down therefore it accumulates in fatty tissue.
- In the 1960s birds of prey such as ospreys suffered a decline in numbers which was due to the toxic effects of DDT.
- The use of DDT as an insecticide was banned in many countries in the 1970s.

Green chemistry - atom economy

- The % atom economy tells us the percentage by mass of the reactants that do not end up in the desired product (they are wasted).
- The higher the atom economy for a chemical reaction, the less waste is produced and the more efficient the reaction is.

$$\%\ \text{atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$$

Example:

Fe is produced by the reduction of Fe_2O_3 in a blast furnace. Calculate the atom economy of the reaction.

$$\mathbf{Fe_2O_{3(s)} + 3CO_{(g)} \rightarrow 2Fe_{(s)} + 3CO_{2(g)}}$$