

WORKBOOK

SECOND EDITION

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SACE STAGE 2

Australian Curriculum

Chemistry

Sample



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Nitrogen oxides and ozone are pollutants in the troposphere that are associated with photochemical smog.

- Describe and write equations showing how catalytic converters reduce the quantities of nitrogen oxides generated by motor vehicles.

Motor vehicle exhaust can produce as much as 45% of nitrogen oxides (NO_x) and 50% of the ozone (O₃) in the troposphere. Governments have taken steps to reduce the emissions of nitrogen oxides from motor vehicles by:

- promoting the use of public transport to reduce the number of vehicles.
- promoting the use of bicycles for short-distance commuting.
- implementing vehicle emissions standards that manufacturers must adhere to.

Catalytic converters

A **catalytic converter** is a device that is fitted to the exhaust system of a motor vehicle with the aim of reducing the emissions of nitrogen oxides and other primary pollutants. Figure 1.16 shows the essential components of a catalytic converter used in a motor vehicle.

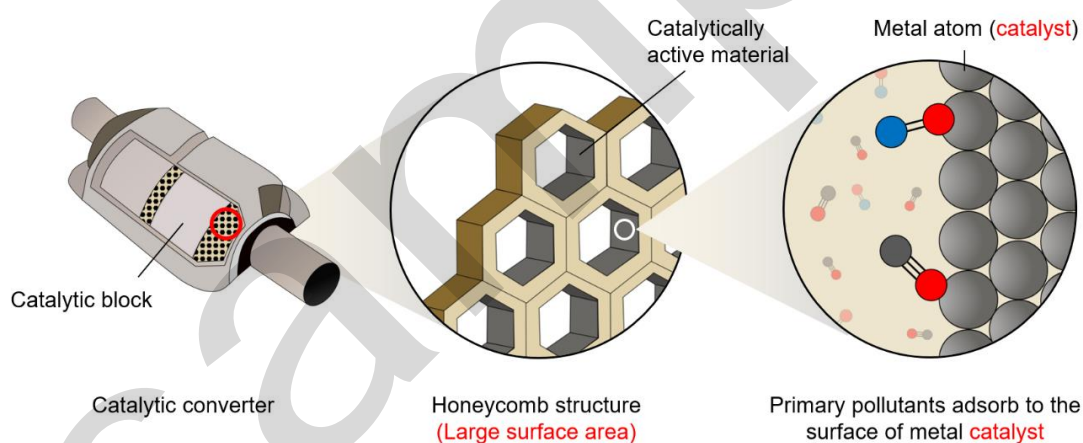
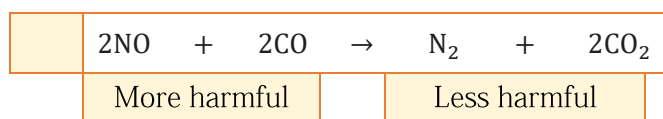


Figure 1.16: Components of a catalytic converter used in a motor vehicle.

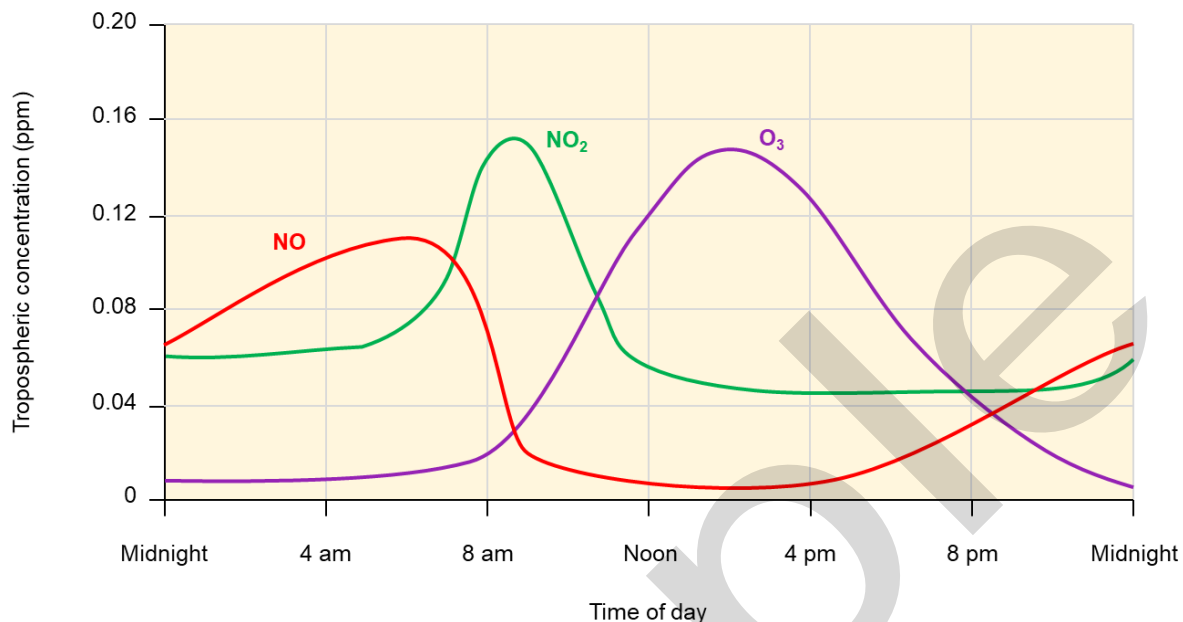
The catalytic converter uses a metal catalyst such as platinum, palladium, or rhodium to transform nitrogen oxides and other pollutants into less harmful substances.



The catalytic converter has a ceramic honeycomb structure coated with finely divided metal which increases the surface area to volume ratio of the catalyst and increases the rate at which primary pollutants are converted into less harmful substances in the catalytic converter.

Question 14

The graph below shows variations in the tropospheric concentrations of three pollutants in 24 hours. The intensity of ultraviolet radiation from the sun is greatest between 10 am and 3 pm.



- (a) State the time of day when the emissions of nitric oxide (NO) are at a maximum and give one reason for the high concentration of nitric oxide in the troposphere at this time.

(2 marks) IAE3

- (b) Use evidence from the graph to explain why the concentration of nitric oxide decreases between 7 am and 9 am.

(2 marks) IAE3

- (c) Ozone is formed in the photodissociation of nitrogen dioxide by ultraviolet radiation.

Write two equations to show the formation of ozone from the photodissociation of nitrogen dioxide.

Equation 1: _____ (2 marks) KA4

Equation 2: _____ (2 marks) KA4

1.3: Volumetric Analysis

Concentrations can be described by using a number of standard conventions.

- Calculate concentration and interconvert units, including: mol L⁻¹, g L⁻¹, %w/v, ppm, and ppb.
- Apply SI prefix conventions to quantities.

Concentration is a measure of the quantity of solute per unit volume of solution. Solution concentrations are described in terms of **mass concentration (ρ)** and **molar concentration (c)**.

Mass concentration

The mass concentration of a solution is the mass of solute per unit volume of solution.

Formula	$\rho = \frac{m}{V}$	
Symbol	Variable	Unit
ρ	Mass concentration	g.L ⁻¹
m	Mass of solute	g
V	Volume of solution	L

Example 1.05

A coffee drink consists of 57.5 grams of sucrose dissolved in 600 mL of solution.

Determine the mass concentration of sucrose in the coffee drink.

$$\begin{aligned}\rho &= \frac{m}{V} \\ \rho &= \frac{57.5}{0.6} \\ \rho &= 95.8 \text{ g.L}^{-1}\end{aligned}$$

Example 1.06

A bottle of balsamic vinegar contains ethanoic acid in a concentration of 60.0 g.L⁻¹.

Determine the mass of ethanoic acid in 250.0 mL of balsamic vinegar.

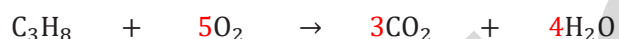
$$\begin{aligned}m &= \rho V \\ m &= 60.0 \times 0.25 \\ m &= 15.0 \text{ g}\end{aligned}$$

Limiting reagent

When reactants combine in a ratio that is less than the stoichiometric ratio, one reactant is completely consumed, and the other is partially consumed. The reactant that is completely consumed is called the **limiting reagent** and the reactant that is partially consumed is in **excess**. The limiting reagent is used when predicting the quantities of products formed in the reaction.

Example 1.17

50 g of propane (C_3H_8) was reacted with 125 g of oxygen (O_2).



Determine the maximum mass of carbon dioxide produced in the reaction.

- The first step is to identify the limiting reagent. One approach is to determine the theoretical number of moles carbon dioxide formed by the available quantities of propane and oxygen.

$n_{C_3H_8} = \frac{m}{M}$	$n_{O_2} = \frac{m}{M}$
$n_{C_3H_8} = \frac{50}{44.094}$	$n_{O_2} = \frac{125}{32.00}$
$n_{C_3H_8} = 1.1 \text{ mol (1.13)}$	$n_{O_2} = 3.9 \text{ mol}$

The theoretical number of moles of carbon dioxide (n_{CO_2}) is determined from the stoichiometric ratio.

Ratio = $3n_{CO_2} : 1n_{C_3H_8}$	Ratio = $3n_{CO_2} : 5n_{O_2}$
$n_{CO_2} = n_{C_3H_8} \times 3$	$n_{CO_2} = \frac{n_{O_2}}{5} \times 3$
$n_{CO_2} = 3.4 \text{ mol}$	$n_{CO_2} = 2.3 \text{ mol (2.34)}$

Oxygen is the limiting reagent as it limits the production of carbon dioxide to 2.3 mol.

- The maximum mass of carbon dioxide produced in the reaction is predicted from the number of moles of the limiting reagent and molar mass of carbon dioxide.

$n_{CO_2} = n_{O_2} \text{ (limiting reagent)}$
$m_{CO_2} = n_{CO_2} M_{CO_2}$
$m_{CO_2} = 2.34 \times 44.01$
$m_{CO_2} = 103 \text{ g}$

The TLC plate is transferred to the vessel and is made to stand vertically with the solvent below the pencil line as shown in Figure 1.34.

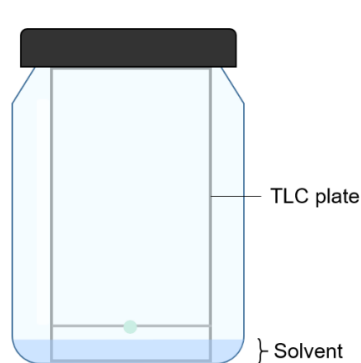


Figure 1.34: TLC plate standing inside the sealed vessel.

The solvent flows vertically over the surface of the TLC plate by **capillary action**. The components of the mixture begin to separate based on the strength of their interactions with the stationary and mobile phases. Components that interact more strongly with the mobile phase travel at a greater rate than those that interact more strongly with the stationary phase.

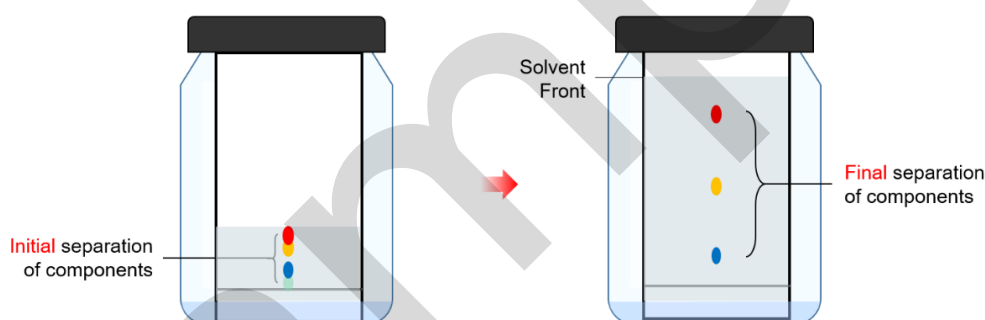


Figure 1.35: Separation of the components of a mixture using TLC.

The TLC plate is removed from the sealed vessel when the **solvent front** approaches the top of the plate. The solvent front is marked using a pencil, and the TLC plate is allowed to dry. The dried TLC plate is called a **chromatogram** (Figure 1.36).

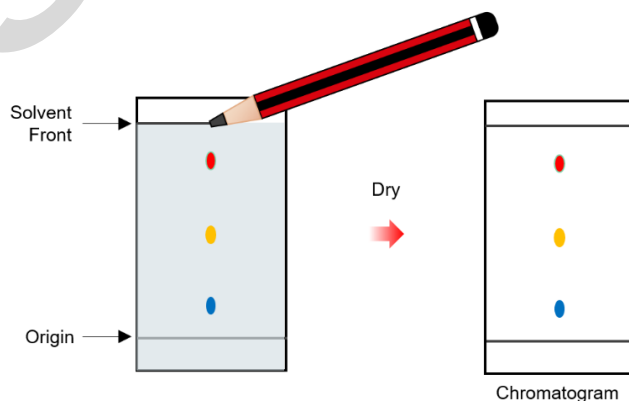


Figure 1.36: Producing a chromatogram.

Data from chromatography techniques can be used to determine the composition and purity of substances.

- Calculate and apply R_f values and retention times in the identification of components in a mixture.

The components of a mixture move at different rates along the surface of a TLC plate. Compounds that interact more strongly with the stationary phase move at a lower rate and travel a shorter distance on the TLC plate while those that interact more strongly with the mobile phase move at a greater rate and travel a greater distance. Each component on a chromatogram is assigned a **retention factor** (R_f) which is the ratio of the distance travelled by a component to the solvent front.

$$R_f = \frac{\text{distance travelled by component}}{\text{solvent front}}$$

Figure 1.37 shows a chromatogram with three visible components of a mixture. The distance travelled by each component has been identified.

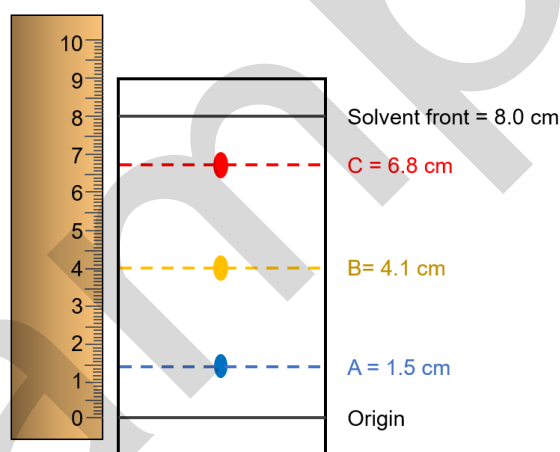


Figure 1.37: Distances travelled by each component of the mixture.

The retention factor of each component is calculated below.

$R_f = \frac{A}{\text{solvent front}}$	$R_f = \frac{B}{\text{solvent front}}$	$R_f = \frac{C}{\text{solvent front}}$
$R_f = \frac{1.5}{8.0}$	$R_f = \frac{4.1}{8.0}$	$R_f = \frac{6.8}{8.0}$
$R_f = 0.19$	$R_f = 0.51$	$R_f = 0.85$

The retention factor indicates the relative affinity of a component for the stationary and mobile phases. Components with a high R_f (close to 1.0) have a greater affinity for the mobile phase and travel a greater distance along the TLC plate. Components with a low R_f (closer to 0) are more strongly adsorbed to the stationary phase and travel a shorter distance from the origin.

Ion chromatography (also known as ion exchange chromatography) is used to remove either cations or anions from a mixture by replacing them with ions of another type.

- Explain, using equilibrium principles, how ions attached to the surface of a resin can be exchanged with ions in aqueous solution.

Ion exchange chromatography (IC) is an analytical technique used to separate the components of a mixture containing charged substances including ions and polar molecules and is commonly used in the separation of amino acids and proteins. The separation of components occurs inside a column containing porous beads. The beads are composed of a charged polymer resin with cations or anions attached to the surface. Figure 1.47 shows the structures of two polymer resins used in ion exchange chromatography.

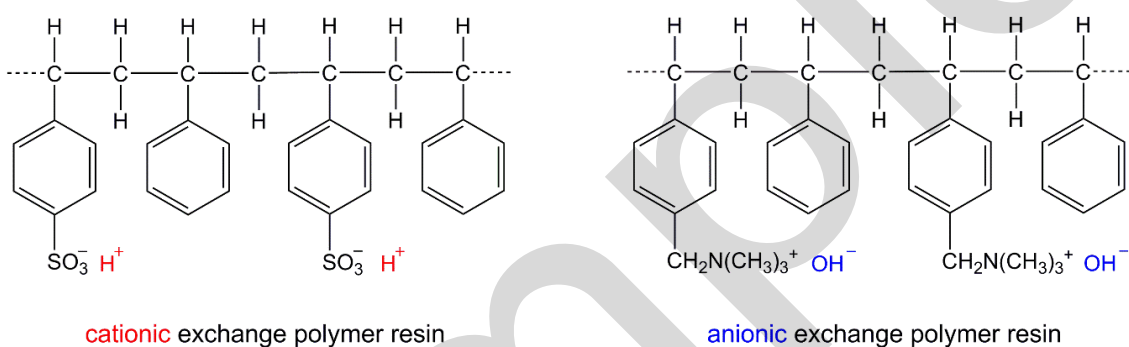


Figure 1.47: Polymer resins used in ion exchange chromatography.

Ions on the surface of the polymer resin are exchanged with ions of the same charge in the mixture passing through the column. For example, negatively charged components in a mixture are exchanged with anions bound to the surface of the anionic polymer resin as shown in Figure 1.48.

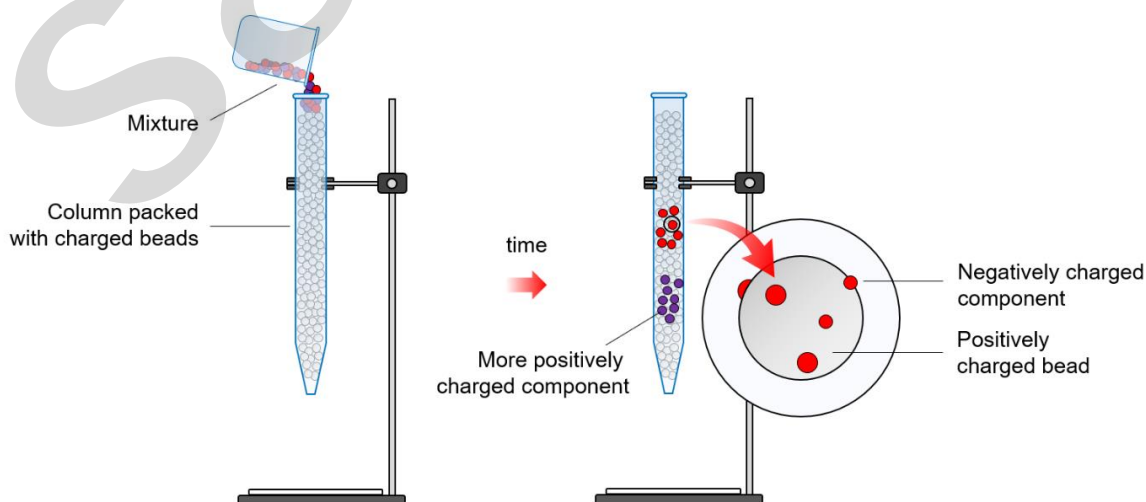


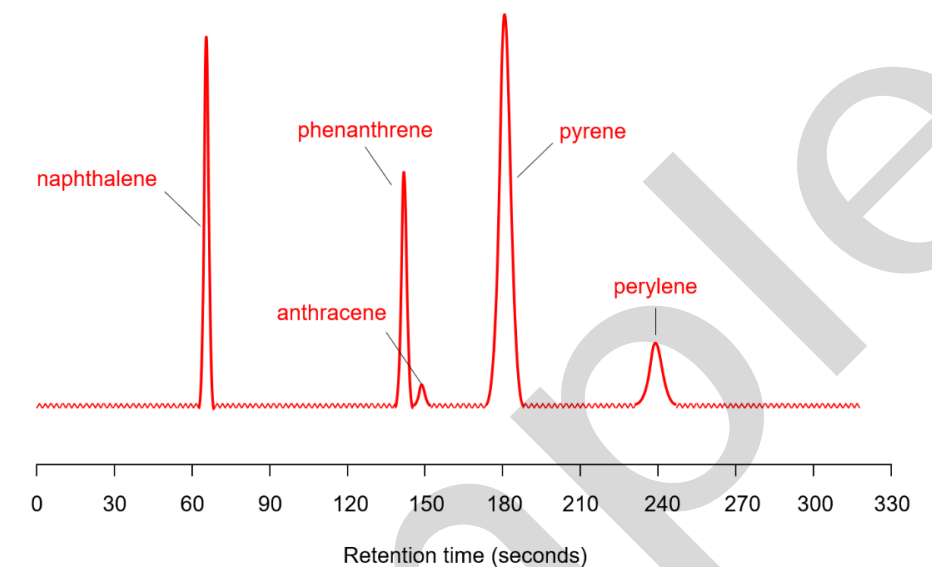
Figure 1.48: Exchange of negatively charged particles in IC.

Question 3

Polycyclic aromatic hydrocarbons (PAH) are organic compounds that enter the troposphere and cause air pollution when hydrocarbons are burnt in an internal combustion engine.

A sample of polluted air was obtained from a city street during heavy traffic.

The sample was analysed using gas chromatography with a column containing a non-polar stationary phase and the resulting chromatogram is provided below.



- (a) Determine the retention time of perylene.

_____ (1 mark) IAE3

- (b) Use evidence from the chromatogram to identify two PAHs with a similar chemical structure.

 _____ (2 marks) IAE3

- (c) Identify and explain the most polar PAH compound on the chromatogram.

 _____ (3 marks) IAE3

- (d) Ozone is a component of polluted air in the troposphere.

Write equations to show the formation of ozone in the troposphere.

 _____ (2 marks) KA4

Question 4

Read the following passage:

The environmental protection agency (EPA) monitors the long-term ambient air quality around South Australia to improve understanding of air pollution trends and the long-term impacts on local communities. This information is used in conjunction with industries and community engagement programs to underpin future policy directions aimed at reducing long-term risks to human health and the environment. In addition, some industries undertake their own ambient air monitoring in metropolitan Adelaide as well as regional centres around South Australia.

The EPA has instruments located at fixed positions around the state that measure air pollutant concentrations every hour, and the concentrations are displayed in $\mu\text{g}/\text{m}^3$ for particles and ppm for ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. The EPA uses a standardised procedure for data validation which involves checking that the data is accurate and either correcting or removing data that is incorrect. Air quality is then described by the EPA as good, fair or poor based on a comparison between pollutant concentrations and the relevant National Environment Protection Measure (NEPM) standards. The data is presented to the public approximately half an hour after the measurements are taken and validated. Some air pollutants including lead, cadmium and antimony are measured less frequently (once every six days) as samples need to be collected and sent away for analysis.

Discuss how this example illustrates the key concepts of science as a human endeavour.

(6 marks) KA3

Energy production

Chemical manufacturing plants are large facilities that use huge amounts of electrical and thermal energy. Most manufacturing plants have steam turbines and electrical generators on site that produce the electricity required to power chemical reactions and daily operations. The components of a steam turbine and electrical generator are identified in Figure 2.27.

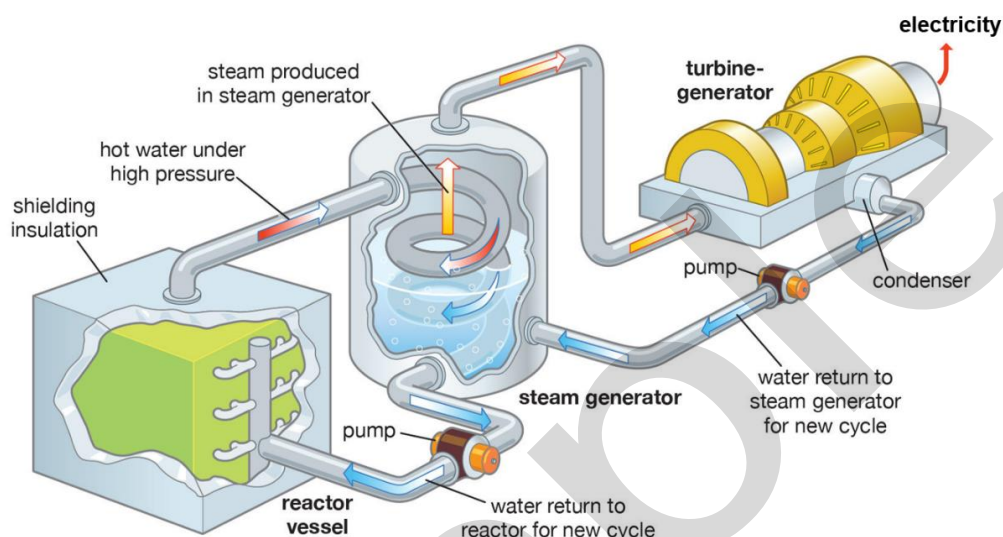


Figure 2.27: Components of a steam turbine and electrical generator.

Most thermal and electrical energy used in a chemical manufacturing plant is derived from the combustion of fossil fuels including coal, petroleum and natural gas. Fossil fuels are non-renewable resources and their combustion releases large quantities of greenhouse gases and other pollutants into the atmosphere. In addition, manufacturers pay taxes based on greenhouse gas emissions which reduces profits.

Engineers design manufacturing plants and processes that reduce energy costs, preserve non-renewable resources, and reduce emissions of harmful pollutants. Two methods used to reduce the costs associated with energy consumption are identified in the table below.

Method	Description
Recycling heat	Heat released in exothermic reactions is transferred to a material such as water that stores the energy and transports it to another part of the manufacturing plant where it can be used.
Operating continuously	Heating certain reaction mixtures to the appropriate temperature each day requires energy. It is more energy-efficient to maintain a constant temperature rather than reduce the energy output of the reactor vessels.

Systematic naming of alcohols with positional isomers

Alcohols with three or more carbon atoms have **positional isomers**. A method of naming alcohols with three or more carbon atoms is described in the example below.

Example 3.06

Figure 3.09 shows the three positional isomers of an alcohol.

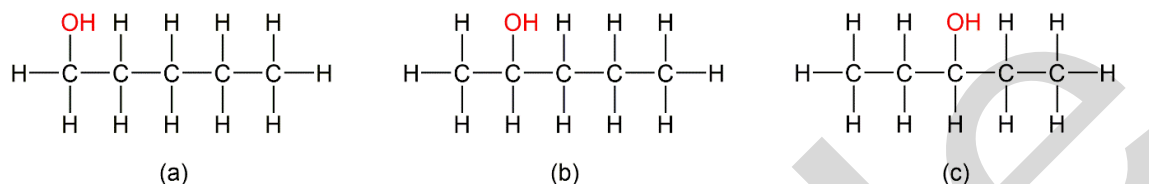
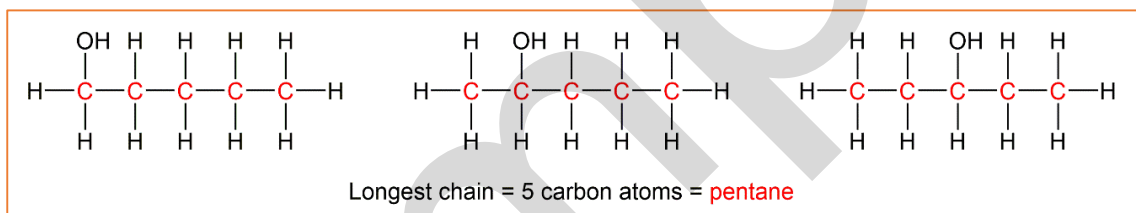


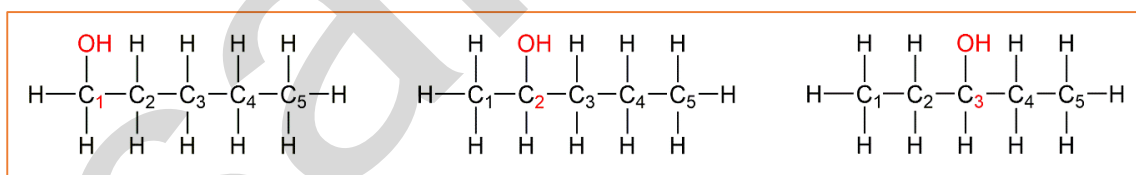
Figure 3.09: Positional isomers of an alcohol.

The systematic names of the alcohols are derived using the following steps.

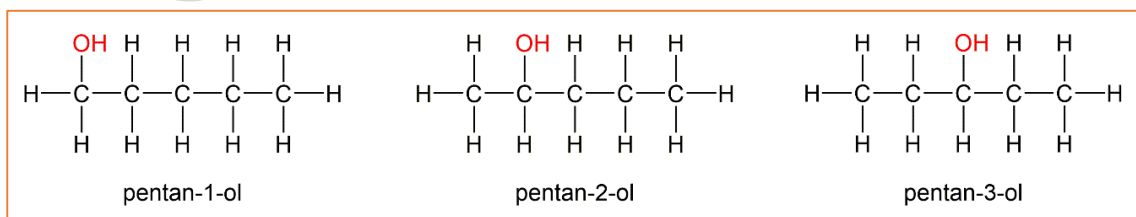
- Determine the prefix by identifying the longest continuous carbon chain in the alcohol.



- Number the carbon atoms in the longest chain sequentially, giving the lowest possible number to the carbon atom that is bonded to the hydroxyl group.



- Remove the “e” from the ending of the alkane, add the position number of the hydroxyl group and conclude with the suffix “ol”.



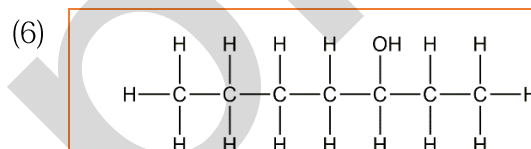
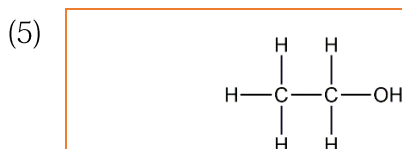
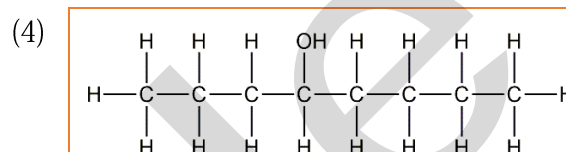
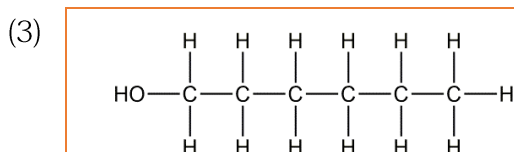
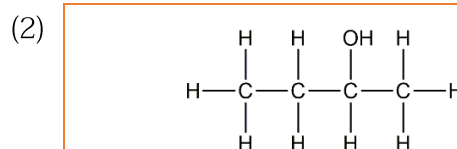
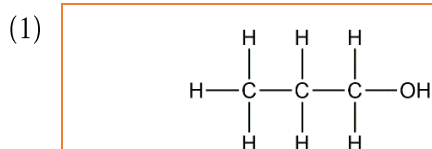
Alternatively, the position number is written before the name of the alcohol as shown below.

(a)	1-pentanol	(b)	2-pentanol	(c)	3-pentanol
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Question 72

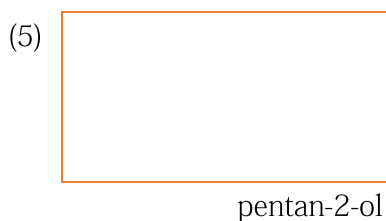
Alcohols are a family of organic compounds that contain one or more hydroxyl groups.

(a) Write the systematic names of the following alcohols.



(12 marks) KA4

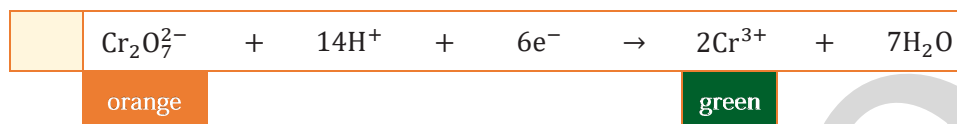
(b) Draw the extended structural formulae of the following alcohols.



(12 marks) KA4

Oxidation of alcohols

Primary and secondary alcohols are distinguished from tertiary alcohols by their reaction with acidified dichromate solution. Primary and secondary alcohols undergo oxidation when reacted with acidified dichromate solution. Electrons are transferred from primary and secondary alcohols which reduces dichromate ions to chromium (III) ions as shown in the redox half-equation below. An orange to green colour change is observed as dichromate ions are reduced to chromium (III) ions.



Organic compounds undergo oxidation through the loss of one or more hydrogen atoms. A hydrogen atom is removed from the alpha carbon in the oxidation of primary and secondary alcohols. Tertiary alcohols cannot undergo oxidation as do not have a hydrogen atom bonded to the alpha carbon.

Example 3.10

Acidified dichromate solution was transferred to separate test tubes containing three different alcohols as shown in Figure 3.14.

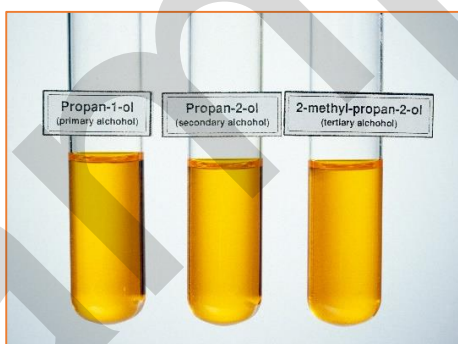


Figure 3.14: Three different alcohols mixed with acidified dichromate solution.

The test tubes were transferred to a beaker containing warm water and the solutions containing primary and secondary alcohols changed colour from orange to green as shown in Figure 3.15.

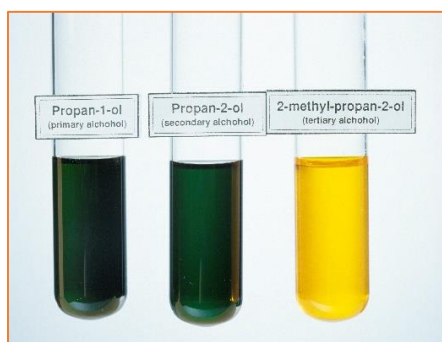
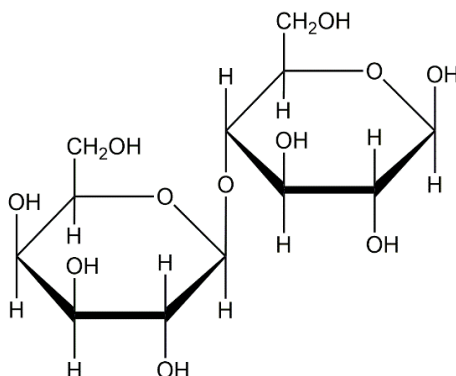


Figure 3.15: Oxidation of primary and secondary alcohols using acidified dichromate solution.

Question 90

Lactose ($C_{12}H_{22}O_{11}$) is a carbohydrate present in milk and milk products.



- (a) State whether lactose is a monosaccharide or disaccharide.

(1 mark) KA2

- (b) Lactose is hydrolysed by the enzyme lactase in the small intestine of mammals.

- (1) Draw the structural formulae of the two products formed in the hydrolysis reaction.



(4 marks) KA4

- (2) Write a fully balanced equation for the hydrolysis of lactose.

(2 marks) KA4

- (c) Lactose intolerance is a set of symptoms caused by the incomplete hydrolysis of lactose.

- (1) State the most likely cause of the incomplete hydrolysis of lactose in the human body.

(1 mark) KA2

- (2) Lactose accumulates in the intestines where it absorbs water which can result in watery faeces and diarrhoea.

State the feature of the lactose molecule that allows it to absorb large quantities of water.

(1 mark) KA2

Solubility of carboxylic acids

The water-solubilities of carboxylic acids are greater than alkanes, alcohols, aldehydes and ketones with the same number of carbon atoms due to the presence of the highly polar carboxyl group. The presence of one or more carboxyl groups increases the solubility of carboxylic acids by allowing the molecules to form multiple hydrogen bonds with water molecules as shown in Figure 3.53.

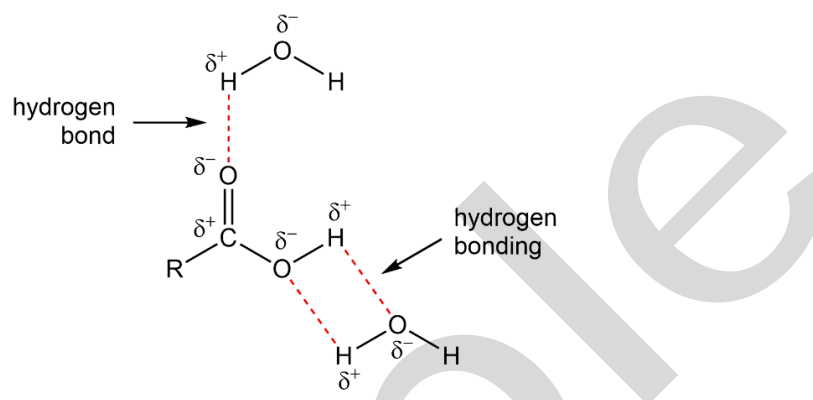


Figure 3.53: Hydrogen bonding between a carboxylic acid and water.

The table below shows the water-solubilities of several carboxylic acids at 20°C.

Carboxylic acid	Solubility (g.L ⁻¹)
methanoic acid	miscible
ethanoic acid	miscible
propanoic acid	miscible
butanoic acid	miscible
pentanoic acid	50
hexanoic acid	11
heptanoic acid	2.4
octanoic acid	0.7

The table shows that the water-solubilities of carboxylic acids decrease with molecular size.

Dispersion forces are stronger between the electron clouds of larger carboxylic acids which prevent the molecules from separating and forming a solution when mixed with water.

Conversely, the dispersion forces are much weaker between the electron clouds of smaller carboxylic acids which allows the molecules to separate more readily and form a solution when mixed with water. This property is reflected in the miscibility of methanoic acid, ethanoic acid, propanoic acid and butanoic acid meaning that these compounds dissolve completely in water in all proportions.

3.7: Esters

Carboxylic acids undergo condensation reactions with alcohols to form esters.

- Identify, name systematically, and draw structural formulae of methyl and ethyl esters of acids containing up to eight carbon atoms in the main chain, with side chains limited to a maximum of two carbon atoms.
- Draw the structural formula of the ester produced by the condensation reaction of a carboxylic acid and alcohol, given their structural formulae or vice versa.

Esters are a family of organic compounds containing an ester functional group (R_1COOR_2).

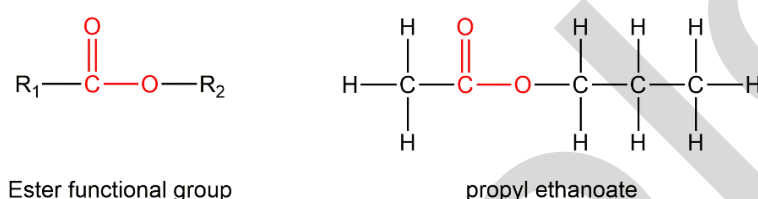


Figure 3.69: Ester functional group.

Esters are produced in the condensation reaction of an alcohol and a carboxylic acid. The reaction is reversible and will only proceed in the presence of a strong acid catalyst. Figure 3.70 illustrates an **esterification reaction** between an alcohol (propan-1-ol) and a carboxylic acid (ethanoic acid).

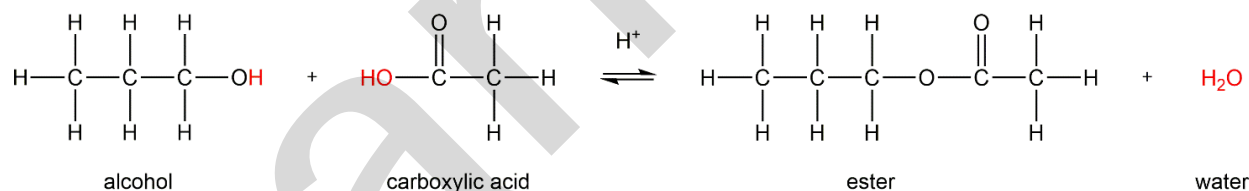


Figure 3.70: Esterification reaction.

Systematic naming of esters

The systematic name of an ester is derived from the names of the alcohol and carboxylic acid used in the esterification reaction (Figure 3.71).

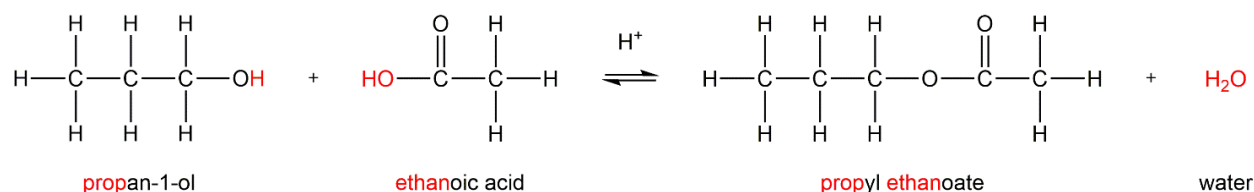
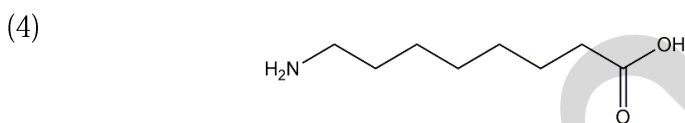
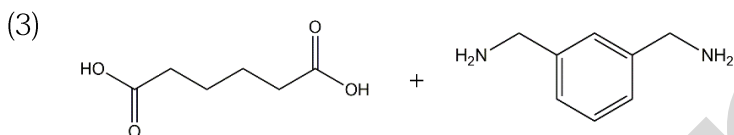
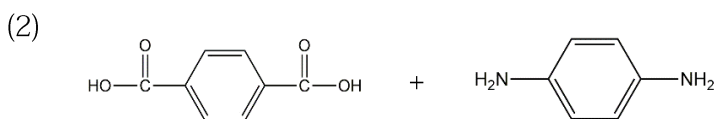
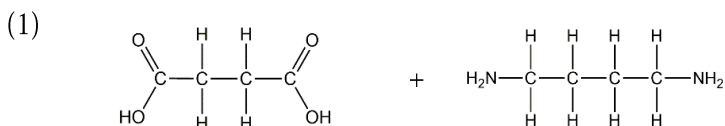


Figure 3.71: Derivation of the systematic name of an ester.

Question 114

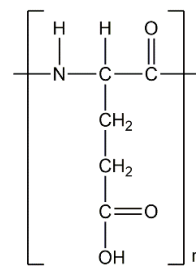
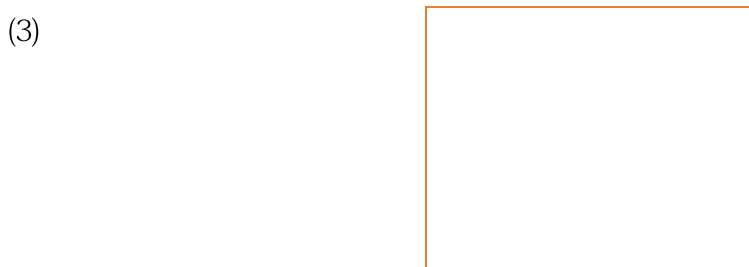
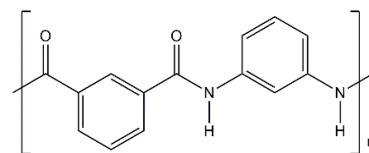
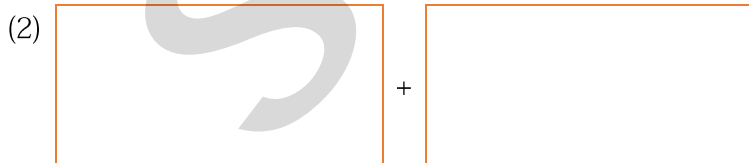
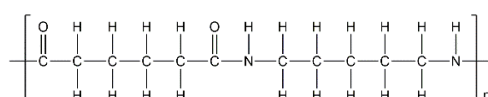
Polyamides are polymer molecules formed in the reaction of a dicarboxylic acid and a diamine.

- (a) Draw the structural formula of the repeating unit of the polyamide formed in the following reactions.



(8 marks) KA4

- (b) Draw the structural formula of the monomer(s) used in the synthesis of the polyamides below.



(10 marks) KA4

Melting points of edible fats and oils

Edible fats are triglycerides that are solid at 25°C and are generally* derived from animals.

Conversely, edible oils are triglycerides that are liquid at 25°C and are generally derived from plants and marine animals. The higher melting points of edible fats are due to the higher proportion of saturated fatty acids present in the triglyceride molecules. The presence of saturated fatty acids results in a more linear and ordered structure that allows the triglyceride molecules to pack more closely together which increases the strength of the dispersion forces between the electron clouds of these molecules. Figure 3.97 shows the structure of tripalmitin which is a triglyceride in beef fat.

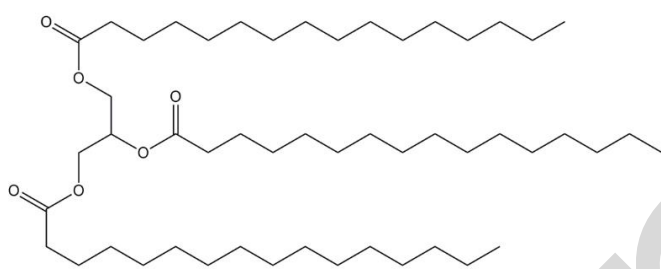


Figure 3.97: Structure of tripalmitin and a sample of beef fat.

The lower melting points of edible oils are due to a higher proportion of unsaturated fatty acids present in the triglyceride molecules. The presence of unsaturated fatty acids results in a disordered structure that prevents the triglyceride molecules from packing closely together. Consequently, the dispersion forces between the electron clouds are weaker which accounts for the lower melting points of edible oils. Figure 3.98 shows the structure of triolein which is a triglyceride in olive oil.

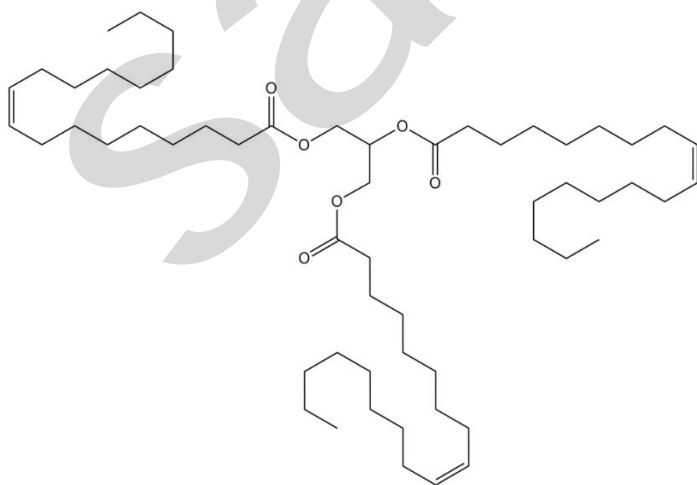


Figure 3.98: Structure of triolein and a sample of olive oil.

*Edible fats and oils are mixtures of triglycerides and most contain both saturated and unsaturated triglycerides. In addition, many plant oils including palm oil and coconut oil contain a high proportion of saturated fats.

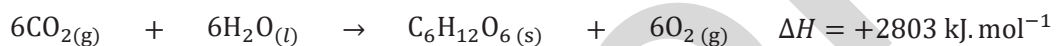
4.1: Energy

Photosynthesis and respiration are important processes in the cycling of carbon and oxygen on Earth. In photosynthesis, the light energy absorbed by chlorophyll is stored as chemical energy in carbohydrates such as glucose.

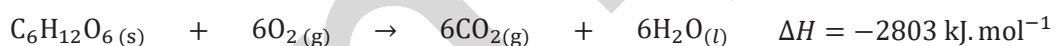
The chemical energy present in carbohydrates can be accessed by respiration and combustion.

- Describe and write the equation for photosynthesis.
- Describe and write the equation for the aerobic respiration of glucose.

Carbon and oxygen are elements present in all compounds essential to life processes in living things. The source of carbon and oxygen in most living things is carbon dioxide (CO_2) which is present in air, freshwater, and seawater. Algae, phytoplankton, and plants transform carbon dioxide into glucose in **photosynthesis** which is summarised in the equation below.



Photosynthesis is an endothermic process. Photosynthetic organisms contain **chlorophyll** which facilitates the absorption and transformation of light energy in sunlight into chemical energy that is stored in carbohydrates. Other living things consume the stored carbohydrates and the chemical energy is released in **aerobic respiration** which is summarised in the equation below.



Photosynthesis and aerobic respiration are components of the **carbon cycle** which is the natural circulation of carbon in various forms through nature (Figure 4.01).

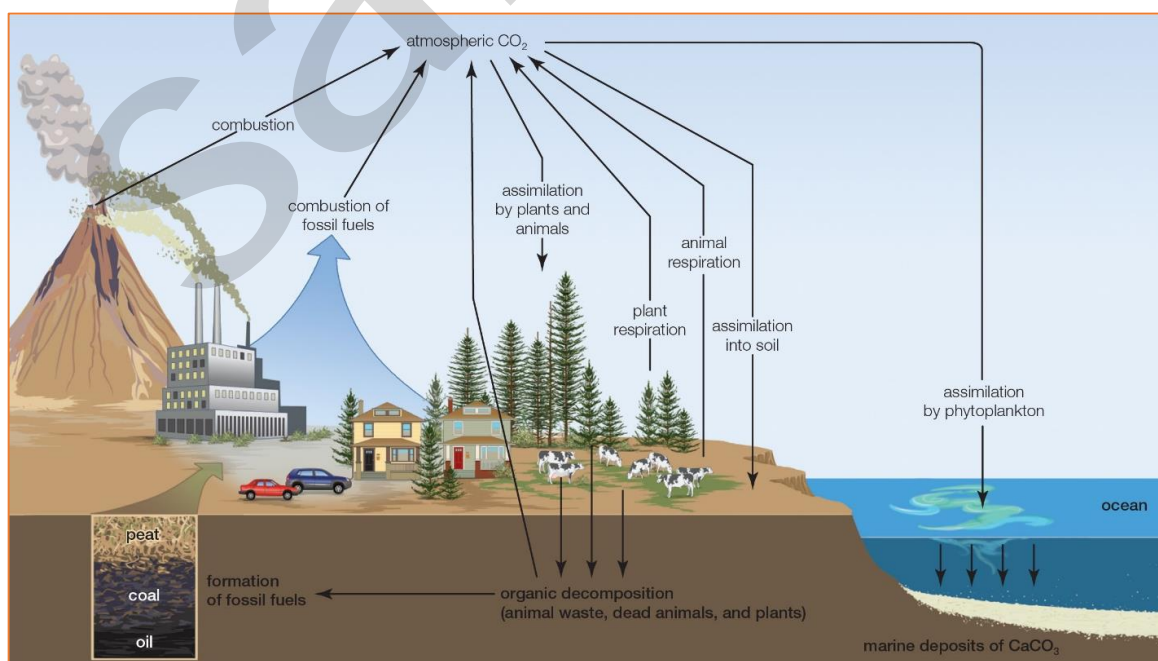


Figure 4.01: The carbon cycle.

Photovoltaic cells

Electricity may also be generated using **photovoltaic cells** which are also known as **solar cells**. Solar cells transform light energy into electrical energy through the **photovoltaic effect** which is a process in which a potential difference is produced when two dissimilar materials in close contact are struck by light. The potential difference produced by the photovoltaic effect is used to drive electric current (electricity). The basic structure and components of a photovoltaic cell are shown in Figure 4.13.

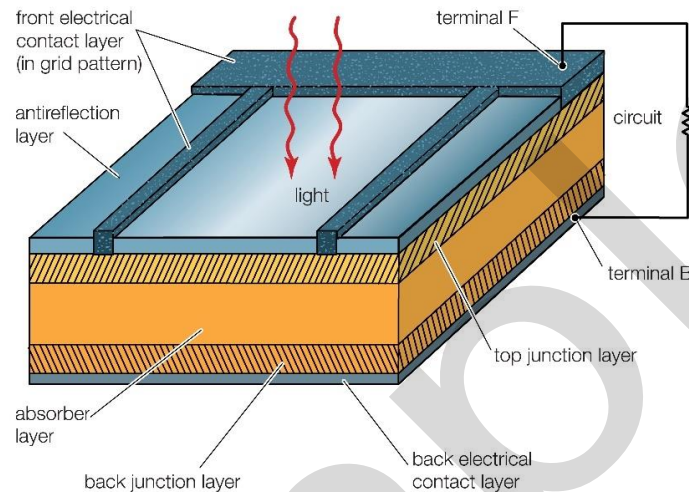


Figure 4.13: Structure and components of a photovoltaic cell.

Photovoltaic cells and arrays are capable of absorbing sunlight during the day and converting the energy into electricity that can be used to power electronic devices (called **loads**). In addition, any excess electricity may be stored in batteries or distributed back into the electrical power grid as depicted in Figure 4.14.

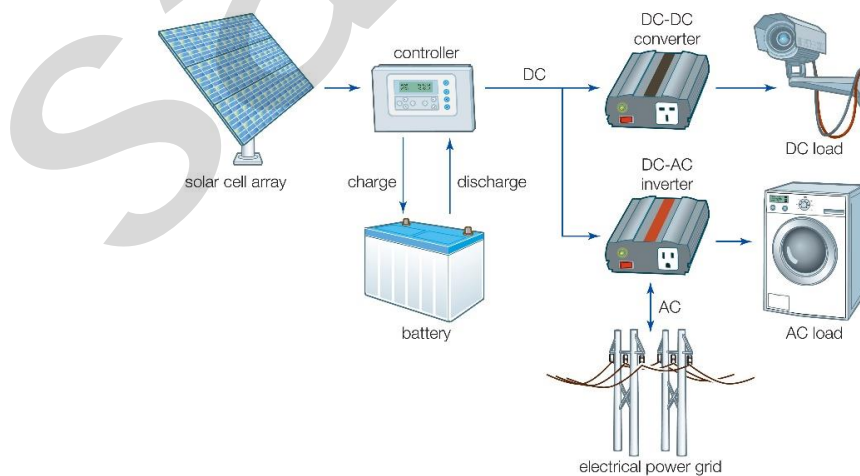


Figure 4.14: Conversion of light energy to electrical energy using a photovoltaic cell.

Photovoltaic cells produce no pollutants or greenhouse gases during operation. However, pollutants and greenhouse gases are generated in the manufacturing of photovoltaic cells.

Example 4.04

A **hydrogen fuel cell** generates an electric current using hydrogen gas as a fuel and oxygen from air as an oxidiser. The components of a simple hydrogen fuel cell are shown in Figure 4.16.

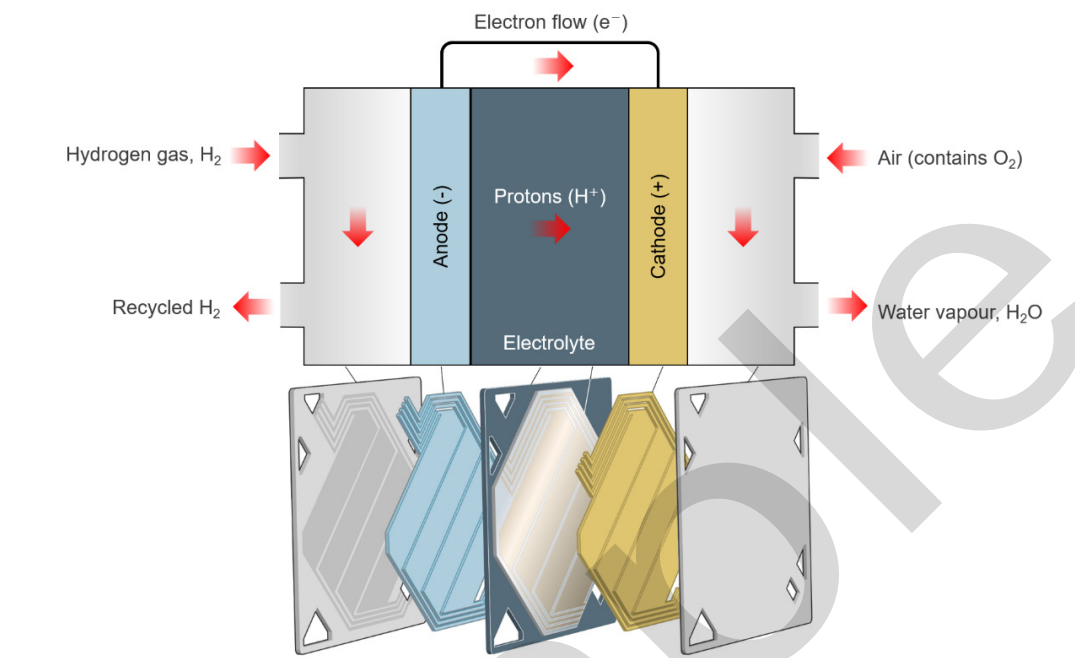


Figure 4.16: Components of a simple hydrogen fuel cell.

Hydrogen gas flows over the porous anode. The anode is impregnated with a precious metal such as platinum that catalyses the oxidation of hydrogen to protons (H^+) as shown in the oxidation half-equation below.



The electrons flow through the external circuit in the direction of the cathode, and the protons dissolve in the electrolyte and flow to the cathode. The protons and electrons combine with oxygen flowing over the surface of the cathode. The cathode contains a precious metal that catalyses the reduction of oxygen to water vapour as shown in the half-equation below.



The unreacted hydrogen flows out of the outlet at the anode and is recycled and the water vapour produced at the cathode flows out of the fuel cell. The overall cell reaction is determined by combining the half-equations occurring at the anode and cathode.



The energy released in the reaction is used to power electrical and mechanical devices and some is wasted as heat.

Example 4.05

A vanadium redox battery (VRB) is a rechargeable flow battery used to store and discharge electrical energy. The components of a vanadium redox battery are shown in Figure 4.18.

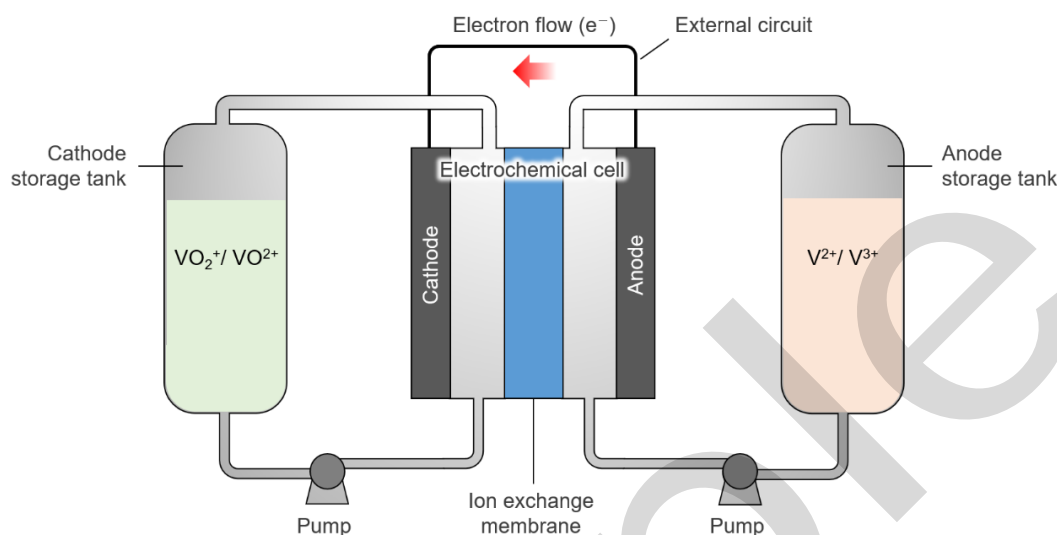


Figure 4.18: Components of a vanadium redox battery.

Discharging

An electrolyte solution containing V^{2+} is pumped from the anode storage tank to the electrochemical cell where it is oxidised to V^{3+} at the anode.



Electrons flow from anode to cathode through the external circuit and do work on any electronic devices connected to the cell. An electrolyte solution containing VO_2^{+} is pumped from the cathode storage tank to the electrochemical cell where it is reduced to VO^{2+} at the cathode.



Charging

The electrode potentials are reversed and the original reactants are regenerated by redox reactions described in the half-equations below.



Conventional water treatment

Conventional water treatment involves many stages that are carried out in a water treatment facility. The stages of water conventional water treatment are depicted in Figure 4.19 and a brief description of each stage is provided in the table below.

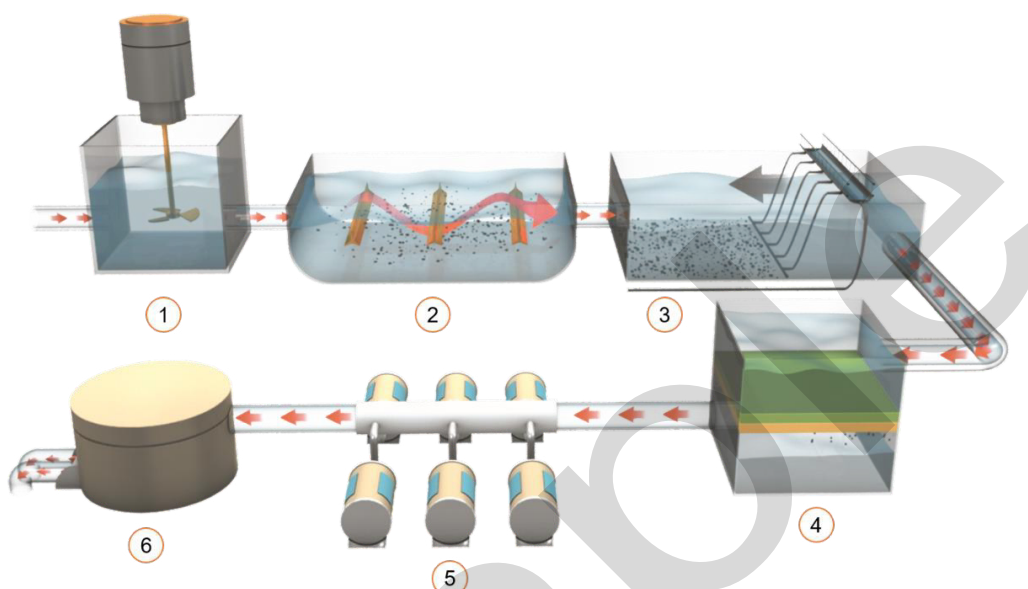


Figure 4.19: Stages of conventional water treatment.

Stage	Process	Description
1	Coagulation	A process used to neutralise charges on silicate particles forming larger particles.
2	Flocculation	The process of agitation that encourages the particles to flocculate into masses large enough to settle or be filtered.
3	Sedimentation	Sediments in water are left to settle for several hours before the water is transferred to a filtration tank.
4	Filtration	Water passes through several filters that remove impurities.
5	Disinfection	Water is treated with a disinfectant to kill microorganisms. The disinfectant may be a chemical agent or UV radiation.
6	Storage	Treated drinking water is stored in tanks to provide water during periods of increased domestic or rural consumption.

Coagulation and Flocculation

Untreated water contains dissolved and suspended particles from the erosion of land by wind and flowing water. The mixture of eroded particles includes silicate clay minerals, sand, and organic matter (humus). Silicate clay particles are negatively charged, and this property causes them to repel strongly, creating a suspension in water as shown in Figure 4.20.



Figure 4.20: Untreated water showing suspension of silicate clay minerals.

Suspended silicate clay minerals are removed from water through the processes of coagulation and flocculation. Chemical compounds called **coagulants** are added to neutralise the negative charges on silicate clay minerals in untreated water. Coagulants are soluble salts of highly charged cations and cationic polymers. Some common coagulants used in water treatment are identified below.

Coagulant	Formula
Aluminium sulfate	$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$
Iron(III) chloride	FeCl_3
PolyDADMAC	

Coagulants attract silicate clay minerals into an insoluble mass called **floc** that is removed by sedimentation and filtration. The effect of coagulation and flocculation are shown in Figure 4.21.



Figure 4.21: Effect of coagulation and flocculation on untreated water.

Reverse osmosis is a filtration technique whereby water is forced, under pressure, through a semi-permeable membrane.

Desalination is a process used to remove minerals from saline water to produce fresh potable water. Reverse osmosis and thermal distillation are two widely used methods for desalination.

- Explain how reverse osmosis produces potable water from saline water.
- Describe the disadvantages of using desalination for the production of potable water.

More than 700 million people currently suffer from a shortage of potable water. The global water shortage is predicted to increase as a result of climate change, the increase in global population and the increase in demand for agriculture. One method of increasing the quantity of potable water available for human consumption is **desalination**.

Desalination

97% of the water on Earth is stored in the oceans as **seawater**. Seawater contains a high concentration of dissolved salts and is described as **saline**. Saline water causes dehydration in animals and plants and is unsuitable for human consumption and cannot be used in agriculture. Saline water is made potable by removing dissolved salts through a process called **desalination**. The two widely used methods of desalination are **thermal distillation** and **reverse osmosis (RO)**.

Method	Description
Thermal distillation	Saline water is heated until it boils and turns to steam. The steam is condensed, and the pure water is recovered.
Reverse osmosis	Saline water is forced under pressure through a semi-permeable membrane that removes dissolved salts, impurities and microorganisms.

The processes of thermal distillation and reverse osmosis are depicted in Figure 4.24.

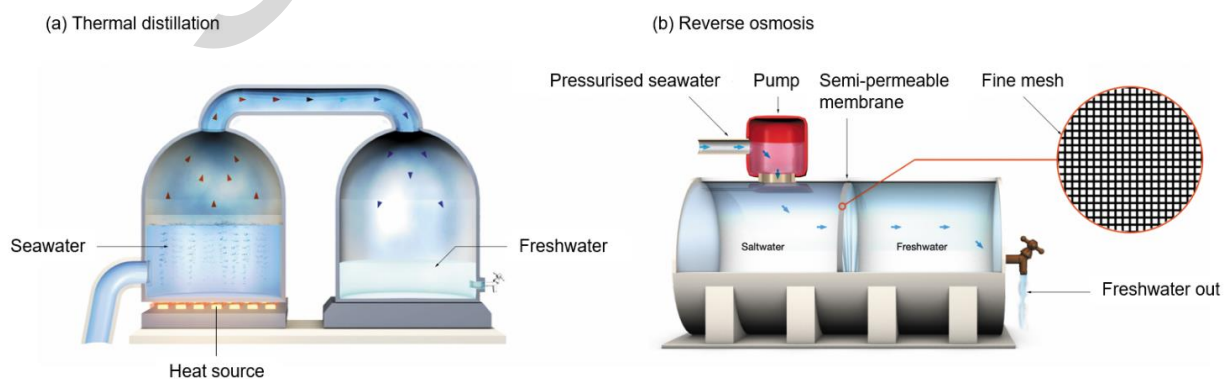


Figure 4.24: Thermal distillation (left) and reverse osmosis (right).

4.3: Soil

Plants require nutrients, which they obtain from the soil.

- Explain why plants need soil nutrients in soluble form.

Soil is a heterogeneous mixture of organic and inorganic materials in the uppermost layer of Earth's crust that acts as a reservoir for water and nutrients required for the growth of plants (Figure 4.25).

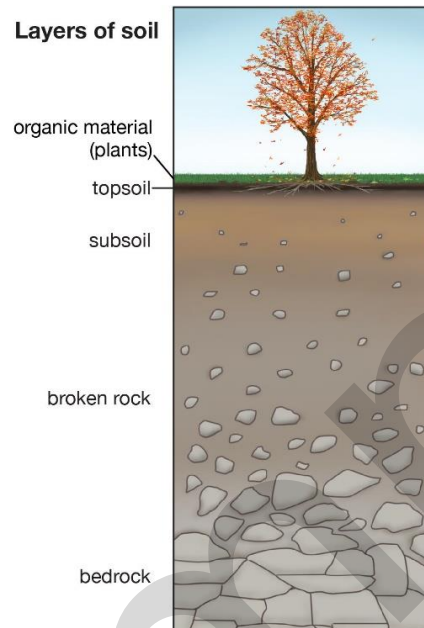


Figure 4.25: Layers of soil.

Plant nutrients

Plant nutrients are materials required for the maintenance of life processes in plants including metabolism, respiration, and growth. Plant nutrients are classified as **macronutrients** and **micronutrients** depending on the quantities required to maintain life processes. Macronutrients are required in relatively large quantities whereas micronutrients are required in smaller quantities.

Nutrient type	Examples
Macronutrients	Nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur.
Micronutrients	Iron, zinc, copper, chloride, manganese, boron, and molybdenum.

Plants obtain the majority of nutrients from the **soil solution** which is a solution of water-soluble inorganic ions including SO_4^{2-} , NO_3^- , NH_4^+ , HPO_4^{2-} , H_2PO_4^- , K^+ , Ca^{2+} , and Mg^{2+} that are contained within the topsoil. Nutrients are absorbed directly from the soil solution into plant roots by passive diffusion and active transport.

Cations adsorbed on the surface of soil silicates and aluminosilicates are in equilibrium, and can be exchanged with, the cations in soil water, which are available as sources of plant nutrients.

Soil silicates and aluminosilicates are able to adsorb H^+ and release cations.

- Explain how cations on the surface of soil silicates and aluminosilicates become available to plants.

Soil is composed of small particles formed by the weathering of rocks. Soil particles are classified as **sand**, **silt**, or **clay** depending on their composition and size.

Classification	Particle size (μm)	Composition
Sand	50–2000	Quartz, SiO_2
Silt	2–50	Silicates
Clay	<2	Aluminosilicates

Soil particles are surrounded by the soil solution which is a thin film of water containing dissolved nutrients that diffuse into the root cells of plants (Figure 4.29).

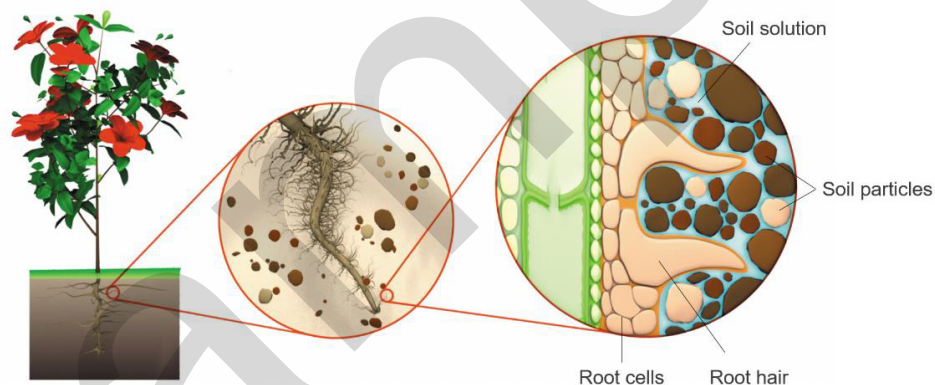


Figure 4.29: Plant-soil interaction

Mineral cations required for plant growth such as K^+ and Ca^{2+} are adsorbed to the surface of negatively-charged clay particles in soils as shown in Figure 4.30.

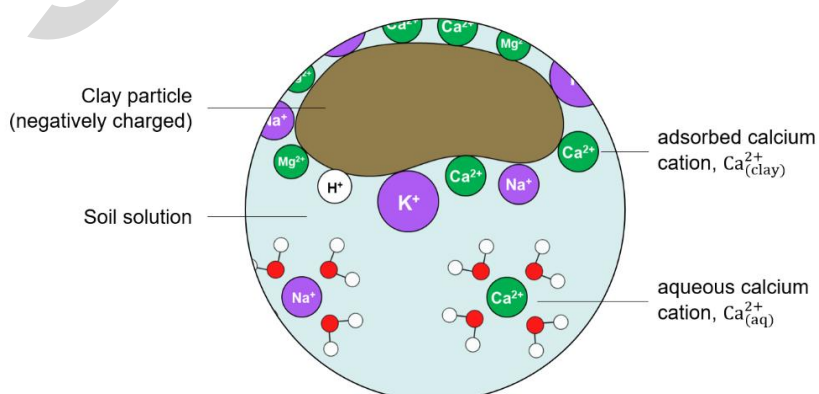


Figure 4.30: Cations adsorbed to clay particles in soils.

Stage 4: Electrolysis

The melting point of alumina is 2070°C making the material unsuitable as an electrolyte for electrolysis as the expense associated with generating and maintaining high temperatures would exceed the revenue earned from the sale of the aluminium metal.

A solvent called **cryolite** (Na_3AlF_6) is used to dissolve alumina forming a solution containing aluminium (Al^{3+}) and oxide (O^{2-}) ions. Calcium fluoride (CaF_2) is added to lower the melting point of the solution to approximately 930°C which reduces the energy costs associated with maintaining the molten state of the electrolyte. Figure 4.46 shows the electrolytic cell used to obtain aluminium from molten aluminium oxide.

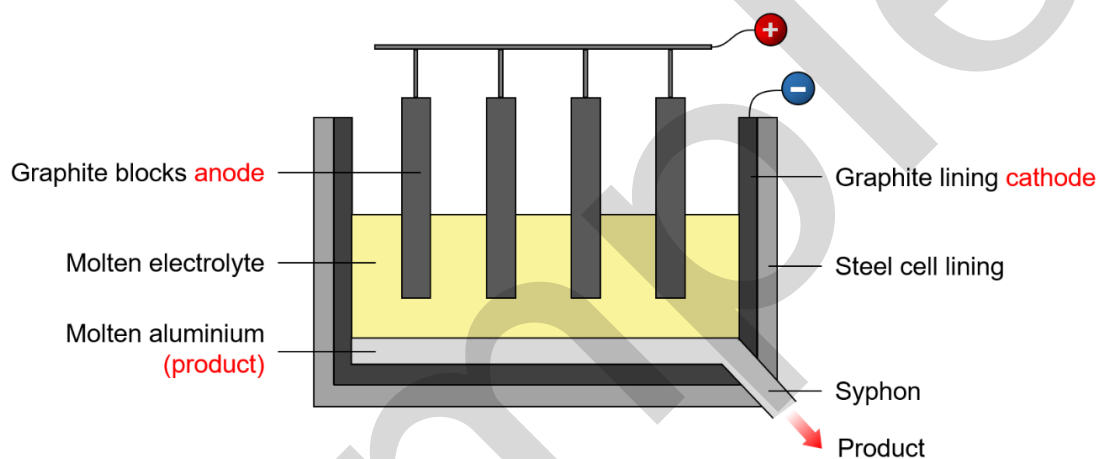


Figure 4.46: Electrolysis of molten alumina.

A very large electric current (150,000 to 350,000 amperes) is used to reduce aluminium ions in the electrolyte to aluminium atoms at the cathode.



The aluminium is in a molten state as it forms in the cell (as the melting point of aluminium is less than the temperature of the electrolyte). Oxide ions are oxidised at the anode forming oxygen gas.



The anode electrodes are made from graphite which is composed of carbon atoms. The oxygen gas produced at the anode electrodes reacts with carbon in graphite forming carbon dioxide.



Consequently, the graphite anodes are replaced as they are consumed.

Composite materials comprise two or more constituent materials to produce a material with properties different from the individual components.

- Explain the advantages using of composite materials.
- Explain the difficulties associated with recycling materials and objects comprising two or more different materials with different properties.

A **composite material** is prepared by physically combining two or more materials with different properties into a material with properties that are different to the individual components.

Structure of composites

Most composites are a combination of two materials: **matrix** and **reinforcement**.

- The matrix is the central material that gives bulk to the composite. The matrix may be a metal, ceramic or polymer.
- The reinforcement is the material embedded in the matrix. The reinforcement material is composed of particles or fibres that are dispersed throughout the matrix (Figure 4.47).

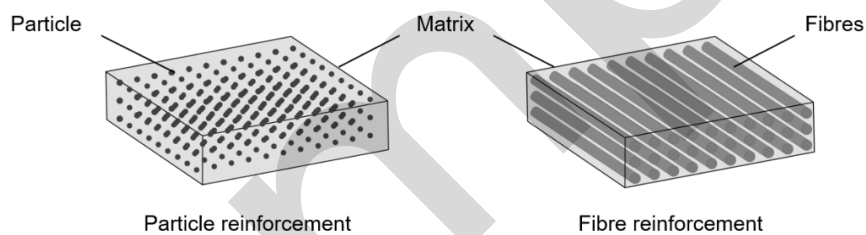


Figure 4.47: Composite materials with different reinforcements.

Example 4.22

Glassfibre reinforced polymer (fibreglass) is a composite material used in the manufacture of building panels, water tanks, surfboards, canoes and car bodies. Fibreglass is composed of thin glass fibres distributed throughout a thermoset polymer matrix (Figure 4.48). Fibreglass is stronger and less brittle than glass and can be moulded into any shape before being set.

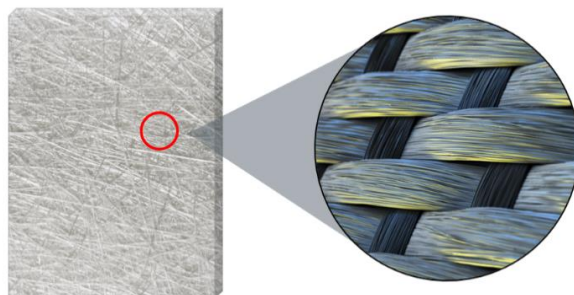


Figure 4.48: Structure of fibreglass showing thin glass fibres (right).

Example 4.23

Carbon fibres are thin fibres composed of carbon atoms that are derived from synthetic polymers including polyacrylonitrile and rayon. Carbon fibre reinforced polymer (CFRP) is an extremely strong and light-weight composite composed of thin carbon fibres embedded within a thermoset polymer matrix as shown in Figure 4.49.

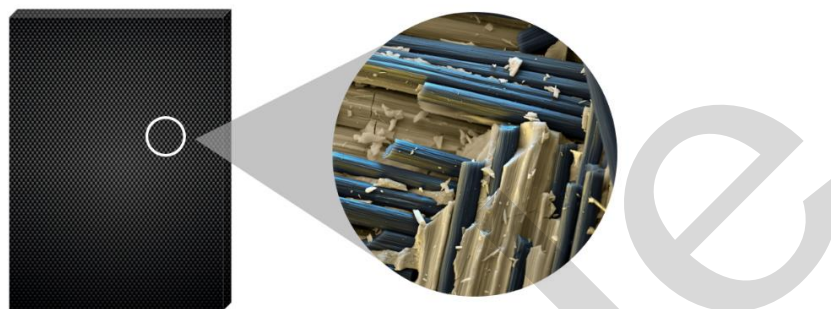


Figure 4.49: Structure of CFRP showing carbon fibres (dark) in thermoset polymer (yellow).

CFRP has a very high strength-to-weight ratio and is extremely rigid which has seen it replace steel and aluminium in the construction of racing cars, sporting goods, and aeroplanes.

Advantages of composites

Some advantages of composite materials are identified below.

Advantage	Explanation
Improved properties	Composite materials have improved properties that are not present in the individual (separate) components.
Made for use	The composite can be designed for a particular use by altering the properties of the materials used in the matrix and reinforcement.
Design flexibility	Most composites can be moulded into a particular shape before being thermoset which increases the range of applications.

Recycling composites

Most composites are not easily recycled because they contain a thermoset polymer matrix that cannot be melted down and reshaped. The two current methods of recycling composites are **mechanical grinding** and **pyrolysis**. Mechanical grinding involves physically grinding the composite material into smaller particles that are used as filler. Pyrolysis involves heating the composite in oxygen to combust the thermoset polymer matrix and retain the reinforcement fibres.



Sample

**SOLUTIONS TO
CHAPTER QUESTIONS
AND REVIEW TESTS**



22	(a)	$n_{\text{PbS}} = \frac{m_{\text{PbS}}}{M}$ $n_{\text{PbS}} = \frac{50\,000}{(207.2 + 32.06)}$ $n_{\text{PbS}} = 209 \text{ mol (208.98)}$	1
		$2n_{\text{PbO}} : 2n_{\text{PbS}}$ $n_{\text{PbO}} = n_{\text{PbS}}$ $n_{\text{PbO}} = 209 \text{ mol (208.98)}$	1
		$n_{\text{O}_2} = \frac{m_{\text{O}_2}}{M}$ $n_{\text{O}_2} = \frac{15\,000}{(16.00 \times 2)}$ $n_{\text{O}_2} = 469 \text{ mol (468.75)}$	1
		$2n_{\text{PbO}} : 3n_{\text{O}_2}$ $n_{\text{PbO}} = \frac{n_{\text{O}_2}}{3} \times 2$ $n_{\text{PbO}} = \frac{468.75}{3} \times 2$ $n_{\text{PbO}} = 313 \text{ mol (312.5)}$	1
		$n_{\text{PbS}} \text{ is the limiting reagent as it produces fewer moles of PbO.}$	
		$m_{\text{PbO}} = n_{\text{PbO}} \times M$ $m_{\text{PbO}} = 208.98 \times (207.9 + 16.00)$ $m_{\text{PbO}} = 47 \times 10^3 \text{ g (46 790)}$	1
		$m_{\text{PbO}} = 47 \times 10^3 \text{ g (46 790)}$	1
	(b)	Method A:	
		$n_{\text{PbO}} = \frac{m_{\text{PbO}}}{M}$ $n_{\text{PbO}} = \frac{45\,000}{(207.9 + 16.00)}$ $n_{\text{PbO}} = 201 \text{ mol (200.98)}$	1
		$1n_{\text{Pb}} : 1n_{\text{PbO}}$ $n_{\text{Pb}} = 201 \text{ mol (200.98)}$	1
		$m_{\text{Pb}} = n_{\text{Pb}} \times M$ $m_{\text{Pb}} = 200.98 \times 207.9$ $m_{\text{Pb}} = 42 \times 10^3 \text{ g (41784)}$	1
		Method B:	
		$3n_{\text{Pb}} : 2n_{\text{PbO}}$ $n_{\text{Pb}} = \frac{200.98}{2} \times 3$ $n_{\text{Pb}} = 302 \text{ mol (301.47)}$	1
		$m_{\text{Pb}} = n_{\text{Pb}} \times M$ $m_{\text{Pb}} = 301.47 \times 207.9$ $m_{\text{Pb}} = 6.3 \times 10^4 \text{ g (62676)}$	1

31	(a)		2
	(b)	<p>Histidine is the most polar amino acid on the chromatogram.</p> <p>Histidine moved the shortest distance from the origin/has lowest R_f.</p> <p>Histidine was least soluble/dissolved least in the non-polar mobile phase; OR: was most strongly adsorbed to the stationary phase.</p>	1 1 1
	(c)	<p>Either:</p> <p>Isoleucine and leucine or;</p> <p>Phenylalanine and tryptophan</p> <p>Have similar R_f values/moved similar distances from the origin.</p>	1 1
	(d)	<p>Turn the chromatogram 90°;</p> <p>Draw a new origin line in pencil and place the chromatogram in a different solvent (mobile phase);</p> <p>Allow the amino acids to separate and remeasure the R_f values.</p>	1 1 1
	(e)	<p>The same amino acids are present in both chromatograms.</p> <p>The chromatograms are evidence that diet does not affect the type of amino acids present in human perspiration.</p>	1 1
	32	(a)	As the sample contains salicylic acid (impurity) as well as aspirin.
(b)		$R_f(B) = \frac{B}{\text{solvent front}} = \frac{1.4 \text{ cm}}{3.6 \text{ cm}}$ $R_f(B) = 0.39$ $R_f(C) = \frac{C}{\text{solvent front}} = \frac{2.4 \text{ cm}}{3.6 \text{ cm}}$ $R_f(C) = 0.67$ $\Delta R_f = R_f(C) - R_f(B)$ $\Delta R_f = 0.67 - 0.39$ $\Delta R_f = 0.28$	1 1 1
(c)		<p>Non-polar solvent;</p> <p>Aspirin has the greater R_f/moved the greatest distance from the origin.</p> <p>Aspirin is the most non-polar material in the sample and dissolved more/had a greater affinity for/is more soluble in the non-polar solvent (mobile phase);</p>	1 1 1
(d)		<p>Components of a mixture have different polarities.</p> <p>Separation occurs because the components of a mixture have varying affinities for the stationary and mobile phases.</p>	1 1
(e)			1