

Chemistry Summary

Smith's Hill High School

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Revision 1.2

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Introduction

This summary contains answers to all the “Students learn to” syllabus points and some of the “Students” syllabus points. Not all of the “Students” syllabus points were answered since they are best learnt by actually doing the experiment or working on questions as intended by the board. A large part of your study will involve memorising and understanding the contents of this summary. However, an equally important part is to do questions. Since, only when you have applied the knowledge you have learnt will you be able to satisfy the requirement of the course. I hope this summary helps your studies and please feel free to distribute it within the school.

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9.2 Production of Materials

Contextual Outline

Humans have always exploited their natural environment for all their needs including food, clothing and shelter. As the cultural development of humans continued, they looked for a greater variety of materials to cater for their needs.

The twentieth century saw an explosion in both the use of traditional materials and in the research for development of a wider range of materials to satisfy technological developments. Added to this was a reduction in availability of the traditional resources to supply the increasing world population.

Chemists and chemical engineers continue to play a pivotal role in the search for new sources of traditional materials such as those from the petrochemical industry. As the fossil organic reserves dwindle, new sources of the organic chemicals presently used have to be found. In addition, chemists are continually searching for compounds to be used in the design and production of new materials to replace those that have been deemed no longer satisfactory for needs.

This module increases students' understanding of the implications of chemistry for society and the environment and the current issues, research and developments in chemistry.

1. Fossil fuels provide both energy and raw materials such as ethylene, for the production of other substances

Students learn to:

- **Identify the industrial source of ethylene from the cracking of some of the fractions from the refining of petroleum**
- Due to the need for smaller hydrocarbons the larger ones can be cracked down into smaller ones using special catalysts
- The catalyst used is called a *zeolite*
- If it is not decomposed entirely the Hydrocarbons are further decomposed by steam cracking
 - A mixture of alkanes with steam is passed through very hot metal tubes.

- **Identify that ethylene, because of the high reactivity of its double bond, is readily transformed into many useful products**
- The double bond is where the reaction would occur
- Other atoms can be easily added when the double bond is broken

- **Identify that ethylene serves as a monomer from which polymers are made**
- The double bond breaks so that it can join to other ethylene.

- **Identify polyethylene as an addition polymer and explain the meaning of this term**
- The double bond opens up to form two single bonds that can bond with other things, this is called an addition reaction
- If these connect to other similar molecules (monomers), it is an addition polymer

- **Outline the steps in the production of polyethylene as an example of a commercially and industrially important polymer**
- **Polymerisation** is a chemical reaction in which many identical small molecules combine to form one large molecule.
- **Type 1**
 - high pressure (1000-3000Atmos) and high temperature(300°C) and an initiator (organic peroxide, compound containing –O–O– group, some times oxygen is used)
 - results in significant chain branching
 - results in loosely packed material
- **Type 2**
 - Newer method
 - A few atmospheres and temperatures of about 60°C with catalyst of titanium (III) chloride and a trialkylaluminium compound
 - called **Ziegler-Natta process**
 - Forms unbranched molecules which pack together tightly, therefore has higher density

- **Identify the following as commercially significant monomers:**
 - vinyl chloride
 - styrene
- **By both their systematic and common names**
- Polyvinyl chloride or PVC or polychloroethene
 - used for insulation and drain pipes
 - water resistant and doesn't conduct
- Polystyrene or polyethenylbenzene
 - used for tool handles and foam cups
 - hard because benzene ring restricts branching
 - gas can be blown in to make it soft for cups and packaging
- **describe the uses of the polymers made from the above monomers in terms of their properties**
- *see above*

Students:

- **Gather and present information from first-hand or secondary sources to write equations to represent all chemical reactions encountered in the HSC course**
- **Identify data, plan and perform a first-hand investigation to compare the reactivity of appropriate alkenes with the corresponding alkanes in bromine water**
- Due to the high reactivity of the double bond alkenes react fast with bromine water under UV light
- alkanes react *very* slowly under UV light
- Equations for reaction with bromine water
 - $Br_2 + H_2O \rightleftharpoons HOBr + Br^- + H^+$
 - $CH_3 - CH_2 - CH = CH - CH_2 - CH_3 + HOBr \rightarrow CH_3 - CH_2 - \underset{\substack{| \\ OH}}{CH} - \underset{\substack{| \\ Br}}{CH} - CH_2 - CH_3$
- **Analyse information from secondary sources such as computer animations, molecular model kits or multimedia resources to model the polymerisation process**

2. Some scientists research the extraction of materials from biomass to reduce our dependence on fossil fuels

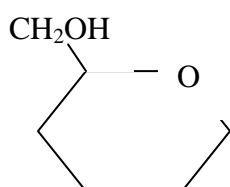
Students learn to:

- **discuss the need for alternative sources of the compounds presently obtained from the petrochemical industry**
- Since the petrochemical industry relies on crude oil for its raw component
- Crude oil will run out in about 40 years
- Scientists argue that we should start using alternative sources such as obtaining ethanol from fermentation.
- Others argue that as oil supplies diminish then costs will rise and it will eventually become too expensive to use. Then, naturally, people will stop using oils and alternative fuels will become more cost effective.
- Others say that remaining crude oil will be exclusively used for the petrochemical industry; cars will use solar power etc.

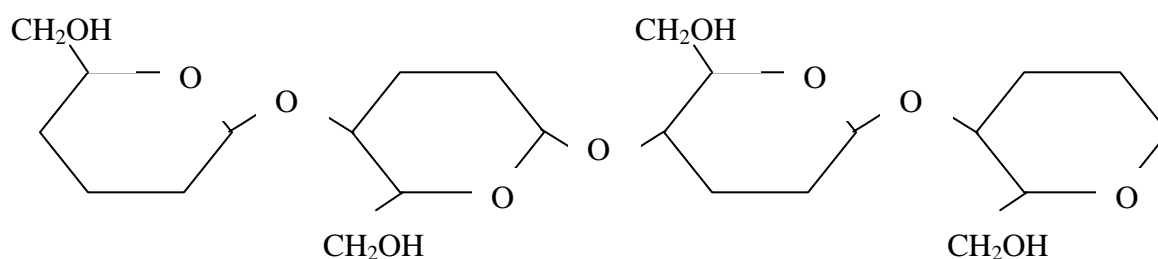
- **explain what is meant by a condensation polymer**
- Condensation polymers are polymers that form by the elimination of a small molecule (often water) when pairs of monomers molecules join together

- **describe the reaction involved when a condensation polymer is formed**
- Glucose has the formula $C_6H_{12}O_6$, it can be written as $HO-C_6H_{10}O_4-OH$
- When glucose joins together to form cellulose $HO-C_6H_{10}O_4-O\boxed{H\ HO}-C_6H_{10}O_4-OH$
- a water is lost and two free bonds are formed to join the monomers together

- **describe the structure of cellulose and identify it as an example of a condensation polymer found as a major component of biomass**
- See above to see why it is a condensation polymer
- Structure of Glucose (Schematic)



- Structure of Cellulose (Schematic)



- **identify that cellulose contains the basic carbon-chain structures needed to build petrochemicals and discuss its potential as a raw material**
- Cellulose has 4 carbons joined in a chain so it would be regarded as the basic structure for making molecules for petrochemicals
- Cellulose has been used as the raw material for many biopolymers such as cellophane
- Biopolymers are biodegradable unlike traditional petrochemical polymers

Students:

- **Use available evidence to gather and present data from secondary sources and analyse progress in the recent development and use of a named biopolymer. This analysis should name the specific enzyme(s) used or organism used to synthesise the material and an evaluation of the use or potential use of the polymer produced related to its properties**
- Biopolymers are polymers that are made totally or in large part by living organisms
- Biopolymers are biodegradable and renewable
- Definitions
 - Biodegradable
 1. Capable of being decomposed by e.g. bacteria
 - Renewable
 1. Broken down into compounds that are used to make the product
 2. for example, ethanol is combusted into CO₂ and H₂O, these are used by plants to make starch the basis of ethanol
- Biopolymer PHB (β -hydroxybutanoate)
 - Made by micro-organisms *Alcaligenes eutrophus* or Genetically Modified E-Coli
 - Similar properties/uses of polypropylene
 - fed nutrients then a particular until they multiply in size
 - then one is removed (eg Nitrogen)
 - They start to produce biopolymers until 30-80% of dry weight
 - Polymer is dissolved and filtered out
 - Advantage is that is biodegradable
- Cellulose / Starch
 - Made by plants as the cell wall to their cells
 - Used in industry to make paper and as cotton
 - Paper is discarded regularly so it must be biodegradable
 - Used to make adhesives, cosmetics and textiles
 - expensive to make compared to petrochemical polymers
 - water sensitivity is also a problem
 - lack of understanding of how natural polymers react with other chemicals

3. Other resources, such as ethanol, are readily available from renewable resources such as plants

Students learn to:

- **describe the dehydration of ethanol to ethylene and identify the need for a catalyst in this process and the catalyst used**
- Using a concentrated Sulphuric acid catalyst ethanol can be turned into ethylene and water with some heat

- **describe the addition of water to ethylene resulting in the production of ethanol and identify the need for a catalyst in this process and the catalyst used**
- Using a dilute Sulphuric acid catalyst ethylene and water can be hydrated to ethanol with a little heat.

- **describe and account for the many uses of ethanol as a solvent for polar and non-polar substances**
- The C-O and H-O bonds in ethanol make it a polar molecule
- It is also able to form hydrogen bonds, this allows it to dissolve substances such as glucose and sucrose
- Also has carbon chain so it can dissolve carbon chemicals such as hexane

- **outline the use of ethanol as a fuel and explain why it can be called a renewable resource**
- Ethanol is a hydrocarbon so it can combust to form H₂O and CO₂
- It can be created from biomass using a process called fermentation
- It is renewable since plants (biomass) use H₂O and CO₂ to grow

- **describe conditions under which fermentation of sugars is promoted**
- Yeast is added
- Use simple sugars or starch
- Concentration of alcohol is less than 15%
- Kept at blood temperature (37°C)
- Air is excluded

- **summarise the chemistry of the fermentation process**
- Under suitable conditions (described above) fermentation of sugars is carried out.
- $C_6H_{12}O_6(aq) \xrightarrow{\text{Yeast}} 2CH_3 - CH_2 - OH(aq) + 2CO_2(g)$
- Once the concentration of alcohol reaches 15% the solution must undergo fractional distillation to continue fermentation (since the alcohol kills the yeast)
- Under typical industrial conditions concentrations of about 95% can be reached from repeated fractional distillation

- **define the molar heat of combustion of a compound and calculate the value for ethanol from first-hand data**
- Molar heat of combustion is the energy released from 1 mole of substance combusting completely
- same as minus the enthalpy change (ΔH)

assess the potential of ethanol as an alternative fuel and discuss the advantages and disadvantages of its use

- advantages
 - renewable resource
 - since it is water soluble it can be put out with water (risk analysis)
- disadvantage
 - fertiliser run-off from growing plants
 - waste material from fermentation is smelly and difficult to dispose of
- **identify the IUPAC nomenclature for straight-chained alkanols from C1 to C8**
 - Same as alkenes but replace –ene with –anol.

Students:

- **process information from secondary sources such as molecular model kits, digital technologies or computer simulations to model:**
 - the addition of water to ethylene
 - the dehydration of ethanol
- **process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane**
- In order to process the cellulose it must be broken down into simple sugars with acid then neutralised with a base

- **process information from secondary sources to summarise the use of ethanol as an alternative car fuel, evaluating the success of current usage**
- It is currently uneconomical to ferment ethanol specifically for use car fuel due to the high cost of distillation.
- Water dissolves easily in ethanol which proves a transport problem
- If used in unmodified engines may cause problems since dissolved water may rust fuel lines
- Currently ethanol is mixed into petrol and used in standard engines without modification
- Levels up to 10% provides no problems
- This is done to reduce use of fossil fuels

- **solve problems, plan and perform a first-hand investigation to carry out the fermentation of glucose and monitor mass changes**
- **present information from secondary sources by writing a balanced equation for the fermentation of glucose to ethanol**
- **identify data sources, choose resources and perform a first-hand investigation to determine and compare heats of combustion of at least three liquid alkanols per gram and per mole**
- Use calorimeter

4. Oxidation-reduction reactions are increasingly important as a source of energy

Students learn to:

- **explain the displacement of metals from solution in terms of transfer of electrons**
- A *displacement reaction* is a reaction in which a metal converts the ion of another metal to the neutral atom
- For example, when copper displaces silver from solution
 - $Cu(s) + 2Ag^+(aq) \rightarrow 2Ag(s) + Cu^{2+}(aq)$
 - Copper gives 2 silver atoms an electron each to displace them from solution
- **identify the relationship between displacement of metal ions in solution by other metals to the relative activity of metals**
- The more active metals will displace the less active metals from solution
- **account for changes in the oxidation state of species in terms of their loss or gain of electrons**
- For positive monatomic ions the oxidation state is the charge on the ion
- This changes, as there is a loss or gain of electrons. For example
 - $Fe^{2+} \rightarrow Fe^{3+} + e^-$ iron's oxidation state goes from 2 to 3
 - $Sn^{4+} + 2e^- \rightarrow Sn^{2+}$ tin goes from 4 to 2
- To calculate oxidation state remember
 - Oxygen is always -2
 - Hydrogen is always +1
- For example,
 - Fe_2O_3 would indicate Fe has oxidation state of +3
 - H_2SO_4 would indicate S has oxidation state of +6
- **describe and explain galvanic cells in terms of oxidation/reduction reactions**
- Redox reactions involve the transfer of electrons from one reactant to another
- Galvanic cells make use of this transfer of electrons by placing the reactions at different locations and allowing the electrons to pass through a wire
- For the copper-silver cell the reactions go like this
 - $Cu \rightarrow Cu^{2+} + 2e^-$ (Oxidation)
 - $Ag^+ + e^- \rightarrow Ag$ (Reduction)
 - $Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$ (Redox)
- The electron released by the copper does work in the circuit before being given to the silver
- **outline the construction of galvanic cells and trace the direction of electron flow**
- 2 electrodes (zinc, copper)
- 2 electrolytes (zinc nitrate, copper nitrate)
- salt bridge (potassium nitrate)
- In galvanic cell electrons go from oxidation to reduction (anode to cathode)
- Zinc is anode since it more readily oxidises

- **define the terms anode, cathode, electrode and electrolyte to describe galvanic cells**
- Anode: The conductor where oxidation occurs
- Cathode: The conductor where reduction occurs
- Electrode: A conductor where reduction or oxidation occurs (either anode or cathode)
- Electrolyte: The medium where ions flow and is in contact with the Electrodes

Students:

- **perform a first-hand investigation to identify the conditions under which a galvanic cell is produced**
- **perform a first-hand investigation and gather first-hand information to measure the difference in potential of different combinations of metals in an electrolyte solution**
- **gather and present information on the structure and chemistry of a dry cell or lead-acid cell and evaluate it in comparison to one of the following:**
 - **button cell**
 - **fuel cell**
 - **vanadium redox cell**
 - **lithium cell**
 - **liquid junction photovoltaic device (eg the Gratzel cell)**
- **in terms of:**
 - **chemistry**
 - **cost and practicality**
 - **impact on society**
 - **environmental impact**
- **Lead-acid cells** are used in motor car batteries
- Cell diagram
 - $Pb, PbSO_4 | H_2SO_4(aq) | PbO_2, Pb$
- Electrode reactions
 - $$Pb + SO_4^{2-} \rightarrow PbSO_4(s) + 2e^-$$
 - $$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4(s) + 2H_2O$$
- The structure consists of a series of parallel lead plates where there is an alternating coating of lead oxide
- Each cell creates about 2V
- To charge the cell a voltage somewhat greater than 2V is applied so that the reactions reverse
- Advantages
 - can be recharged
 - work in a wide range of temperatures
- Disadvantages
 - bulky and heavy
 - contains relatively strong acid

- **Lithium Cell** is used in mobile phones, pace makers and laptop computers
- Cell diagram
 - $Li, Li^+ | LiI | I_2, I^-$
- Electrode Reactions
 - $Li \rightarrow Li^+ + e^-$
 - $I_2 + 2e^- \rightarrow 2I^-$
- Uses a carbon cathode
- Has solid electrolyte
- Advantages
 - long lasting
 - rechargeable
 - high voltage
 - high power to weight ratio
- Disadvantages
 - high cost
 - needs to be sealed tightly
- **solve problems and analyse information to calculate the potential E° requirement of named electrochemical processes using tables of standard potentials and half-equations**

5. Nuclear chemistry provides a range of materials

Students learn to:

- **distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable**
- radioactive isotopes emit radiation which can be detected
- and isotope is unstable
 - if its atomic number is greater than 83
 - if its ratio of neutrons to protons places it outside the zone of stability

- **describe how transuranic elements are produced**
- some formed by bombarding elements with neutrons in reactor core
 - ${}_{92}^{238}\text{U} + {}_0^1\text{n} \rightarrow {}_{92}^{239}\text{U} \rightarrow {}_{-1}^0\text{e} + {}_{93}^{239}\text{Np}$
unstable
 - neptunium rapidly decays to plutonium, which is more stable
 - ${}_{93}^{239}\text{Np} \rightarrow {}_{-1}^0\text{e} + {}_{94}^{239}\text{Pu}$
- others formed by hitting it with larger positive particles in particle accelerator
 - 106 and above were made this way

- **describe how commercial radioisotopes are produced**
- Molybdenum-99 is formed by putting special UO₂ pellets in a reactor core
- it then undergoes fission to Molybdenum-99
- Molybdenum-99 is then packaged into small glass tubes where it produces ^{99m}Tc continuously.
- It is put in a big shielded container for transport
- In hospitals ^{99m}Tc is extracted by passing saline solution through the ⁹⁹Mo
- ^{99m}Tc is used for diagnosis in hospitals

- **identify instruments and processes that can be used to detect radiation**
- Photographic film
 - the radiation exposes the film like light
- Cloud chamber
 - an instrument that contains super saturated water vapour
 - different types of radiation produce different tracks along it depending on their ionisation power
- Gieger-Müller counter
 - the radiation ionises the argon molecules in a tube
 - the argon atoms that have been ionised move towards the positive outer shell which registers a click on a counter
- Scintillation counter
 - some substances emit a flash of light when irradiated with radiation
 - this device measures these flashes and records on a counter

- **identify one use of a named radioisotope:**
 - **in industry**
 - Gamma radiation is effective in destroying biological molecules such as DNA. Thus, it can be used to destroy bacteria
 - this can sterilise equipment and extend shelf life of food
 - arguments that this could destroy vitamins and nutrients in food and lead to lax in hygiene standards
 - Cobalt-60 is used since it has a relatively long half life (5-6 years) and not intense enough to make food radioactive
 - **in medicine**
 - technetium-99m is used in diagnosis since it only releases gamma radiation so it does not physically damage tissue much
 - it is injected into the blood stream so that clots and other circulation disorders can be found
 - it can also detect brain tumours
 - it has short half life (6hours) so there is minimum damage to the patient
- **describe the way in which the above named industrial and medical radioisotopes are used and explain their use in terms of their chemical properties**
- *see above*

Students:

- **process information from secondary sources to describe recent discoveries of elements**
- **use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine**
- can be used to track the progress of chemical reactions
- Tritium can be used to track reactions (3_1H)

9.3 The Acidic Environment

Contextual Outline

Acidic and basic environments exist everywhere. The human body has a slightly acidic skin surface to assist in disease control and digestion occurs in both acidic and basic environments to assist the breakdown of the biopolymers constituting food. Indeed, microorganisms found in the digestive system are well adapted to acidic or basic environments.

Many industries use acidic and basic compounds for a wide range of purposes and these compounds are found in daily use within the home. Because of this, an awareness of the properties of acids and bases is important for safe handling of materials. Currently, concerns exist about the increased release of acidic and basic substances into the environment and the impact of these substances on the environment and the organisms within those environments.

This module increases students' understanding of the history, nature and practice of chemistry, the applications and uses of chemistry and implications of chemistry for society and the environment.

1. Indicators were identified with the observation that the colour of some flowers depends on soil composition

Students learn to:

- **classify common substances as acidic, basic or neutral**
- acidic
 - sour taste
 - sting skin
 - blue litmus red
 - $\text{PH} < 7$
- basic
 - soapy feel
 - bitter taste
 - red litmus blue
 - $\text{PH} > 7$
- Neutral
 - neither

- **identify that indicators such as litmus, phenolphthalein, methyl orange and bromothymol blue can be used to determine the acidic or basic nature of a material over a range, and that the range is identified by change in indicator colour**

INDICATOR	COLOUR CHANGE				
	HIGHLY ACIDIC	SLIGHTLY ACIDIC	NEUTRAL	SLIGHTLY ALKALINE	HIGHLY ALKALINE
methyl orange	red	→ yellow	yellow	yellow	yellow
bromothymol blue	yellow	yellow	→ blue	blue	blue
litmus	red	red	→ blue	blue	blue
phenolphthalein	colourless	colourless	colourless	colourless	→ red

- **identify and describe some everyday uses of indicators including the testing of soil acidity/basicity**
- some plants need acidic soil – azaleas and camellias
- some need alkaline soil – most annual flowers and vegetables

Students:

- **perform a first-hand investigation to prepare and test a natural indicator**
- crush up red cabbage with mortar and pestle
- extract dye with methanol
- goes from acid to base in the following colours
- red – purple – green – yellow

- **identify data and choose resources to gather information about the colour changes of a range of indicators**
- *see above*

- **solve problems by applying information about the colour changes of indicators to classify some household substances as acidic, neutral or basic**

2. While we usually think of the air around us as neutral, the atmosphere naturally contains acidic oxides of carbon, nitrogen and sulfur. The concentrations of these acidic oxides have been increasing since the Industrial Revolution

Students learn to:

- **identify oxides of non-metals which act as acids and describe the conditions under which they act as acids**
- An acidic oxide is one which either:
 - reacts with water to form an acid or
 - reacts with bases to form salts (or does both)
- CO_2 NO_2 P_2O_3 P_2O_5 SO_2 SO_3 Cl_2O

- **analyse the position of these non-metals in the Periodic Table and outline the relationship between position of elements in the Periodic Table and acidity/basicity of oxides**
- Non-metals are generally acidic
- Metals are generally basic
- ones in the middle are amphoteric

- **define Le Chatelier's principle**
- If a system at equilibrium is disturbed, then the system adjusts itself so as to minimise the disturbance
- changes could be:
 - concentration
 - If add extra reactant, moves to use up reactant
 - pressure
 - If increase total pressure moves to side with less moles of gas
 - temperature
 - If increase temperature, moves to use up temperature

- **identify factors which can affect the equilibrium in a reversible reaction**
- *See above*

- **describe the solubility of carbon dioxide in water under various conditions as an equilibrium process and explain in terms of Le Chatelier's principle**
- $\text{CO}_2(g) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq)$ $\Delta H = -ve$
- Add more CO_2
 - more reactant so moves right and dissolves more CO_2
- Increase total pressure
 - moves to side with less moles of gas, which is the right so more CO_2 dissolves
- Increase temperature
 - since the reaction is exothermic, it moves left to absorb the extra temperature
- add NaOH
 - NaOH reacts with the product so more CO_2 dissolves to create more product

- **identify natural and industrial sources of sulfur dioxide and oxides of nitrogen**
- Sulphur Dioxide
 - two-thirds comes from geothermal hot springs and volcanoes
 - extracting metals from sulphide ores
 - processing or burning fossil fuels
- Nitrous Oxide
 - formed by bacteria in soils with nitrogen
 - Nitrogen fertiliser provides more raw material for the bacteria
- Nitric Oxide
 - created in combustion since heat fuses the nitrogen and oxygen in the air
 - lightning also creates it, it is a major producer
- Nitrogen Dioxide
 - Created slowly from Nitric Oxide reacting with Oxygen
 - It is also created in combustion and lightning

- **describe, using equations, examples of chemical reactions which release sulfur dioxide and chemical reactions which release oxides of nitrogen**
- For the burning of sulphur in ores and the burning of sulphur in fossil fuels
 - $S(\text{in compounds}) + O_2(g) \rightarrow SO_2(g)$
- For example
 - $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$
- For lightning strikes and combustion engines
 - $O_2(g) + N_2(g) \rightarrow 2NO(g)$
- then it reacts with oxygen
 - $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

- **assess the evidence which indicates increases in atmospheric concentration of oxides of sulfur and nitrogen**
- SO_2 and NO_2 are washed out by rain so there is no significant build up of the concentrations over the last century
- Ice core samples from Antarctica show the atmospheric gasses trapped in the ice over hundreds of years
- They showed that there is a significant increase in the concentration of N_2O and CO_2 in the last 50 years.

- **calculate volumes of gases given masses of some substances in reactions, and calculate masses of substances given gaseous volumes, in reactions involving gases at 0°C and 100kPa or 25°C and 100kPa**
- **explain the formation and effects of acid rain**
- Acid rain is rain that has a higher hydrogen ion concentration than normal – higher than about 10^{-5} mol/L
- Generally caused by dissolved Sulphur Dioxide and Nitrogen Dioxide since Carbon Dioxide is already in the air
- *increased acidity in lakes* has a detrimental effect upon fish populations
- *damage to pine forests* in parts of Europe and North America
- *erosion of the marble and limestone building surfaces and decorations*, because such materials contain carbonates, particularly calcium carbonate, and these readily react with acids; in parts of Europe acid rain over past fifty years has done more damage to priceless statuary than the weathering of the previous 500 years

Students:

- **identify data, plan and perform a first-hand investigation to decarbonate soft drink and gather data to measure the mass changes involved and calculate the volume of gas released at 25°C and 100kPa**
- Weigh
- Decarbonate by first shaking then heating gently
- Weigh again, the difference in mass should be the carbon dioxide lost

- **analyse information from secondary sources to summarise the industrial origins of sulfur dioxide and oxides of nitrogen and evaluate reasons for concern about their release into the environment**
- Sulphur dioxide mainly comes from burning coal and sulphide ores in industrialised areas
 - about 0.01 ppm in atmosphere
 - it can make breathing difficult
 - has been significant reduction in release of SO₂ due to regulations
- NO and NO₂ mainly come from motor cars in large cities
 - about 0.01 ppm in atmosphere
 - NO₂ splits to NO and O in sunlight
 1. the O joins with O₂ to form O₃
 - O₃ is toxic, even in small concentrations (>0.1 ppm is harmful)
 - Regulations have failed to reduce concentrations of oxides of Nitrogen since people are using cars to a greater extent
- acid rain
 - sulphur dioxide turns to sulphuric acid (a strong acid) in the atmosphere
$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$
 - $$2H_2SO_3(aq) + O_2(g) \xrightarrow{\text{catalyst}} 2H_2SO_4(aq)$$
 - nitrogen dioxide turns into nitric acid (a strong acid) in the atmosphere
$$2NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$$
 - $$2HNO_2(aq) + O_2(g) \xrightarrow{\text{catalyst}} 2HNO_3(aq)$$

3. Acids occur in many foods, drinks and even within our stomachs

Students learn to:

- **define acids as proton donors and describe the ionisation of acids in water**
- When an acid dissolves in water it loses a proton to the water creating the Hydronium ion H_3O^+
- **identify acids including acetic (ethanoic), citric (2-hydroxypropane-1,2,3-tricarboxylic), hydrochloric and sulfuric acid**
- *acetic acid* is the common name for ethanoic acid ($\text{CH}_3\text{-COOH}$) and is present in vinegar
- *citric acid* is the common name for 2-hydroxypropane-1,2,3-tricarboxylic acid ($\text{C}_6\text{H}_8\text{O}_7$) and occurs in citrus fruits
- **describe the use of the pH scale in comparing acids and bases**
- The pH scale is a scale that represents the hydrogen ion concentration of a solution
- the lower the more acidic
- the higher the more basic
- 7 is neutral
- 14 is also important value to remember since it is equivalent to 0 pH
 - 0 pH is $[\text{H}^+] = 1\text{M}$
 - 14 pH is $[\text{OH}^-] = 1\text{M}$
- **describe acids and their solutions with the appropriate use of the terms strong, weak, concentrated and dilute**
- *Strong* means totally disassociated in solution
- *Weak* means partially disassociated in solution
- *Concentrated* means there are many moles of acid per litre (i.e. high molarity)
- *Dilute* means there are few moles of acid per litre (i.e. low molarity)
- **identify pH as $-\log_{10} [\text{H}^+]$ and explain that a change in pH of 1 means a ten-fold change in $[\text{H}^+]$**
- $\text{pH} = -\log_{10}[\text{H}^+]$
- since it is log base 10 increase of 1 in pH equals 10 times more $[\text{H}^+]$
- **compare the relative strengths of equal concentrations of citric, acetic and hydrochloric acids and explain in terms of the degree of ionisation of their molecules**
- Hydrochloric would have lowest pH
- citric would have higher pH
- acetic would have highest but still under 7
- the lower the pH the more ionised

- **describe the difference between a strong and a weak acid in terms of an equilibrium between the intact molecule and its ions**
- a strong acid dissolved in solution would be completely ionised so the equation would not be an equilibrium one
 - $HCl_{(aq)} \Rightarrow H^+_{(aq)} + Cl^-_{(aq)}$
 - $H_2SO_{4(aq)} \Rightarrow 2H^+_{(aq)} + SO_{4(aq)}^{2-}$
- A weak acid does not fully disassociate so the ionisation is an equilibrium equation
 - $CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$

Students:

- **solve problems and perform a first-hand investigation to use pH meters/probes and indicators to distinguish between acidic, basic and neutral chemicals**
- <7 acid, >7 basic, 7 neutral

- **plan and perform a first-hand investigation to measure the pH of identical concentrations of strong and weak acids**
- use ph probe on HCl and CH₃COOH

- **gather and process information from secondary sources to write ionic equations to represent the ionisation of acids**
- **use available evidence to model the molecular nature of acids and simulate the ionisation of strong and weak acids**
- **gather and process information from secondary sources to explain the use of acids as food additives**
- Acids can be used as a food preservative since bacteria do not survive well in an acidic environment

- **identify data, gather and process information from secondary sources to identify examples of naturally occurring acids and bases and their chemical composition**
- HCl occurs the stomachs of humans
- HCO₃⁻ occurs in rivers as a buffering agent

- **process information from secondary sources to calculate pH of strong acids given appropriate hydrogen ion concentrations**

4. Because of the prevalence and importance of acids, they have been used and studied for hundreds of years. Over time, the definitions of acid and base have been refined

Students learn to:

- **outline the historical development of ideas about acids including those of:**
 - **Lavoisier**
 - Proposed that all acids contained oxygen
 - soon disproved since NaO and CaO both are basic
 - HCl contains no oxygen and is acidic
 - **Davy**
 - Said acids contained replaceable hydrogen
 - hydrogen that could be replaced by metals such as the salts formed (ZnCl₂, FeSO₄, etc)
 - Bases were substances that reacted with acids to form salt and water
 - **Arrhenius**
 - An acid was a substance which ionised in solution to produce hydrogen ions
 - if it is a strong acid it ionises completely and a weak acid doesn't
 - A base is something that produces hydroxide ions in solution
 - narrow since doesn't include metal oxides since they are distinctly basic
- **outline the Brønsted-Lowry theory of acids and bases**
- An acid is a proton donor
- A base is a proton acceptor
- If the solvent is water
- acid
 - $HA + H_2O \rightleftharpoons H_3O^+ + A^-$
- base
 - $B + H_2O \rightleftharpoons HB^+ + OH^-$
- **describe the relationship between an acid and its conjugate base and a base and its conjugate acid**
- When an acid gives up a proton it forms a conjugate base, since the substance it forms can accept a proton
 - $HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$
 - $CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$
 - acid conjugate base of the acid
- Similarly a base forms a conjugate acid
- A conjugate base of a *strong* acid is an *extremely weak base* since the acid completely disassociates
- the conjugate base of a weak acid is a weak base, this the easily seen in the following equations
 - $CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$
 - $CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$
- For diprotic and triprotic acids, they lose protons one at a time

- **identify a range of salts which form acidic, basic or neutral solutions and explain their acidic, neutral or basic nature**
- The reason why the pH of solutions of many salts is different from 7.0 is that many anions and cations can act as acids or bases
- Table to summarise the creation of different salts

	STRONG BASE (NaOH, KOH)	WEAK BASE (NH₃)
STRONG ACID (HCl, HNO₃)	pH = 7 (NaCl, KNO ₃)	pH < 7 (NH ₄ Cl, NH ₄ NO ₃)
WEAK ACID (CH₃COOH, HNO₂)	pH > 7 (CH ₃ COONa, KNO ₂)	pH = 7 (CH ₃ COONH ₄)

- **identify conjugate acid/base pairs**
- “Look for substances that are similar in an equation”
- $$\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{CO}_3^{2-}(aq)$$
- **identify amphiprotic substances and construct equations to describe their behaviour in acidic and basic solutions**
- A substance that can act both as a proton donor and as a proton acceptor is called an *amphiprotic substance*
- Hydrogen carbonate ion is amphiprotic, it reacts with water in two ways
 - $\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{CO}_3^{2-}(aq)$
 - $\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq) + \text{OH}^-(aq)$
- From those two equations it can also be seen that water is amphiprotic
- **identify neutralisation as a proton transfer reaction which is exothermic**
- Neutralisation is acid + base → salt + water
- $\text{HCl}(aq) + \text{NaOH}(aq) \Rightarrow \text{H}_2\text{O}(l) + \text{NaCl}(aq)$
- if the sodium ion is cancelled from both sides
- $\text{HCl}(aq) + \text{OH}^-(aq) \Rightarrow \text{H}_2\text{O}(l) + \text{Cl}^-(aq)$
- This involves proton transfer as OH⁻ receives a proton from HCl to form water
- It is *exothermic*

- **describe the correct technique for conducting titrations and preparation of standard solutions**
- *Volumetric analysis* is a form of chemical analysis in which the concentration (or amount) of a substance A is determined by measuring the volume of a solution of known concentration of another substance B which is just sufficient to react with all of the sample of A
- The *equivalence point* of a chemical reaction is the point at which the amounts of the two reactants are just sufficient to cause complete consumption of both reactants
- Preparing a *primary standard*:
 - A suitable primary standard is one that
 1. is of high purity (doesn't react with the surrounding air)
 2. stability in solution (stays the same concentration)
 3. doesn't absorb much water from air
 4. can be weighed out accurately and dissolved in water making the volume up to an accurately known value
 5. for acid-base titrations suitable ones are anhydrous sodium carbonate or anhydrous sodium hydrogen carbonate
 - steps
 1. make sure the primary standard is as pure as possible and free of moisture
 2. volumetric flask is cleaned well with pure water (distilled or de-ionised)
 3. make sure all the solute from the beaker for weighing is transferred to the volumetric flask
 4. only fill up to etch mark after all the solute is dissolved
 5. bottom of the meniscus should be exactly on the etch mark
 6. shake the prepared solution well before any is withdrawn to ensure uniform mixing
- Using a *pipette*
 - rinse with the *solution*
 - draw solution using pipette filler until it is above the etch mark
 - then let gravity draw the solution out until the bottom of the meniscus sits of the etch mark
 - now let gravity run all the solution into required flask
 - never blow out the last drops as the pipette is calibrated so that they stay there
- Using a *burette*
 - rinse with the *solution*
 - overfilled and let excess run out to remove any bubbles
 - then it is clamped vertically and meniscus is lowered to etch mark
 - fractions of a drop can be dispensed by letting a drop build up and washing it down with a wash bottle
 - to measure the volume of a solution it is not accurate enough to use a measuring cylinder

- Choice of indicator

TITRATION	SUITABLE INDICATOR	COLOUR CHANGE ^a	pH RANGE
strong acid–weak base	methyl orange	red–yellow	3.1–4.4
	bromophenol blue	yellow–blue	3.0–4.6
	bromocresol green	yellow–blue	3.8–5.4
	methyl red	pink–yellow	4.4–6.0
strong acid–strong base	litmus	red–blue	6.0–8.0
	bromothymol blue	yellow–blue	6.2–7.6
	phenol red	yellow–red	6.8–8.4
weak acid–strong base	thymol blue	yellow–blue	8.0–9.6
	phenolphthalein	colourless–red	8.3–10.0

^a acid colour–base colour

BOLD ones are in syllabus

- steps for acid–base titration
 - fill *burette* with solution of known concentration and adjust the solution level in burette to zero mark
 - place a solution of the sample to be analysed in a flask under the burette
 - add a few drops of suitable indicator into flask
 - slowly run solution from burette into the flask with continuous swirling until the indicator just changes colour
 - read the volume delivered by the burette as accurately as possible
 - repeat previous steps until two results are within 0.1ml
 - calculate the required concentration of the unknown using the basic principles of molarity calculations
- qualitatively describe the effect of buffers with reference to a specific example in a natural system**
- A *buffer solution* is a solution which contains comparable amounts of a weak acid and its conjugate base and which is therefore able to maintain an approximate constant pH even when significant amounts of strong acid or strong base are added to it
- $H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$
- if more H^+ was added the equilibrium would move left to minimise the change
- if more OH^- was added the equilibrium would move right to minimise the change
- in lakes and rivers HCO_3^- come from the surrounding rocks, combined with the CO_2 in the air it buffers the water against acid rain

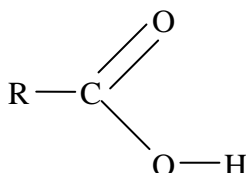
Students:

- **gather and process information from secondary sources to trace developments in understanding and describing acid/base reactions**
- **choose equipment and perform a first-hand investigation to identify the pH of a range of salt solutions**
- **perform a first-hand investigation and solve problems using titrations and including the preparation of standard solutions, and use available evidence to quantitatively and qualitatively describe the reaction between selected acids and bases**
- **perform a first-hand investigation to determine the concentration of a domestic acidic substance**
- **analyse information from secondary sources to assess the use of neutralisation reactions as a safety measure or to minimise damage in accidents or chemical spills**
- Many acids and bases are very corrosive so it is important to neutralise these spills quickly
- Also there are regulation controlling the pH of the sewerage factories and labs discharge
- Sodium Carbonate is used for acid spills
- Hydrochloric acid or sulphuric acid is used for basic spills in controlled neutralisation
- but sodium hydrogen carbonate used for quickly neutralising basic spills as there is no great problem is excess is used
- In fact, because it is amphiprotic it can be used for acidic spills too

5. Esterification is a naturally occurring process, which can be performed in the laboratory

Students learn to:

- describe the differences between the alkanol and alkanolic acid functional groups in carbon compounds
- The *alkanol* function group is –OH attached to an alkane replacing an H
- An *alkanoic acid* is a compound which has the general structure



- where R is a alkyl group or an H atom
- Alkanoic acids* are *weak acids*
- identify the IUPAC nomenclature for describing the esters produced by reactions of straight-chained alkanolic acids from C1 to C8 and straight-chained primary alkanols from C1 to C8**
- Esters are compounds formed when alkanolic acids react with alkanols, or more generally, when carboxylic acids combine with alcohols
- Esters made from alkanols and alkanolic acids are called *alkyl alkanoates*
- named (alcohol)yl (acid)anoate
- ethanoic acid + butanol = butyl ethanoate + water
- acid goes with the anOate since it has the double bond O
- explain the difference in melting point and boiling point caused by straight-chained alkanolic acid and straight-chained primary alkanol structures**
- alkanols* have the C–O polar bond and the O–H hydrogen bond for intermolecular bonding
- alkanoic acids* have both those of the alkanols *plus* an extra C=O bond for intermolecular bonding
- this results in *alkanoic acids* to have a *higher* melting and boiling point compared to equal weight *alkanols*
- identify esterification as the reaction between an acid and an alkanol and describe, using equations, examples of esterification**
- The general equation for esterification is
- Alkanoic acid + alcohol → ester + water
- $$R_a - \text{COOH} + \text{HO} - R_b \xrightarrow[\text{Heat}]{[\text{H}_2\text{SO}_4]} R_a - \text{COO} - R_b + \text{H}_2\text{O}$$
- describe the purpose of using acid in esterification for catalysis**
- Esterification is moderately slow at room temperature and the reaction does not go to completion; it comes to equilibrium
- Sulphuric acid acts as a catalyst and absorbs water from the solution
- the absorption of water shifts the reaction to products

- **explain the need for refluxing during esterification**
- It is impossible to simply boil the solution to speed up the reaction as the alcohol would evaporate
- refluxing is the process of heating a reaction mixture in a vessel with a cooling condenser attached in order to prevent loss of any volatile reactant or product
- It allows the reaction to be brought about at a higher temperature than would otherwise be possible
- To do the reaction in a closed vessel could lead to an explosion

- **outline some examples of the occurrence, production and uses of esters**
- The characteristic smell of many flowers and fruits are a complex mix of many esters
- used in industry to make synthetic flavours and odours since they are cheaper than natural extracts
- ethyl acetate (ethanoate) is used as a solvent in nail polish remover
- high molecular weight esters are used as plasticisers in PVC

Students:

- **identify data, plan, select equipment and perform a first-hand investigation to prepare an ester using reflux**
- Method
 - add to distilling flask
 1. 20ml ethanoic acid
 2. 15ml ethanol
 3. 2ml concentrated sulphuric acid
 - Reflux for 1 hour
 - add saturated sodium chloride to separate aqueous layer from organic layer
 - decant aqueous layer from organic layer
 - add NaHCO_3 to neutralise excess acid
 - separate organic layer again
 - add anhydrous sodium carbonate to remove last amount of water dissolved in ester
 - fractional distillation could also be used to extract the ester
- **process information from secondary sources to identify and describe the uses of esters as flavours and perfumes in processed foods and cosmetics**
- Ethyl ethanoate
 - $\text{CH}_3\text{COOC}_2\text{H}_5$
 - Nail polish remover
- Ethyl butanoate
 - $\text{C}_3\text{H}_7\text{COOC}_2\text{H}_5$
 - Part of pineapple ester

9.4 Chemical Monitoring and Management

Contextual Outline

The state of our environment is an important issue for society. Pollution of air, land and water in urban, rural and wilderness areas is a phenomenon that affects the health and survival of all organisms, including humans. An understanding of the chemical processes involved in interactions in the full range of global environments, including atmosphere and hydrosphere, is indispensable to an understanding of how environments behave and change. It is also vital in understanding how technologies, which in part are the result of chemical research, have affected environments. This module encourages discussion of how chemists can assist in reversing or minimising the environmental problems caused by technology and the human demand for products and services.

Some modern technologies can facilitate the gathering of information about the occurrence of chemicals — both those occurring in natural environments and those that are released because of human technological activity. Such technologies include systems that have been developed to quantify and compare amounts of substances.

This module increases students' understanding of the nature, practice, applications and uses of chemistry and the implications of chemistry for society and the environment.

1. Much of the work of chemists involves monitoring the reactants and products of reactions and managing reaction conditions

Students learn to:

- **outline the role of a chemist employed in a named industry or enterprise, identifying the branch of chemistry undertaken by the chemist and explaining a chemical principle that the chemist uses**
- Burhan works at Qenos, a chemical manufacturing company that makes many different chemicals
- He works in the branch of analytical chemistry
- Monitor's waste water from Qenos
- He uses gas chromatography
- different components move through the column at different rates so they will be separated once they reach the detector at various times
- For a more general example
 - Fred works at some steel works
 - Fred uses atomic absorption spectroscopy (AAS) to monitor wastes from the factory for pollutants
 - Fred's branch is analytical chemistry
 - the workings of AAS are explained *below (section 3)*
- **identify the need for collaboration between chemists as they collect and analyse data**
- There are generally too many jobs in one plant for a chemist to manage so there must be collaboration for the job to be completed
- Monitoring the ozone layer requires many detectors spread over the world so many chemist are needed and collaboration is required to find the result
- **describe an example of a chemical reaction such as combustion, where reactants form different products under different conditions and thus would need monitoring**
- Hydrocarbons burning with oxygen can produce 3 different products depending on the amount of oxygen supplied
 - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
 - $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$
 - $CH_4 + O_2 \rightarrow C + 2H_2O$

Students:

- **gather, process and present information from secondary sources about the work of practising scientists identifying:**
 - the variety of chemical occupations
 - a specific chemical occupation for a more detailed study
 - *See above*

2. Chemical processes in industry require monitoring and management to maximise production

Students learn to:

- **identify and describe the industrial uses of ammonia**
- fertilisers, as source of nitrogen
- fibres and plastics
- nitric acid
- household cleaners
- detergents
- basic chemical for making explosives

- **identify that ammonia can be synthesised from its component gases, nitrogen and hydrogen**
- $N_2(g) + 3H_2 \rightleftharpoons 2NH_3(g)$ $\Delta H = -92 \text{ kJ/mol}$

- **describe that synthesis of ammonia occurs as a reversible reaction that will reach equilibrium**
- At normal temperatures and pressures the equilibrium lies well to the left

- **identify the reaction of hydrogen with nitrogen as exothermic**
- 92kJ/mol too!

- **explain why the rate of reaction is increased by higher temperatures**
- because the higher the temperature the more energy and the more frequently the atoms will collide thus increasing the rate of reaction

- **explain why the yield of product in the Haber process is reduced at higher temperatures using Le Chatelier's principle**
- Since the reaction is exothermic if the temperature of the chemicals are increased the reaction will move right to absorb the extra energy thus reducing the yield

- **explain why the Haber process is based on a delicate balancing act involving reaction energy, reaction rate and equilibrium**
- At higher temperature there will be less yield but will be achieved faster
- At lower temperatures there will be more yield but will be achieved slower
- a compromise is achieved at 700K and 250 atmospheres

- **explain that the use of a catalyst will lower the reaction temperature required and identify the catalyst(s) used in the Haber process**
- An iron/iron oxide catalyst is used, (Fe_3O_4)
- A catalyst will reduce the reaction temperature but will not change the yield
- It is used to increase the reaction rate, thus reducing costs

- **analyse the impact of increased pressure on the system involved in the Haber process**
- An increase in pressure will move the equilibrium to the products
- 4 moles of gas \rightarrow 2 moles of gas
- An increase in pressure favours the side with the less moles of gas

- **explain why monitoring of the reaction vessel used in the Haber process is crucial and discuss the monitoring required**
- Temperature and total pressure must to monitored to make sure optimum efficiency is maintained
- The composition of incoming gasses must be monitored
 - make sure there is no O_2 since it may cause explosion
 - make sure there that the ratio of the H_2 to N_2 is kept at 3:1 so that there is no build up of excess reactant
 - make sure there is no carbon monoxide since it will poison the catalyst
 - build up of uncreative gasses such as argon or methane can reduce the efficiency of the conversion

Students:

- **gather and process information from secondary sources to describe the conditions under which Haber developed the industrial synthesis of ammonia and evaluate its significance at that time in world history**
- The Haber process was developed during World War 1 by Germany, since the Allies broke Germany's only natural source of nitric acid which was saltpetre from Chile
- Since Nitric acid is a major component in the production of explosives, Germany needed a new source of nitric acid
- Due to this need Carl Bosch industrialised the synthesis of Ammonia from its elements
- Ammonia can be used to produce explosives and fertiliser which are important to the war effort
- This is important for the rest of the world since the worlds supplies of saltpetre can't cope with the demand for Nitrogen rich fertiliser

3. Manufactured products, including food, drugs and household chemicals, are analysed to determine or ensure their chemical composition

Students learn to:

- deduce the ions present in a sample from the results of tests

– Cation tests

CATION	TESTS
Pb ²⁺	1 with Cl ⁻ forms a white precipitate
	2 with I ⁻ forms a yellow precipitate
Ba ²⁺	1 with SO ₄ ²⁻ forms a white precipitate
	2 gives a green flame colour
	3 no precipitate with OH ⁻ or F ⁻ (compare Ca ²⁺)
Ca ²⁺	1 with SO ₄ ²⁻ forms a white precipitate (if solution not too dilute)
	2 with F ⁻ forms white precipitate
	3 gives brick-red flame colour
Cu ²⁺	1 with OH ⁻ forms a blue precipitate
	2 this precipitate dissolves in NH ₃ to form a deep blue solution
	3 gives a blue-green flame colour
Fe ²⁺	1 with OH ⁻ forms a white precipitate which quickly turns brown ^a
	2 decolourises acidified dilute potassium permanganate solution
Fe ³⁺	1 with OH ⁻ forms a brown precipitate
	2 with SCN ⁻ forms a deep red solution

^a depending on conditions, a precipitate may just look brown without first being white.

– Anion tests

ANION	TESTS
carbonate	1 solution has pH between 8 and 11 (pH paper suffices)
	2 addition of dilute HNO ₃ produces bubbles of colourless gas (CO ₂) ^a
sulphate	1 addition of Ba(NO ₃) ₂ to an acidified sample of the solution produces a thick white precipitate
	2 acidification and addition of Pb(NO ₃) ₂ produces a white precipitate
chloride	1 addition of AgNO ₃ to an acidified sample produces a white precipitate ^b
	2 this precipitate dissolves in ammonia solution and darkens in sunlight
phosphate	1 addition of ammonia followed by Ba(NO ₃) ₂ produces a white precipitate
	2 addition of Mg ²⁺ in an ammonia, ammonium nitrate buffer produces a white precipitate of Mg(NH ₄)PO ₄

^a Any strong acid (i.e. H₃O⁺) would do but for analysing mixtures (next section) we do not want to introduce any Cl or SO₄²⁻

^b In non-acidic solutions silver nitrate also produces precipitates with carbonate and phosphate (and with sulphate at all pHs if sulphate concentration is moderately high), so this test alone does not prove the presence of chloride: it is also necessary to prove the absence of sulphate

- **describe the use of atomic absorption spectroscopy (AAS) in detecting concentrations of metal ions in solutions and assess its impact on scientific understanding of the effects of trace elements**
- AAS detects trace metal ions by
 - An atomised mist of the solution is sprayed into an acetylene flame
 - The heat of the flame vaporises the solution into individual atoms
 - A bulb specific to the metal that is being analysed shoots a particular wavelength of light at the flame
 - This particular wavelength is able to excite the metal atom that is being analysed which absorbs the light
 - After passing through the flame a detector detects the intensity of the light
 1. the more ions there are in the solution the more of the light will be absorbed
 - thus the concentration of the particular metal ion can be detected
- Like all instruments it must be calibrated with standard solutions first
 - since the curve of intensity Vs concentration tends to flatten of towards the end only small concentrations are used to calibrate
 - If the measured concentration is outside the calibrated range the solution must be diluted before it can be measured
- AAS has allows scientists to detect trace elements
 - these are elements that are significant in very small concentrations (ppm or ppb)
 1. they could be significant in that they are important for human or plant function
 2. or they could be toxic in these small concentrations
 - It allowed scientists discover that these elements are important in these trace amounts
 - It also showed that these elements are present in water and soil
 - over all it has greatly improved scientific understanding of trace elements in organisms

Students:

- **perform first-hand investigations to carry out a range of tests, including flame tests, to identify the following ions:**
 - **phosphate**
 - **sulphate**
 - **carbonate**
 - **chloride**
 - **barium**
 1. apple-green colour
 - **calcium**
 1. Orange-Red colour
 - **lead**
 - **copper**
 1. blue-green colour
 - **iron**

- **gather, process and present information to describe and explain evidence for the need to monitor levels of one of the above ions in substances used in society**
- Phosphate
 - can cause eutrophication of rivers (build up of algae)
- lead
 - toxic in small concentrations
 - bioaccumulation and bioconcentration
 - builds up in the brain causing slurred speech and loss of coordination

- **identify data, plan, select equipment and perform first-hand investigations to measure the sulphate content of lawn fertiliser and explain the chemistry involved**
- Use barium to precipitate out the sulphate
- Then filter/measure etc.

- **analyse information to evaluate the reliability of the results of the above investigation and to propose solutions to problems encountered in the procedure**
- It should be considered reliable since there is only one chemical reaction done
- errors would occur during the measuring and transferring of chemicals
- precipitate very fine so cannot use regular filter paper
 - use sintered glass filter with vacuum pump
- Barium may precipitate other anions
- Precipitate should be washed to remove any ions
- repeat more than once

- **gather, process and present information to interpret secondary data from AAS measurements and evaluate the effectiveness of this in pollution control**
- generally the calibration graph will be a straight line
- it can be used to detect lead in water supplies, this is important since lead is toxic in very small concentrations
- Due to the ease in analysing water samples with AAS, industry is forced to take notice of environmental issues

4. Human activity has caused changes in the composition and the structure of the atmosphere. Chemists monitor these changes so that further damage can be limited

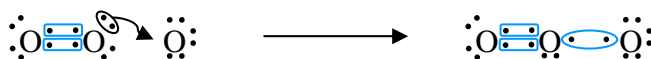
Students learn to:

- **describe the composition and layered structure of the atmosphere**
- Troposphere (0-15km)
 - 90% of atmosphere
 - Temperatures down to -50°C
 - Mostly nitrogen, oxygen, argon
- Stratosphere (15-50km)
 - 9.99% of atmosphere
 - temperatures from -50°C up to 0°C
 - Mostly oxygen and ozone
- Mesosphere (50-85km)
 - 0.009% of atmosphere
 - temperatures from 0°C down to -100°C
 - Mostly oxygen
- There is this layered structure due to the temperature changes
 - the temperature changes cause inversions layers which locks gasses in their respective layers
 - gasses from the stratosphere almost doesn't filter down to the troposphere
 - gasses from the troposphere filter very slowly up to the stratosphere
- The temperature changes are created by the various chemical reactions that occur in the layers
- **identify the main pollutants found in the lower atmosphere and their sources**

POLLUTANT	SOURCE
carbon monoxide	motor cars, cigarettes, fires, slow combustion stoves
oxides of nitrogen (NO + NO ₂)	combustion (vehicles and power stations), lightning
airborne lead	leaded petrol (used in pre-1986 cars), lead smelters, old house renovations
sulphur dioxide	combustion (sulphur compounds in fuel), metal extraction from sulphide ores
ozone	photochemical smog (created by NO ₂ creating O free radicals, which react with O ₂)
particulates (including asbestos)	combustion, pre-1968 fibrous cement boards in old buildings and from their demolition

- **describe ozone as a molecule able to act both as an upper atmosphere UV radiation shield and a lower atmosphere pollutant**
- upper atmosphere UV shield
- A series of reactions absorb the UV radiation, these reactions reuse the chemicals so very little concentrations of O₃ and O₂ are required to absorb much of the harmful radiation
 - $O_2 + u.v.light (< 240 \text{ nm}) \rightarrow 2O$
 - $O + O_2 \rightarrow O_3$
 - $O_3 + u.v.light (200 - 300 \text{ nm}) \rightarrow O + O_2$
- lower atmosphere pollutant
 - if ozone is breathed in to the human body it attaches an O to the many complex carbon molecules in the human body, which interferes with the proper function of the organism

- **describe the formation of a coordinate covalent bond**
- both the shared electrons in a covalent bond come from the same atom
- **demonstrate the formation of coordinate covalent bonds using Lewis electron dot structures**



- **compare the properties of the oxygen allotropes O₂ and O₃ and account for them on the basis of molecular structure and bonding**
- Ozone is more reactive than Oxygen because the co-ordinate covalently bonded O is easily split off
- Poisonous, because the O gets attached to the complex carbon molecules, disrupting bodily functions

PROPERTY	OXYGEN, O ₂	OZONE, O ₃
	<ul style="list-style-type: none"> ○ colourless gas condensing to a pale blue liquid ○ odourless ○ essential for all living matter (though pure O₂ for extended periods will kill) 	<ul style="list-style-type: none"> ○ colourless gas condensing to a distinctly blue liquid ○ strong distinctive odour (0.01ppm is detectable) ○ poisonous (with detrimental effects observable at concentrations as low as 0.1ppm)
boiling point	-183°C	-111°C
density	about the same as air	about 1.5 times that of air
solubility in water	sparingly soluble (9ppm from air at 20°C)	considerably more soluble than O ₂
stability	very stable	easily decomposed to O ₂
reactivity	<ul style="list-style-type: none"> ○ reacts with most other elements to form oxides ○ moderately strong oxidising agent 	<ul style="list-style-type: none"> ○ much more reactive than oxygen ○ very strong oxidising agent
uses	<ul style="list-style-type: none"> ○ widely used medically to overcome breathing problems ○ steel-making (to oxidise carbon from pig iron) ○ oxy-acetylene torches ○ liquid O₂ used in space shuttles and rockets as oxidiser for the fuel (often liquid H₂) 	<ul style="list-style-type: none"> ○ in sterilisers in food shops and kitchens (prepared in situ by passing air through a silent electric discharge) ○ purification of water and as a bleaching agent in paper and textile making (it is replacing chlorine for these uses)

- **compare the properties of the gaseous forms of oxygen and the oxygen free radical**
- Oxygen radical is a neutral oxygen atom with two unpaired electrons
- Highly reactive

- **identify the origins of chlorofluorocarbons (CFCs) and halons in the atmosphere**
- Refrigerators use CFCs as refrigerants
- halons used for anaesthetics, insecticides, propellants and in fire extinguishers

- **identify and name examples of isomers (excluding geometrical and optical) of haloalkanes up to eight carbon atoms**
- Straight chain halogenated hydrocarbons are named using the following rules:
 1. Bromo-, chloro-, fluoro and iodo- are used as prefixes to the hydrocarbon name
 2. The position of the halogen (halo) atom is denoted by a number (as was done for double bonds in alkenes, p. 277 CCPC); if more than one of a particular type of halo atom is present di-, tri-, tetra- are used and a location number is given for each such atom.
 3. If more than one type of halo atom is present, they are listed alphabetically with di-, tri-, tetra- being ignored in deciding the order.
- Naming CFCs
- CFC-01234a
 - 0 = number of double bonds (omitted if zero)
 - 1 = Carbon atoms - 1 (omitted if 0)
 - 2 = Hydrogen atoms + 1
 - 3 = Fluorine atoms
 - 4 = Chlorine atoms replaced by Bromine ("B" prefix added)
 - a = letter added to identify isomers, the "normal" isomer in any number has the smallest mass difference on each carbon, and a, b, or c are added as the masses diverge from normal

- **discuss the problems associated with the use of CFCs and assess the effectiveness of steps taken to alleviate these problems**
- CFCs become a problem when they seep past the inversion layer into the stratosphere
- here when they are stuck by UV radiation they give off Chlorine atoms these atoms destroy ozone
 - $CCl_3F + u.v.light \rightarrow Cl + CCl_2F$
 - $Cl + O_3 \rightarrow ClO + O_2$
 - $ClO + O \rightarrow O_2 + Cl$
- to truly appreciate the destructive nature of the chlorine atom the last two equations must be added
 - $Cl + ClO + O_3 + O \rightarrow O_2 + O_2 + ClO + Cl$
- The overall reaction is an ozone and an oxygen atom getting turned into two oxygen molecules, the Chlorine is not affected
- The use and production of CFCs have been banned by the Montreal protocol
 - replacements were scientifically found, eg HCFCs and HFCs
 - by 2003 all CFC use had stopped excepted for very special cases
 - however, since CFCs are a very stable atom they will remain in the atmosphere for many years even after the ban of usage

- **analyse the information available that indicates changes in atmospheric ozone concentrations, describe the changes observed and explain how this information was obtained**
- Ground based instruments can monitor ozone by measuring the amount of UV passing through the atmosphere
- Satellites can monitor ozone concentrations from space
- Before today's advanced technology, huge helium balloons were launched into the stratosphere to measure the ozone concentration
- Today's ozone concentration is compared to results in the past to determine the amount of ozone depletion, thus the evidence of an ozone hole

Students:

- **present information from secondary sources to write the equations to show the reactions involving CFCs and ozone to demonstrate the removal of ozone from the atmosphere**
- **gather, process and present information from secondary sources including simulations, molecular model kits or pictorial representations to model isomers of haloalkanes**
- **present information from secondary sources to identify alternative chemicals used to replace CFCs and evaluate the effectiveness of their use as a replacement for CFCs**
- HCFCs were the first (temporary) replacement for CFCs since most of them are destroyed in the lower atmosphere. However, some still made it to the stratosphere
- HFCs are now the permanent replacement since they do not contain chlorine. They are not as effective refrigerants and more expensive but do not damage the ozone.

5. Human activity also impacts on waterways. Chemical monitoring and management assists in providing safe water for human use and to protect the habitats of other organisms

Students learn to:

- **identify that water quality can be determined by considering:**
 - **concentrations of common ions**
 - Carbonate
 1. add HCl to heated solution and observe if there is CO₂ released
 2. or add Ca²⁺ and precipitate Carbonate
 - Heavy metal
 1. add Na₂S in alkaline then acidic conditions and observe if precipitate forms
 - Use AAS for metals
 - **total dissolved solids**
 - The is the mass of dissolved solids in the water
 1. A high TDS may indicate run off from farms or factories
 2. anything higher than 500ppm is unsuitable for human consumption
 3. sea water has 35000ppm due to the dissolved salt
 - By Evaporation
 1. filter off suspended solids
 2. evaporate to dryness
 3. measure weight of solids left
 - By conductivity
 1. use conductivity probe
 2. since most of the dissolved solids are ions the more there is the better the water can conduct electricity
 3. TDS (in ppm) = 0.65 × (conductivity in mS cm⁻¹)
 - **hardness**
 - A measure of hardness is the concentration of Mg²⁺ and Ca²⁺ ions
 - A high concentration is hard water and a low concentration is called soft water
 - The Magnesium and Calcium ions precipitate with the soap ion, stearic acid
 1. $Ca^{2+}(aq) + C_{17}H_{35}COO^{-}(aq) \rightarrow Ca(C_{17}H_{35}COO)_2(s)$
 2. $Mg^{2+}(aq) + C_{17}H_{35}COO^{-}(aq) \rightarrow Mg(C_{17}H_{35}COO)_2(s)$
 - The precipitate is known commonly as soap scum and reduces the effectiveness of the soap
 - synthetic detergents are not affected by the Calcium and Magnesium ions
 - Hardness can be measured by precipitating with NaCO₃ then filtering if the water is very hard
 - There is also a special titration that can be carried out
 - AAS could also be used

- **turbidity**
- The suspended solids in the water causes the turbidity
 1. a high turbidity gives the water an undesirable appearance and taste
- Use a Secchi disk (a heavy disk with a cross on it that is lowered into the water gradually the distance lowered before the cross becomes invisible is recorded)
- Alternative method is it use a measuring cylinder with a cross on the bottom
 1. water samples a poured into it an the amount required to make the cross invisible when viewed from above is recorded
 2. As with all equipment, it must be calibrated with standard solutions so that a measurement can be made in grams per litre

- **acidity**
- pH is the $-\log[H^+]$
- Use pH meter
- Use pH paper or Universal indicator solution

- **dissolved oxygen and biochemical oxygen demand**
- ***Dissolved Oxygen***
- Dissolved oxygen is important for the survival of most marine creatures
- Oxygen has a low solubility in water ~9ppm, but this is all that is required for the marine creatures
- Oxygen dissolves from the photosynthesis by under water plants and by turbulence on the surface of the water
- if it falls below 5ppm fishes start to die, could fall due to
 1. algal blooms
 2. very still water
 3. organic matter in the water, the bacteria uses the oxygen
- Is detected using a special probe or by special titration
- ***BOD***
- This is a measure of how fast the dissolved oxygen is used up in a particular water sample
- To measure it:
 1. water sample's dissolved oxygen is tested and recorded
 2. the water sample is put in a sealed air free container
 3. the container is placed in the dark at collection temperature for 5 days
 - a. the dark is required since photosynthesis may take place
 - b. oxygen has different solubilities at different temperatures
 4. the dissolved oxygen in the sample is tested again
 5. the difference is the BOD
- in samples where is BOD is expected to be low, nutrient can be added
- in samples where the BOD is expected to be high, oxygen is added often and the oxygen used up is also tested often

- **identify factors that affect the concentrations of a range of ions in solution in natural bodies of water such as rivers and oceans**
- Rain
- pH of rain, acid rain is better at leaching Ca^{2+} , Mg^{2+} and Fe^{3+}
- Human activity
 - land clearing
 - Agriculture
- Effluent discharge
- leaching from rubbish dumps

- **describe and assess the effectiveness of methods used to purify and sanitise mass water supplies**
- Prevent impurities from entering the water catchment area
 - Council regulations
 - Prevent construction in the area around dam
- Sand filtering
 - Chemicals are added to precipitate various impurities from the water. However, these impurities are too small to be filtered out effectively
 - Iron Hydroxide is very insoluble. When it is added as Fe^{3+} reacting with the OH^- in a basic solution, the fine precipitates cling to it and form larger particles
 - These larger particles can be filtered out by sand filtration
 - sand filtration is where the water run through a filter consisting of coarse sand and sometimes hard coal
 - The high carbon content help to remove odour and taste from the water
- Chlorine is used kill off the bacteria and some viruses in the water

- **describe the design and composition of microscopic membrane filters and explain how they purify contaminated water**
- A membrane filter is a thin film of a synthetic polymer with microscopic pores that are relatively uniform in size
- the pores are approx. 0.2 to 0.5 micrometres
- There are two types of membrane filters
 - A sheet that is put around a suitable housing with water pumped through it
 - A capillary that is about 200 micrometres in diameter
 1. dirty water enters the capillary and clean water flows out the middle
 2. usually used in large bunches to provide maximum filtering surface area
 3. it is back flushed with compressed air when dirty
- Advantages
 - Filter out particles much smaller than sand and paper filters
 1. Thus can filter out most bacteria and viruses
 - Thin, so liquid flows through them quickly
 - Strong enough to withstand high pressures
 - Can be cleaned through back-flushing, thus be reused
- Disadvantages
 - Expensive

Students:

- **perform first-hand investigations to use qualitative and quantitative tests to analyse and compare the quality of water samples**
- **gather, process and present information on the range and chemistry of the tests used to:**
 - **identify heavy metal pollution of water**
 - **monitor possible eutrophication of waterways**
- **gather, process and present information on the features of the local town water supply in terms of:**
 - **catchment area**
 - **possible sources of contamination in this catchment**
 - **chemical tests available to determine levels and types of contaminants**
 - **physical and chemical processes used to purify water**
 - **chemical additives in the water and the reasons for the presence of these additives**
 - **Fluorene is added since it is beneficial to the teeth of young humans**

9.5 Option — Industrial Chemistry

Contextual Outline

Industry uses chemical reactions to produce chemicals for use by society. This module develops the ideas that some chemicals have been produced to replace naturally occurring chemicals that are no longer available or are not economically viable. The concepts of qualitative and quantitative equilibrium are further developed.

Industrial chemical processes cover the full range of reactions but concentration on some case studies is sufficient to illustrate the range of reactions and the role of chemists and chemical engineers involved in these processes. This allows some insight into the qualitative and quantitative aspects of the chemical industry and allows a consideration of the analytical processes and monitoring that is necessary for efficient production.

This module increases students' understanding of the history, applications and uses of chemistry, and current issues, research and developments in chemistry.

1. Industrial chemistry processes have enabled scientists to develop replacements for natural products

Students learn to:

- **discuss the issues associated with shrinking world resources with regard to one identified natural product that is not a fossil fuel, identifying the replacement materials used and/or current research in place to find a replacement for the named material**
- Wool was one of the major fibres used for clothing before the 1950's
- As populations grew supply for wool could not keep up with demand
- As wool prices grew synthetic replacements became for popular
- nylon and polyester has now replaced wool as the major fibre used for clothing
- wool has become a speciality
- new polymers are still being developed for textiles

Students:

- **identify data, gather and process information to identify and discuss the issues associated with the increased need for a natural resource that is not a fossil fuel and evaluate the progress currently being made to solve the problems identified**

2. Many industrial processes involve manipulation of equilibrium reactions

Students learn to:

- **explain the effect of changing the following factors on identified equilibrium reactions**
 - **Pressure**
- Equilibrium shifts towards the side with less moles of gas
 - **Volume**
 - **Concentration**
 - **Temperature**
- Shifts to minimise disturbance (Le Chatelier's principle)

- **interpret the equilibrium constant expression (no units required) from the chemical equation of equilibrium reactions**
- Products on top, Reactants on bottom
- If units are not given, concentrations must always be in mol/L
- Do not include solids
- Only include liquid water if it is not in excess (if water is not used a solvent)

- **identify that temperature is the only factor that changes the value of the equilibrium constant (K) for a given equation**
- All other factors have no effect on position of equilibrium

Students:

- **identify data, plan and perform a first-hand investigation to model an equilibrium reaction**
- A person walking backwards on a escalator could be seen as a equilibrium reaction
- When the person walks forward at the same speed as the escalator is moving he/she appears stationary from a macroscopic perspective
- However, his feet which are hidden from view are still moving, thus there are still microscopic changes
- If the escalator speeds up, the person walking will also speed up to minimise the disturbance
- But this change will result in him stopping at a different part of the escalator, thus the position of equilibrium has changed

- **choose equipment and perform a first-hand investigation to gather information and qualitatively analyse an equilibrium reaction**
- **process and present information from secondary sources to calculate K from equilibrium conditions**

3. Sulphuric acid is one of the most important industrial chemicals

Students learn to:

- **outline three uses of sulphuric acid in industry**
- Used as catalyst in the hydration of ethanol from ethene
- Manufacture of lead-acid batteries, the electrolyte is 4M sulphuric acid
- Used in oil refining, many unwanted impurities are removed from petroleum by reacting with sulphuric acid
- Drying air

- **describe the processes used to extract sulphur from mineral deposits, identifying the properties of sulphur which allow its extraction and analysing potential environmental issues that may be associated with its extraction**
- The process of extracting sulphur from deposits is called the *Frasch process*
 - Superheated water at 160°C is pumped down the outer of 3 concentric pipes into the sulphur deposit
 - This melts the sulphur
 - Compressed air is pumped down the inner pipe, which forces the sulphur up the middle pipe where it is collected
 - Once this mixture cools solid sulphur separates from the liquid water
 - 99.5% sulphur is obtained
- Properties of sulphur
 - Sulphur is able to be extracted this way since its melting point is less than superheated water
 - Sulphur is insoluble in water so it can be easily separated
 - The sulphur-water mixture is sufficiently low density for air to lift it to the surface
- Environmental issues
 - Sulphur is easily reduced to hydrogen sulphide (H₂S) or oxidised to sulphur dioxide (SO₂) which both are serious air pollutants
 - The water may have dissolved impurities in the deposit, which are unsuitable for discharge into the environment. So the water is reused
 - It is difficult to backfill the mine so the earth may collapse at that area (subsidence)

- **outline the steps and conditions necessary for the industrial production of H₂SO₄ from its raw materials**
- This is called the *Contact process* because the SO₂ and O₂ must come in contact with a catalyst
- sulphur is converted to sulphur dioxide
 - $S(l) + O_2(g) \rightarrow SO_2(g)$
 - liquid sulphur is sprayed into excess dry air and combusted
 - this reaction is very exothermic so the SO₂ needs to be cooled before continuing to next step
 - Sometimes the SO₂ from the roasting of sulphide ores (eg, ZnS or CuFeS₂) is used rather than producing it from sulphur

- sulphur dioxide is converted to sulphur trioxide
 - $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \quad \Delta H = -99\text{kJ/mol}$
 - This is an equilibrium expression so the reaction must be monitored and controlled, similar to Haber process
 - To force the equilibrium to the products (to increase the % conversion of SO_2 to SO_3)
 1. excess oxygen
 2. high pressure, since less moles of gas on products side
 3. low temperature, since reaction is exothermic
 - It has been found that temperature is the major contributor to yield in this case
 - 400°C produces about 99% yield
 - As with the Haber process reaction rate must be considered
 1. The catalyst used vanadium oxide (V_2O_5) produces a high reaction rate at $>500^\circ\text{C}$
 2. It provides an acceptable rate at 400°C
 - Compromise conditions used
 1. initially the SO_2 is passed over the bed of catalyst at 550°C to rapidly oxidise 70% of the SO_2
 2. then it is cooled to 400°C and passed over another bed of the catalyst and a yield of about 97% is reached
 - However, 3% SO_2 released into the atmosphere is not acceptable according to today's standards
 1. SO_3 is removed by processing it to H_2SO_4 (next step)
 2. the remaining SO_2 is passed over another catalyst bed at 400°C to produce a total of 99.7% conversion of SO_2
 - the 0.3% release of SO_2 into the atmosphere is acceptable in most countries
- sulphur trioxide is absorbed by water to form sulphuric acid
 - $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$
 - Spraying water directly into the SO_3 mist is ineffective since it would produce a fine mist of H_2SO_4 , which is difficult to extract
 - To overcome this problem the SO_3 is passed through concentrated sulphuric acid since SO_3 readily dissolves in H_2SO_4 to form oleum
 1. $SO_3(g) + H_2SO_4(l) \rightarrow H_2S_2O_7(l)$
 - Oleum then reacts with water to form sulphuric acid
 1. $H_2S_2O_7(l) + H_2O(l) \rightarrow 2H_2SO_4(l)$
 - Two absorber towers are used to absorb the SO_3
 1. one to absorb the bulk of the SO_3
 2. the other to absorb the rest so that there is minimal release of SO_2 into the atmosphere
- This process produces about 98% sulphuric acid (remaining 2% is water)
- Since many of these reactions are exothermic, the energy released can be used to contribute to the running of the plant
 - this reduces costs
 - benefits the environment

- **describe the reaction conditions necessary for the production of SO₂ and SO₃**
- *See above*

- **apply the relationship between rates of reaction and equilibrium conditions to the production of SO₂ and SO₃**
- *See above*

- **describe, using examples, the reactions of sulphuric acid acting as:**
 - **an oxidising agent**
 - Sulphuric acid is a moderately strong oxidising agent
 - An *oxidising agent* is a substance that brings about oxidation
 - $Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$
 - Copper ion take electrons from the zinc metal so it is the oxidising agent (or oxidant)
 - A *reducing agent* is a substance that brings about reduction
 - $Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$
 - Zinc metal gives the copper ion electrons so it is the reducing agent (or reductant)
 - Hot sulphuric acid can oxidise carbon to carbon dioxide
 - $C(s) + 2H_2SO_4(l) \rightarrow CO_2(g) + 2SO_2(g) + 2H_2O(l)$
 - It is evident here that carbon's oxidation state has been raised from 0 to 4
 - Therefore sulphuric acid has oxidised carbon to carbon dioxide
 - Sulphuric acid is used to oxidise Pb to Pb²⁺ in lead-acid batteries
 - Electrode reactions
 - $Pb + SO_4^{2-} \rightarrow PbSO_4(s) + 2e^-$
 - $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4(s) + 2H_2O$
 - Overall reaction
 - $Pb + PbO_2 + 4H^+ + 2SO_4^{2-} \rightarrow 2PbSO_4(s) + 2H_2O$
 - **a dehydrating agent**
 - Sulphuric acid can absorb water from mixtures such as moist air and form an aqueous solution
 - This property results in it being used to dry gasses such as air or LPG since they do not react with it
 - It is also able to suck hydrogen and oxygen molecules out of compounds to form water
 - The most dramatic reaction that demonstrates the dehydrating power of concentrated sulphuric is its reaction with sucrose (sugar) C₁₂H₂₂O₁₁ (or C₁₂(H₂O)₁₁)
 - $C_{12}H_{22}O_{11}(s) \xrightarrow{[H_2SO_4]} 12C(s) + 11H_2O(\text{in solution with } H_2SO_4)$
 - A simple example showing its dehydration power is its ability to turn blue copper sulphate pentahydrate into white anhydrous copper sulphate by storing it in a desiccator with sulphuric acid
 - $CuSO_4 \cdot 5H_2O(s) \xrightarrow{H_2SO_4} \underset{\text{white}}{CuSO_4}(s) + 5H_2O(\text{in solution with } H_2SO_4)$
 - It is also used to dehydrate ethanol to ethene

- **describe and explain the exothermic nature of sulphuric acid ionisation**
- When concentrated sulphuric acid (98%) is diluted with water a lot of heat is released
 - $H_2SO_4(98\%) \rightarrow H_2SO_4(\text{very dilute solution}) \quad \Delta H = -90\text{kJ/mol}$
 - so much heat is released that there is danger of the vaporisation of the water and splashing the acid
- this is not the case when diluting other strong acids such as concentrated HCl or HNO₃
- The reason concentrated sulphuric acids releases so much heat is because its dilution involves breaking the molecule into ions
 - $H_2SO_4(l) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$
- in concentrated sulphuric acid there are very few ion, most of the water is tied up as hydrates such as $H_2SO_4 \cdot H_2O$
- when water is added in the dilution process the molecules can ionise which releases much heat
- in concentrated HCl and NO₃ all the acid molecules are already ionised

- **identify and describe safety precautions that must be taken when using and diluting concentrated sulphuric acid**
- Since the dilution of concentrated sulphuric acid releases much heat care need to be taken in the dilution process
- adding water to the acid is dangerous since the heat produced would vaporise the water and splash the acid
- **ALWAYS** add the concentrated acid slowly to the water
- *“always do what ya oughter, add acid to the water”*
- When using sulphuric acid always wear safety goggle, lab coat, gloves, etc.
- have a ready supply of running water
- have a supply of sodium carbonate ready to dilute any spills

Students:

- **gather, process and present information from secondary sources to describe the steps and chemistry involved in the industrial production of H₂SO₄ and use available evidence to analyse the process to predict ways in which the output of sulphuric acid can be maximised**
- **perform first-hand investigations to observe the reactions of sulphuric acid acting as:**
 - an oxidising agent
 - a dehydrating agent
- **use available evidence to relate the properties of sulphuric acid to safety precautions necessary for its transport and storage**
- Concentrated sulphuric acid have very few ion so it doesn't attack iron or steel
 - it can be safely stored in steel containers
 - and transported in steel tankers
- When diluted it vigorously attacks iron or steel
 - must be stored in glass or plastic containers
 - this makes it more difficult to transport since glass and plastic are weak
 - care must be taken not to contaminate concentrated acid with water when transporting in steel container or there will be a vigorous reaction between acid and container

4. The industrial production of sodium hydroxide requires the use of electrolysis

Students learn to:

- **explain the difference between galvanic cells and electrolytic cells in terms of energy requirements**
- A *galvanic cell* is a device in which a chemical reaction generates electricity (converts chemical energy into electricity energy)
- A cell in which *electrolysis* occurs is called an *electrolytic cell*
- *Electrolysis* is a process in which electrical energy is used to bring about chemical change (converts electrical energy into chemical energy)
- lead-acid cells act as *galvanic cell* when used but act as *electrolytic cell* when being recharged

- **outline the steps in the industrial production of sodium hydroxide from sodium chloride solution and describe the reaction in terms of net ionic and full formulae equations**
- Sodium Hydroxide is produced industrially by the electrolysis of a concentrated sodium chloride solution
- $2\text{NaCl}(aq) + 2\text{H}_2\text{O}(l) \xrightarrow{\text{electrolysis}} 2\text{NaOH}(aq) + \text{Cl}_2(g) + \text{H}_2(g)$
- At the anode (oxidation)
 - $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^-$
- At the cathode (reduction)
 - $2\text{H}_2\text{O} + 2e^- \rightarrow \text{H}_2 + 2\text{OH}^-$
- Adding these we have the net ionic equation
 - $2\text{Cl}^- + 2\text{H}_2\text{O} \rightarrow \text{Cl}_2 + \text{H}_2 + 2\text{OH}^-$
- Adding the spectator ions we get the ionic equation
 - $2\text{Na}^+ + 2\text{Cl}^- + 2\text{H}_2\text{O} \rightarrow \text{Cl}_2 + \text{H}_2 + 2\text{Na}^+ + 2\text{OH}^-$
- Combing the ions the neutral species equation (full formulae, balanced formulae)
 - $2\text{NaCl}(aq) + 2\text{H}_2\text{O}(l) \rightarrow \text{Cl}_2(g) + \text{H}_2(g) + 2\text{NaOH}(aq)$
- Practical problems
 - Keeping the H_2 and Cl_2 gasses separate since they react vigorously together
 - minimising contact between hydroxide ion and chlorine in solution (because $\text{OH}^- + \text{Cl}_2$ forms the unwanted chlorite, ClO^-)
 - minimising the amount of chloride that is present in the final hydroxide solution

- **distinguish between the three electrolysis methods used to extract sodium hydroxide:**
 - **diaphragm process**
- titanium anode to withstand chlorine formed
- iron mesh cathode, not affected by hydroxide solution
- the diaphragm (made of asbestos) is designed to allow sodium to flow through, thus completing the circuit and create sodium hydroxide
- However, the diaphragm also lets small amounts of chloride and hydroxide through, causing problems
- A slight positive pressure is maintained on the anode side to stop the problematic migration of hydroxide to the anode side
- A barrier stops the chlorine and hydrogen mingling
- Since there will be NaCl in the NaOH solution extracted
 - the solution is evaporated to about 50% by mass of NaOH
 - since NaOH is more soluble the NaCl crystallises out of solution
 - It is filtered off and the remaining solution is about 99% NaOH
- Advantage
 - cheap and fast to produce
- Disadvantages
 - Always small amount of chlorine in sodium hydroxide
 - health and environmental problems with small losses of asbestos into the atmosphere
 - there may be hypochlorite, ClO^- , a strong oxidant, in the waste brine solution and this needs to be removed before brine is discharged to the environment
- **mercury process**
- Uses liquid mercury as the cathode, sodium is reduced and incorporated into the mercury
- At the cathode
 - $\text{Na}^+ + e^- \rightarrow \text{Na}(\text{dissolved in mercury})$
- At the anode
 - $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^-$
- Overall reaction
 - $2\text{Na}^+ + 2\text{Cl}^- \rightarrow \text{Cl}_2(\text{g}) + 2\text{Na}(\text{dissolved in mercury})$
- The mercury flows into a second chamber containing pure water
- The sodium in the mercury reacts with the pure water to form sodium hydroxide and hydrogen gas
 - $2\text{Na}(\text{dissolved in mercury}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$
- Rather than small cells like in the membrane and diaphragm cells, one big cell is used for a mercury cell
- Advantages
 - produces very pure sodium hydroxide
 - avoids using asbestos
- Disadvantages
 - there is some loss of mercury to the environment, mercury is toxic when it enters food chain

- **membrane process**
- Basically the same as a diaphragm cell but with a more advanced diaphragm
- the diaphragm is a polymer made from polytetrafluoroethylene (PTFE)
 - this is an ion exchange membrane so it only lets some ion through
 - has anionic groups incorporated in the polymer so only sodium can pass through
 - Can stand immersion in Sodium Hydroxide for long times
- due to the ion exchange membrane it produces almost pure sodium hydroxide
- on the reduction side dilute NaOH is pumped in and concentrated
- Advantages
 - very pure sodium hydroxide
 - avoids use of toxic materials
- Disadvantages
 - expensive due to new technology
- **by describing each process and analysing the technical and environmental difficulties involved in each process**
- *See above*

Students:

- **identify data, plan and perform a first-hand investigation to identify the products of the electrolysis of sodium chloride**

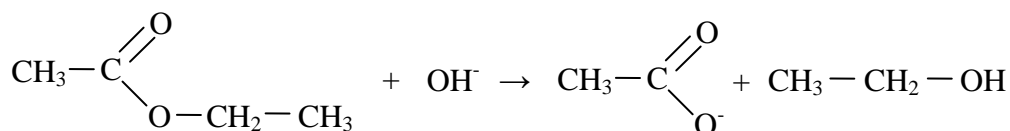
CONDITIONS USED	PRODUCT FORMED	
	at the anode	at the cathode
molten	Cl ₂	Na
concentrated aqueous solution, inert electrodes	Cl ₂	H ₂
dilute aqueous solution, inert electrodes (<0.1M)	O ₂	H ₂
concentrated aqueous solution, Hg cathode	Cl ₂	Na

- **analyse information from secondary sources to predict and explain the different products of the electrolysis of aqueous and molten sodium chloride**
- *See above*

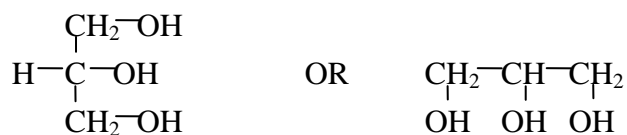
5. Saponification is an important organic industrial process

Students learn to:

- describe saponification as the conversion in basic solution of fats and oils to glycerol and salts of fatty acids
- To understand the process of saponification of fats and oils a simpler case must be considered
- The reaction between an ester and hydroxide ion to form an alcohol and a carboxylate anion is called *saponification*
 - for example ethyl acetate (ethanoate) can be converted into ethanol and the acetate anion by heating it in a NaOH solution

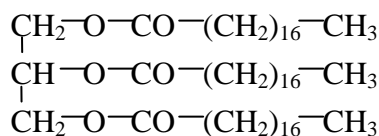


- This can be written as
- $R_a-\text{COO}-R_b + \text{OH}^- \rightarrow R_a-\text{COO}^- + R_b-\text{OH}$
- R_a is one alkyl group and R_b is another alkyl group (R_b may be the same as R_a)
- remember that $-\text{COO}-$ represents the structure in the diagram
- Fats and oils are essentially more complex esters, they are esters of glycerol, a derivative of propane containing an alcohol group on each carbon atom
- glycerol has the structure

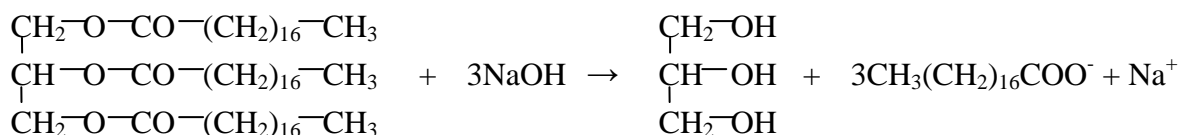


- fats and oils are esters where *one* alcohol molecule is combined with *three* acid molecules
- the acids involved are usually long-chain ones (12+ carbons) these are called fatty acids
- saturated (all single bonds) fatty acids lead to solid fats
- unsaturated (not all single bonds) fatty acids lead to liquid fats

- Fats and oil have the chemical name *triglyceride*
- A common triglyceride is glyceryl tristearate, a fat found in animals



- note that the -CO- is the C=O structure found in esters
- When these triglycerides (fats and oils) are heated with NaOH, they saponify just like normal esters to form glycerol and the sodium salts of the carboxylic acids. for glyceryl tristearate

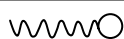
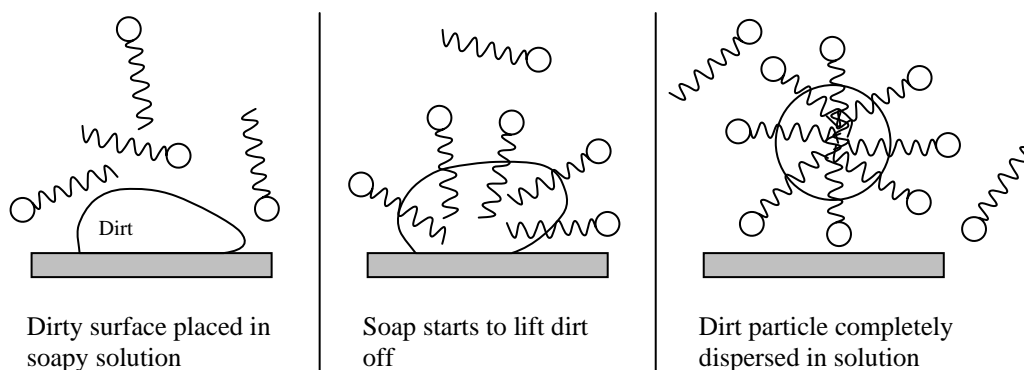


- **describe the conditions under which saponification can be performed in the school laboratory and compare these with industrial preparation of soap**
- saponification is a school laboratory
 - generally carried out with simple esters rather than the long chain fats and oils
 - to saponify them they need to be boiled with NaOH
 - esters and the alcohols they form are usually volatile so the reaction need to be performed with a reflux condenser so that there is no loss from evaporation
 - after the reaction is complete the resulting mixture is usually homogeneous (all dissolved)
 - This mixture is separated by fractional distillation
- making soap in industry
 - this is a saponification reaction involving long chain fats and oils
 - the reactants and products formed are non-volatile so refluxing is not necessary
 - the oils or chopped up fats are heated with about 30% NaOH solution until all the fat and oil has dissolved
 - any solid residue is skimmed off
 - the solution is cooled and nearly saturated brine is added
 - after standing the mixture settles into two distinct layers
 1. curds of soap on the top with glycerol dissolved in brine on the bottom
 - the curds are skimmed off
 1. then washed
 2. perfume and colouring added
 3. pressed into bars
 - Glycerol is extracted through distillation
 1. this can be used to make dynamite (nitro-glycerine)
- making soap in laboratory
 - essentially the same as in industry but at a smaller scale
 - Care need to be taken in handling NaOH, it is corrosive to skin, hair, flesh, eyes, etc.
 - Goggles, lab coat, gloves, etc must be worn

- **account for the cleaning action of soap by describing its structure**
- definitions
 - soap
 1. a cleaning agent made from naturally occurring fats and oils
 - detergent
 1. a synthetic cleaning agent (use term synthetic surfactant rather than detergent)
 - surfactant
 1. short for surface active substance
 2. soaps and detergents are surfactants
 3. it reduces the surface tension of water and disperses dirt and grease into the water
- Soap has the structure
 - $\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-(CH}_2\text{)}_5\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-COO}^-$
- or schematically




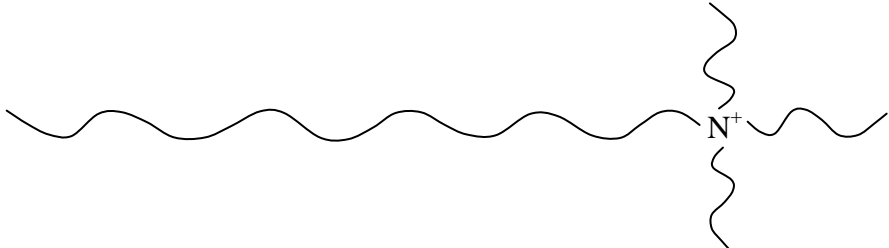


- this is sometimes described as a ‘tadpole’ structure
- the water soluble anionic head is said to be *hydrophilic* (water loving) while the water-repelling tail is described as *hydrophobic* (water hating)
- cleaning action
 - the hydrophobic end attaches to dirt and oil particles in the water
 - the hydrophilic end remains dissolved in the water
 - this pulls the dirt or oil off the surface it was once attached to, thus cleaning it
 - once the oil or dirt particles are removed they do not reattach to the surface or combine together since they are all negatively charged
 - soap is able to remove non oily dirt particles because they reduce the water’s surface tension so the water is able to wet (remember ‘water’ in preliminary course) the particles and remove them
- schematically



-ve side

- **explain that soap, water and oil together form an emulsion with the soap acting as an emulsifier**
- an emulsion is a dispersion of small droplets of one liquid throughout another liquid, for example
 - milk
 - lipsticks
 - moisturisers
- soap, oil and water emulsion
 - the soap acts as the emulsifier which breaks the oil into very small droplets and disperses it through the water
 - the droplets remain dispersed almost indefinitely
 - the process where the soap breaks up the oil can be seen in the cleaning process of soap *above*
- **distinguish between soaps and synthetic detergents in terms of:**
 - **the structure of the molecule**

TYPE	STURCTURE (SCHEMATIC)
soap	
anionic (synthetic)	
non-ionic (synthetic)	
cationic (synthetic)	

– **chemical composition**

TYPE	CHEMICAL COMPOSITION
soap	long hydrocarbon tail with anionic $-\text{COO}^-$ head
anionic (synthetic)	long hydrocarbon tail with anionic $-\text{R}-\text{O}-\text{SO}_2-\text{O}^-$ head sometimes benzene ring at end of hydrocarbon tail
non-ionic (synthetic)	long hydrocarbon tail with a long polar segment as head polar end is formed by joining several ethoxy groups ($-\text{CH}_2-\text{CH}_2-\text{O}-$) with H on end A typical non-ionic surfactant is dodecyl alcohol ethoxylate $\text{CH}_3-\text{CH}_2-\text{CH}_2-(\text{CH}_2)_6-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{O}-(\text{CH}_2-\text{CH}_2-\text{O})_n-\text{CH}_2-\text{CH}_2-\text{OH}$ n is typically between 5 and 50 as the name suggests these are molecules rather than ions
cationic (synthetic)	derivatives of the ammonium ion where the H atoms are replaced by alkyl groups generally there are one or two long chain hydrocarbons and two or three methyl groups the long chain hydrocarbons are the oil soluble tail(s) the charged N^+ atom is the water soluble part The simplest cationic surfactant is cetyl trimethyl ammonium bromide $\text{CH}_3-\text{CH}_2-\text{CH}_2-(\text{CH}_2)_9-\text{CH}_2-\text{CH}_2-\overset{\oplus}{\underset{\text{CH}_3}{\text{N}}}-\text{CH}_3 \quad \text{Br}^-$

– **effect in hard water**

TYPE	EFFECT IN HARD WATER (Mg^{2+} and Ca^{2+})
soap	Precipitates (forms soap scum) soap ions and greatly reduces cleaning power
anionic (synthetic)	forms soluble complexes with hard water, slightly reduces cleaning power
non-ionic (synthetic)	no effect
cationic (synthetic)	no effect

- **distinguish between anionic, cationic and non-ionic synthetic detergents in terms of:**
 - **chemical composition**
- *see above*
 - **uses**

TYPE	USES
anionic (synthetic)	very effective at removing oil so not used for personal hygiene Used in laundry detergents and dishwashing liquids Generates a lot of foam so not used in low foam applications (foam is not essential for cleaning except for low water applications such as shampooing) foam can be a problem in some applications such as automatic dishwashers and front loading washing machines
non-ionic (synthetic)	forms much less foam than anionic surfactants they are used where foam can be a problem large amounts are used in dishwasher powders some is added to laundry detergents the main use of non-ionic surfactants are in paints, adhesives, pesticides and cosmetics
cationic (synthetic)	Cleans plastics most effectively they absorb into hair and fibres in textiles to reduce friction and stop static charges forming so they are used in hair conditioners and fabric softeners Many cationic surfactants are effective biocides so they are used in many disinfectants

Students:

- **perform a first-hand investigation to carry out saponification and test the product**

- gather, process and present information from secondary sources to identify a range of fats and oils used for soap-making

NAME (NUMBER OF C ATOMS)	STRUCTURE	MELTING POINT (°C)
<i>Saturated</i>		
lauric (12)	$\text{CH}_3-(\text{CH}_2)_{10}-\text{COOH}$	44
myristic (14)	$\text{CH}_3-(\text{CH}_2)_{12}-\text{COOH}$	58
palmitic (16)	$\text{CH}_3-(\text{CH}_2)_{13}-\text{COOH}$	63
stearic (18)	$\text{CH}_3-(\text{CH}_2)_{16}-\text{COOH}$	70
<i>Unsaturated</i>		
oleic (18)	$\text{CH}_3-(\text{CH}_2)_7-\text{CH}=\text{CH}-(\text{CH}_2)_7-\text{COOH}$	16
ricinoleic (18)	$\text{CH}_3-(\text{CH}_2)_5-\text{CH}(\text{OH})-\text{CH}_2-\text{CH}=\text{CH}-(\text{CH}_2)_7-\text{COOH}$	8
linoleic (18)	$\text{CH}_3-(\text{CH}_2)_4-\text{CH}=\text{CH}-\text{CH}_2-\text{CH}=\text{CH}-(\text{CH}_2)_7-\text{COOH}$	-5
linolenic (18)	$\text{CH}_3-\text{CH}_2-\text{CH}=\text{CH}-\text{CH}_2-\text{CH}=\text{CH}-\text{CH}_2-\text{CH}=\text{CH}-(\text{CH}_2)_7-\text{COOH}$	-11

- perform a first-hand investigation to gather information and describe the properties of a named emulsion and relate these properties to its uses
- French salad dressing emulsion
 - French dressing is made by adding very small amounts of mustard powder to a small amount of red wine vinegar.
 - Small amounts are added 'bit by bit' until all of it has been added. The mixture is shaken vigorously then allowed to stand.
 - Thus, the mustard is suspended in the red wine vinegar
 - French dressing is a water-in-oil emulsion that is used on salads; therefore, taste, texture and presentation are important.
 - The production of the emulsion means that there is not a layer of oil "floating" in the dressing; therefore, it looks more appetising.
 - The even distribution of oil and red wine particles means that there is a consistent texture and taste to the dressing – not the individual components of the dressing.
- Bile in human body
 - Bile in the human body forms an emulsion with the fat and oil in the small intestine.
 - The liver produces bile, stored in the gall bladder. It passes down the bile duct and enters the small intestine where it emulsifies fat and oil.
 - The oil droplets become so small that they can be absorbed through the wall of the small intestine into the bloodstream.

- **perform a first-hand investigation to demonstrate the effect of soap as an emulsifier**
- **solve problems and use available evidence to discuss, using examples, the environmental impacts of the use of soaps and detergents**
- Soap
 - very little environmental impact since it is easily broken down by bacteria
 - it is *biodegradable*
- Synthetic surfactants
 - the earliest synthetic surfactants weren't biodegradable and caused considerable environmental impact
 - since it remained in the river it managed to create "rivers of foam"
 - later they were designed to be biodegradable and this problem disappeared
- cationic surfactants
 - these are biocides so there is danger in using large amounts since that would result in killing the bacteria in the treatment plants
- phosphate builders
 - as mentioned above anionic surfactants are affected by hard water
 - builders are chemicals that tie up the magnesium and calcium ions in complexes so that they don't affect the cleaning process
 - a common builder is sodium tripolyphosphate $\text{Na}_5\text{P}_3\text{O}_{10}$
 1. this forms complexes with Ca^{2+} and Mg^{2+}
 2. it buffers to solution to slightly alkaline which is the optimum condition for cleaning
 3. it stops removed dirt from flocculating (clumping together) and re-settling on clothes
 - there are environmental problems with use of phosphates
 1. phosphate is a nutrient so it can cause harmful algal blooms
 2. algal blooms lead to eutrophication of water ways

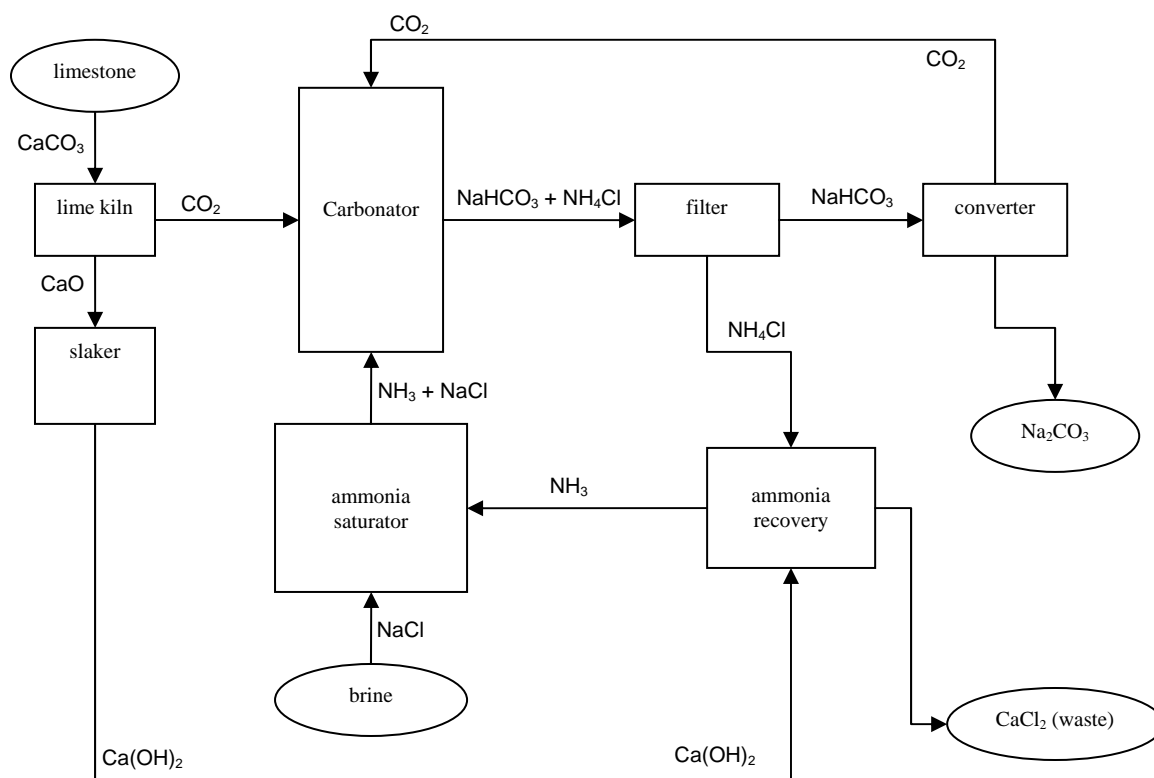
6. The Solvay process has been in use since the 1860s

Students learn to:

- **identify the raw materials used in the Solvay process and name the products**
- Raw materials
 - limestone
 - brine
- products
 - CaCl_2 (waste)
 - Na_2CO_3

- **describe the uses of sodium carbonate**
- Glass making (major use)
 - window glass is made by melting a mixture of sodium carbonate, calcium carbonate and sand (silicon dioxide)
 - also called soda glass
- Making soaps and detergents
 - often used as a cheaper alternative to NaOH
- Water treatment
 - used to soften water since it precipitates Ca^{2+} and Mg^{2+}
- As a common base
 - to neutralise acid spills
 - to do reactions involving bases

- identify, given a flow chart, the sequence of steps used in the Solvay process and describe the chemistry involved in:
 - brine purification
 - hydrogen carbonate formation
 - formation of sodium carbonate
 - ammonia recovery
- Flowchart



- Steps in creation of sodium carbonate
 - brine (NaCl) is purified so that it is suitable for use in process
 - sodium hydrogen carbonate (NaHCO_3) is formed from the reaction between carbon dioxide (CO_2), water (H_2O), ammonia (NH_3) and sodium chloride (NaCl)
 - sodium hydrogen carbonate (NaHCO_3) is heated and turned into sodium carbonate (Na_2CO_3)
 - ammonium chloride (NH_4Cl) formed in the reaction is turned back to ammonia (NH_3) and reused

- Brine purification
 - Brine obtained from the is not pure sodium chloride, there are many impurities such as
 1. Iron
 2. Calcium
 3. Magnesium
 - these would precipitate during the creation of sodium carbonate and cause the end product to be impure
 - to avoid this the brine is purified by first precipitating out these ions
 1. with Carbonate (CO_3^{2-})
 2. $\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$
 3. with hydroxide (OH^-)
 4. $\text{Mg}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Mg}(\text{OH})_2(\text{s})$
 5. $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^-(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 5. Carbonate and hydroxide are used because most ions precipitate with them
 - the precipitates are filtered off and the brine is fed into the ammonia saturator
- Hydrogen Carbonate formation
 - Carbon dioxide is obtained from the lime kiln
 1. limestone (CaCO_3) is heated in the lime kiln
 2. $\text{CaCO}_3(\text{s}) \xrightarrow{\text{heat}} \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
 3. the calcium oxide (CaO) is sent to the slaker (*discussed later*)
 - this carbon dioxide is bubbled through the brine saturated with ammonia in the carbonator
 - this is most easily observed step by step
 1. the carbon dioxide dissolves in the solution
 2. $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
 3. the weak acid carbonic acid (H_2CO_3) reacts with the weak base ammonia (NH_3)
 4. $\text{NH}_3(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$
 5. Sodium ions (Na^+) precipitate the hydrogen carbonate ion (HCO_3^-), sodium ions don't usually precipitate. However, this is a special case. The precipitate (NaHCO_3) is slightly soluble. But, insoluble enough to be filtered out
 6. $\text{Na}^+(\text{aq}) + \text{HCO}_3^-(\text{aq}) \rightleftharpoons \text{NaHCO}_3(\text{s})$
 - Adding these reactions together we obtain the net-ionic equation
 1. $\text{Na}^+(\text{aq}) + \text{CO}_2(\text{g}) + \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NaHCO}_3(\text{s}) + \text{NH}_4^+(\text{aq})$
 - if we add the chlorine ion (Cl^-), which was a spectator from NaCl , to this reaction we get the molecular equation
 1. $\text{NaCl}(\text{aq}) + \text{CO}_2(\text{g}) + \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NaHCO}_3(\text{s}) + \text{NH}_4\text{Cl}(\text{aq})$

- formation of sodium carbonate
 - since NH_4Cl is soluble, NaHCO_3 is filtered of and fed to a converter
 - in this converter the NaHCO_3 is heated to form sodium carbonate
 1. $2\text{NaHCO}_3(s) \rightarrow \text{Na}_2\text{CO}_3(s) + \text{CO}_2(g) + \text{H}_2\text{O}(g)$
 - the carbon dioxide formed here is fed back into the carbonator to reduce costs
 - the amount of CO_2 produced is approximately half of what is used so CO_2 from the lime kiln still needs to be continuously fed into the carbonator
- ammonia recovery
 - ammonia is relatively expensive so it is advantageous to recycle it in the production process
 - a product from the lime kiln is calcium oxide (CaO), this was fed to the slaker
 - in the slaker this CaO is mixed with water to form a base calcium hydroxide (Ca(OH)_2)
 1. $\text{CaO}(s) + \text{H}_2\text{O}(l) \rightarrow \text{Ca(OH)}_2(aq)$
 - ammonium chloride (NH_4Cl) from the filter is reacted with this Ca(OH)_2
 1. $\text{Ca(OH)}_2(aq) + 2\text{NH}_4\text{Cl}(aq) \rightarrow \text{CaCl}_2(aq) + 2\text{H}_2\text{O}(l) + 2\text{NH}_3(g)$
 - clearly ammonia (NH_3) is regenerated
 - the only waste is the CaCl_2 which is non-toxic at low concentrations
- **discuss environmental issues associated with the Solvay process and explain how these issues are addressed**
- Disposal of calcium chloride
 - most Solvay plants dump their CaCl_2 into the ocean (at suitable dilution)
 - CaCl_2 is non-toxic to has little effect on the oceans
 - inland Solvay plants cannot dump their waste into rivers since it would significantly increase the Cl^- concentration in the rivers
 - for inland Solvay plants the solution is to evaporate the CaCl_2 to dryness and bury it in special burial sites
- Ammonia losses
 - Ammonia is a significant air pollutant so loss on ammonia to the atmosphere must be kept at a minimum, particularly near cities
- Waste heat
 - the overall Solvay process is exothermic so considerable amounts of waste heat needs to be disposed of
 - thermal pollution (raising the temperature of the water) of oceans needs to be taken into account
 - Inland plants need to use cooling ponds since rivers and lakes are considerably more susceptible to thermal pollution
- Mining
 - Mining of the limestone or brine (for inland plants) could cause environmental damage, particularly if the mining site is in sensitive areas

Students:

- **perform a first-hand investigation to assess risk factors and then carry out a chemical step involved in the Solvay process, identifying any difficulties associated with the laboratory modelling of the step**
- the step involving the reaction of ammonia and brine with carbonic acid is difficult to model in the laboratory due to the following
 - high concentrations of ammonia is extremely toxic and must be used in a fume cupboard

- **process information to solve problems and quantitatively analyse the relative quantities of reactants and products in each step of the process**
- **use available evidence to determine the criteria used to locate a chemical industry using the Solvay process as an example**
- availability of raw materials (brine, limestone), transport is expensive
- availability of sufficient energy at competitive rates
- location of markets for the product (product can be sold)
- availability of a workforce at reasonable cost
- suitability of nearby sites for disposal of wastes (waste is CaCl_2)
- environmental controls on discharge to air and water (so there is acceptable air/water/thermal pollution)

Summary Tables

Flame Colours

Element	Flame Colour
<i>Definitely needed</i>	
Barium (Ba)	Yellowish Green
Calcium (Ca)	Yellowish to Orange Red
Copper (Cu)	Blue Green
Lead (Pb)	pale Green
<i>Probably not needed</i>	
Lithium (Li)	Crimson Red
Strontium (Sr)	Crimson Red
Sodium (Na)	Intense Yellow
Boron (B)	Bright somewhat yellowish Green
Phosphorous (P)	Pale blue Green
Zinc (Zn)	bluish Green
Potassium (K)	pale Violet

Solubility

soluble compounds	except	insoluble compounds	except
Group 1, NH ₄ ⁺		Carbonates (CO ₃ ²⁻)	Group 1, NH ₄ ⁺
Nitrates (NO ₃ ⁻)		Sulfites (SO ₃ ²⁻)	Group 1, NH ₄ ⁺
acetates (ethanoate) CH ₃ COO ⁻		phosphates (PO ₄ ³⁻)	Group 1, NH ₄ ⁺
Chlorides, Bromides, Iodides	Ag ⁺ , Pb ²⁺	hydroxides (OH ⁻)	Group 1, NH ₄ ⁺ , Ba ²⁺ , Sr ²⁺ , Ca ²⁺
Sulfates (SO ₄ ²⁻)	Ag ⁺ , Pb ²⁺ , Ba ²⁺ , Sr ²⁺ , Ca ²⁺	oxides (O ²⁻)	Group 1, NH ₄ ⁺ , Ba ²⁺ , Sr ²⁺ , Ca ²⁺
		sulfides (S ²⁻)	Group 1, 2, NH ₄ ⁺

note: some of these insoluble compounds are still slightly soluble, so will dissolve in excess water

Indicators

INDICATOR	COLOUR CHANGE				
	HIGHLY ACIDIC	SLIGHTLY ACIDIC	NEUTRAL	SLIGHTLY ALKALINE	HIGHLY ALKALINE
methyl orange	red	→ yellow	yellow	yellow	yellow
bromothymol blue	yellow	yellow	→ blue	blue	blue
litmus	red	red	→ blue	blue	blue
phenolphthalein	colourless	colourless	colourless	→ red	red
red cabbage	red	purple	→ green	green	yellow

Catalyst Type Things

- **Catalytic Cracking**
 - Zeolite
- **Low Density Polyethylene**
 - Organic peroxide (something containing -O-O- Group) initiator
 - O_2 can be used
- **High Density Polyethylene**
 - Titanium (III) Chloride and Trialkylaluminium compound
- **Dehydration of Ethanol**
 - Concentrated Sulphuric Acid (H_2SO_4)
- **Hydration of Ethene**
 - Dilute H^+ catalyst (eg. H_3PO_4 or H_2SO_4)
- **Esterification**
 - Concentrated sulphuric acid is used, it absorbs water and catalyses the reaction
- **Haber process (production of ammonia)**
 - Iron/iron oxide (Fe_3O_4)
- **Contact process (production of sulphuric acid)**
 - Vanadium Oxide (V_2O_5)