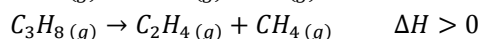
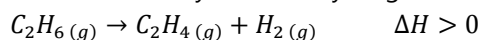


# Production of Materials

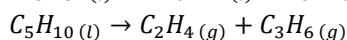
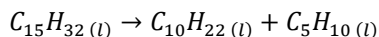
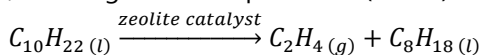
## 1.1 Energy and Raw Materials from Fossil Fuels

### 1.1.1 Identify the industrial source of ethylene from the cracking of some of the fractions from the refining of petroleum

- **Petroleum** is a mixture of crude oil and natural gas.
- **Fractional distillation** is used to separate crude oil into *fractions* according to their boiling point ranges (each fraction contains hydrocarbons of similar molecular weight). Lighter fractions with lower boiling point rise higher in the column.
- The main industrial source of ethylene is from the cracking of fractions obtained from the refining of petroleum. Low-demand, long-chain hydrocarbons are cracked to produce smaller chains such as ethylene, which is the starting product for many synthesis reactions.
- Steam (thermal) cracking:
  - Cracking of petroleum fractions was initially achieved by thermal cracking, where the fraction is heated to high temperatures (1000°C) in the absence of air.
  - In Australia, steam cracking is the major industrial source of ethylene for the petrochemical industry. It provides a high yield of ethylene, as the reaction is endothermic.
  - Ethane ( $C_2H_6$ ), which is obtained from petroleum and natural gas, is mixed with steam and passed through hot metal coils to form ethylene and hydrogen:

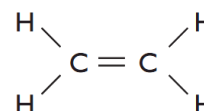


- Catalytic cracking:
  - Catalytic cracking is the process of breaking long-chain hydrocarbons into smaller chains. Zeolite is used as a catalyst, allowing lower temperatures (500°C) to be used.
- This process uses less heat than thermal cracking, but it cannot decompose large molecules (C15-C25) completely into ethylene, so it is insufficient in meeting the demands of industry.



### 1.1.2 Identify that ethylene, because of the high reactivity of its double bond, is readily transformed into many useful products

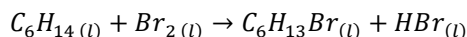
- Alkanes and their corresponding alkenes are non-polar carbon chain molecules with weak dispersion forces between the molecules. Their *physical* properties (e.g. melting point and solubility) are due to intermolecular forces and thus are similar.
- The *chemical* properties of alkanes and alkenes are very different. The presence of the carbon-carbon double bond in alkenes makes them much more reactive than alkanes. Alkanes are saturated as they only have carbon-carbon single bonds, and so are unreactive. Alkenes are unsaturated and hence more reactive, as they undergo addition reactions readily.
- Ethylene has a **highly reactive double bond** (a site of high electron cloud density) which allows it to undergo polymerisation. The double bond breaks open to form two single bonds.



- Useful products derived from ethylene:

Process	Product	Formula	Use
Polymerisation	Polyethylene	$(CH_2)_n$	Plastic
Hydration	Ethanol	$C_2H_5OH$	Solvents, antiseptics
Halogenation	Polyvinyl chloride	$(C_2H_3Cl)_n$	Pipes, insulation

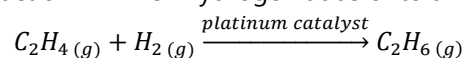
- Alkanes* undergo **substitution reactions**, where an atom in a molecule is replaced by another atom or group of atoms.



- Alkenes* commonly react with molecules (e.g.  $Cl_2$ ,  $Br_2$ ,  $HCl$ ,  $H_2O$ ) through **addition reactions**, where a small molecule adds across a double or triple bond of a hydrocarbon molecule.

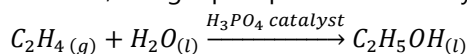
– Hydrogenation:

- This is an addition reaction in which hydrogen adds onto an unsaturated molecule:



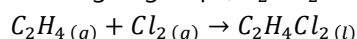
– Hydration:

- Ethylene is reacted with water, using a phosphoric acid catalyst, to produce ethanol:



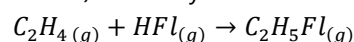
– Halogenation:

- Reactive molecules from the halogen group ( $Fl_2$ ,  $Cl_2$ ,  $Br_2$ ) can all react with ethylene:



– Hydrohalogenation:

- A hydrohalogen (e.g.  $HCl$  or  $HFl$ ) and ethylene react to form a haloethane

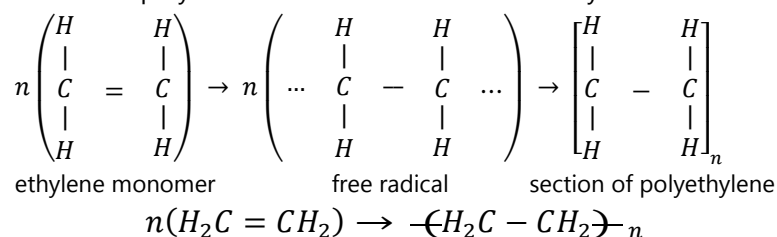


### 1.1.3 Identify that ethylene serves as a monomer from which polymers are made

- Ethylene serves as a monomer from which polymers are made. It is the starting material for the production of other commercially significant monomers such as chloroethene and phenylethene.
- Ethylene undergoes addition polymerisation due to its reactive double bond.

### 1.1.4 Identify polyethylene as an addition polymer and explain the meaning of this term

- Polymers** are long-chain molecules composed of repeating sub-units called **monomers**.
- Addition polymerisation is the polymerisation of monomers by an addition reaction.
- An **addition polymer** forms when small monomers (e.g. ethylene) add together to produce longer chain molecules called polymers (e.g. polyethylene), and no other product.
- In addition polymerisation, the monomers add to the growing polymer chain so that all atoms present in the monomer are present in the polymer. There is no gain or loss of atoms.
- One of the bonds in the  $C = C$  double bond is broken, providing each carbon atom with extra bonding capacity, which it uses to form single bonds between the monomers.
- Polyethylene is an addition polymer made from the monomer ethylene:



**1.1.5 Outline the steps in the production of polyethylene as an example of a commercially and industrially important polymer****1.1.6 Analyse information from secondary sources such as computer simulations, molecular model kits or multimedia resources to model the polymerisation process**

- Addition polymerisation requires a catalyst or initiator molecule to start the reaction. Once it is underway, the reaction proceeds rapidly as addition polymerisation is a chain reaction (it is also known as chain-growth polymerisation).
- Stages in the production of polyethylene:
  - **Initiation**
    - The initiator molecule (e.g. peroxide) decomposes to form reactive free radicals.
$$R - O - O - R \rightarrow 2R - O \cdot$$
    - The free radicals break the double bond of an ethylene monomer to form an ethylene free radical.
$$\begin{array}{ccccccc} R - O \cdot & + & CH_2 = CH_2 & \rightarrow & R - O - CH_2 - CH_2 \cdot \\ \text{radical} & & \text{ethylene} & & \text{ethylene radical} \end{array}$$
  - **Propagation**
    - This ethylene free radical (called an 'activated monomer') reacts with another ethylene monomer, and this process continues with the polymer chain length increasing (i.e. chain growth occurs).
$$\begin{array}{ccccccc} R - O - CH_2 - CH_2 \cdot & + & CH_2 = CH_2 & \rightarrow & R - O - CH_2 - CH_2 - CH_2 - CH_2 \cdot \\ \text{ethylene radical} & & \text{ethylene} & & \text{polyethylene radical} \end{array}$$
  - **Termination**
    - When two free radical ethylene chains combine, a complete polyethylene molecule is formed and the process stops.
$$\begin{array}{ccccccc} R - O - (CH_2 - CH_2)_n \cdot & + & R - O - (CH_2 - CH_2)_n \cdot & \rightarrow & R - O - (CH_2 - CH_2)_{2n} - O - R \\ \text{polyethylene radical} & & \text{polyethylene radical} & & \text{polyethylene} \end{array}$$
- An inhibitor is added to halt the formation of free radicals. This can occur at any time, so the size and molecular weight of polymer chains can be regulated.
- Methods used to produce polyethylene:
  - **High pressure method**
    - This process uses high temperature and pressure and an initiator molecule (e.g. organic peroxide). This initiator is not a catalyst as it is incorporated into the final polymer formed.
    - This creates **low-density polyethylene (LDPE)** which has significant chain branching, i.e. **branched** chains of polyethylene that cannot be packed together tightly.
      - » This results in a soft, flexible, low density plastic with low melting point (due to low dispersion forces between chains).
  - **Ziegler-Natta process**
    - This process uses a much lower temperature and pressure and a transition metal catalyst (Ziegler-Natta catalyst).
    - This creates **high-density polyethylene (HDPE)**, i.e. **unbranched**, linear polyethylene molecules that can be packed together very densely.
      - » Extensive dispersion forces make HDPE stronger and less flexible than LDPE.
- In both these processes, the initiator or catalyst activates an ethylene molecule by attaching to it.

### 1.1.7 Identify vinyl chloride and styrene as commercially significant monomers by both their systematic and common names

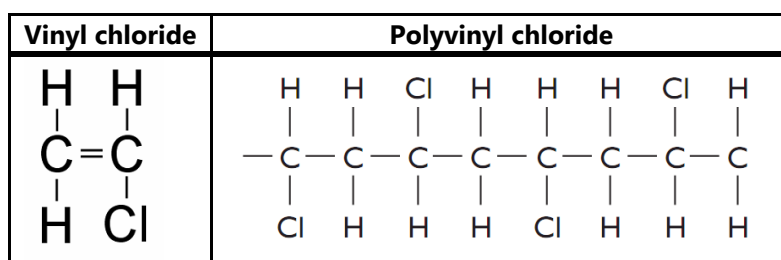
### 1.1.8 Describe the uses of the polymers made from the above monomers in terms of their properties

#### • Ethylene

- *Polymer*: polyethylene
- Uses of polyethylene:
  - *Low-density polyethylene* (highly branched):
    - » The extensive chain-branching of LDPE makes it relatively *soft* and *flexible* so it is used in making **plastic cling wrap** and **plastic bags**.
  - *High-density polyethylene* (unbranched):
    - » HDPE has no chain branching so linear polymer chains pack closely together, held tightly by dispersion forces. This results in the polymer being *rigid* and *hard*, so it is used in making durable items such as **kitchen utensils and containers** and **rubbish bins**.

#### • Vinyl chloride

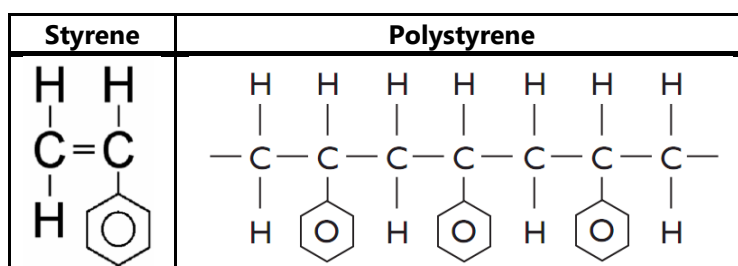
- *Systematic name*: **chloroethene**
- Vinyl chloride is an ethylene molecule with a *H* atom substituted with a *Cl* atom.
- *Polymer*: **polyvinyl chloride** (PVC).



- Uses of polyvinyl chloride:
  - PVC is hard, inflexible and brittle, and the large *Cl* atoms increase the polymer's stiffness. These *rigid* forms of PVC can be used for **drainage and sewage pipes** and **guttering**.
  - Softer PVC can be produced by adding a plasticiser, which decreases the dispersion forces between the polymer chains and makes the polymer more *flexible*. This makes PVC useful for **electrical insulation** and **flexible tubing**.

#### • Styrene

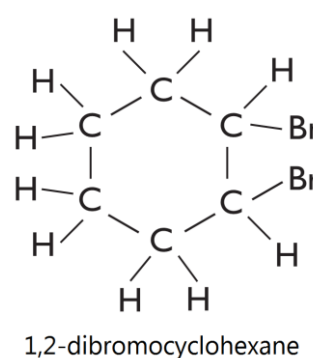
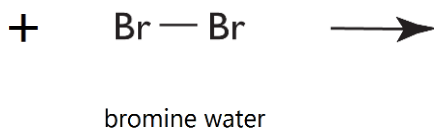
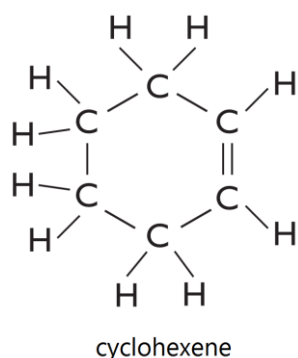
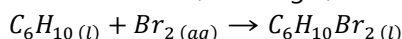
- *Systematic name*: **phenylethene** or **ethenyl benzene**
- Styrene is an ethylene molecule with an *H* atom replaced by a benzene ring (a 6C ring with alternating double bonds).
- *Polymer*: **polystyrene** (PS)



- Uses of polystyrene:
  - Polystyrene is *electrically insulative* and very *hard* and *rigid* due to the presence of the large side group benzene rings along the polymer chains. This makes it suitable for **car battery cases** and **tool handles**.
  - The minimal chain branching also makes polystyrene very crystalline, so it can be formed into *clear, transparent* objects such as **drinking glasses** and **CD cases**.
  - If gas is bubbled through the polymer as it forms, styrofoam is formed. Styrofoam is used for insulation and packaging as it is a good heat insulator and shock absorber.

### 1.1.9 Identify data, plan and perform a first-hand investigation to compare the reactivities of appropriate alkenes with the corresponding alkanes in bromine water

- Aim: To compare the reactivity of cyclohexane and cyclohexene bromine water.
- Equipment: two test tubes, cyclohexane, cyclohexene, 0.01M bromine water.
- Method:
  1. 2 mL of cyclohexane was added to one test tube and 2 mL of cyclohexene was added to the other test tube.
  2. 1 mL of bromine water was added to each liquid and the test tubes were shaken to the same extent.
  3. The test tubes were left to settle, and then observed.
- Cyclohexene and cyclohexane were used (instead of ethylene or propene) because:
  - C1 to C4 are gases at room temperature and would be hard to manage. Cyclohexene is a clear, colourless liquid and bromine water is an aqueous brown/yellow solution.
  - Cyclohexene/cyclohexane is more stable, less toxic and has a longer shelf-life than hexene/hexane.
- Results: It was observed that the **cyclohexene immediately decolourised the bromine water from yellow to colourless**, while the cyclohexane remained yellow. This showed which hydrocarbon decolourised the bromine water, allowing them to be *distinguished* from each other. The cyclohexene reacted with the bromine water, forming 1,2-dibromocyclohexane.



- Risk Assessment:
  - Safety goggles were worn to protect from splashing of any solutions.
  - Organic hydrocarbons (cyclohexene and cyclohexane) are highly volatile and flammable so they were kept away from heat sources or flames at all times. They also release moderately toxic vapour, so only small quantities were used and a fume cupboard was used to perform the experiment. Experimental time was kept to a minimum.
  - Bromine water is highly toxic if ingested and is slightly corrosive.

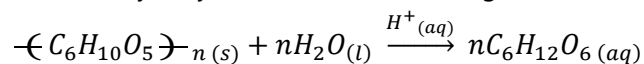
## 1.2 Materials from Biomass

### 1.2.1 Discuss the need for alternative sources of the compounds presently obtained from the petrochemical industry

- Fossil fuels such as crude oil and natural gas are **non-renewable** resources. Consumption of these resources has accelerated in the last century and these fossil fuels could be completely used up within the next few decades.
- Alternative sources of compounds must be developed to meet future energy and material needs.
  - **Ethanol** is the main alternative source of ethylene, as it can be produced by fermentation of starch and sugars, and can be easily converted to ethylene.
  - **Cellulose** (a major component of renewable biomass) is a major source of carbon compounds as it contains the basic carbon chain structures needed to build compounds presently obtained from petrochemicals, and is relatively abundant.
  - **Biopolymers**, produced using enzymes and bacteria, could also be a replacement for plastics.

### 1.2.2 Identify that cellulose contains the basic carbon-chain structures needed to build petrochemicals and discuss its potential as a raw material

- Cellulose consists of 6C glucose units so it contains the basic carbon-chain structures needed to build petrochemicals for use as fuels or raw materials in the production of polymers.
- Cellulose has great potential as a raw material because it is **renewable, readily available** in large amounts and can be **converted to petrochemicals**, reducing our reliance on petroleum (which is a non-renewable resource).
  - Cellulose can be **converted** to products that can be readily metabolised and used as a food source. For example, the acid hydrolysis of cellulose to form glucose:



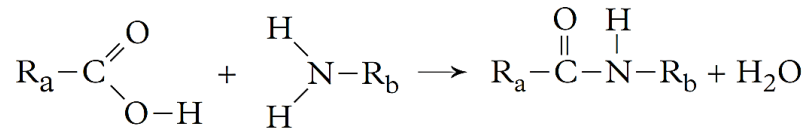
- The existing polymer chains in cellulose can be **modified** to make new polymers (e.g. rayon).
  - Cellulose can be **broken down** into smaller molecules to produce a source of carbon compounds which can be used to make new synthetic polymers. Ethanol, derived from glucose, can be decomposed to form ethylene, an important starting chemical in the production of plastics.
- However, there is currently no efficient method of cellulose decomposition, due to difficulties in hydrolysing cellulose. The conversion of cellulose to ethylene via ethanol has high energy requirements, and is much more expensive than current methods of obtaining ethylene.
- Nevertheless, scientific research continues to develop more efficient and low-cost ways of using cellulose as a raw material. Thus, in the future, biomass (renewable) could be used instead of fossil fuels (non-renewable) to make polymers.

### 1.2.3 Explain what is meant by a condensation polymer

- A **condensation polymer** is one that forms by the elimination of a small molecule (often water) when pairs of monomers join together.
- *Natural* polymers include cellulose, starch, protein and DNA.
  - All biological polymers, such as proteins and starch, are condensation polymers.
- *Manufactured* polymer fabrics include silk, polyester and nylon.

### 1.2.4 Describe the reaction involved when a condensation polymer is formed

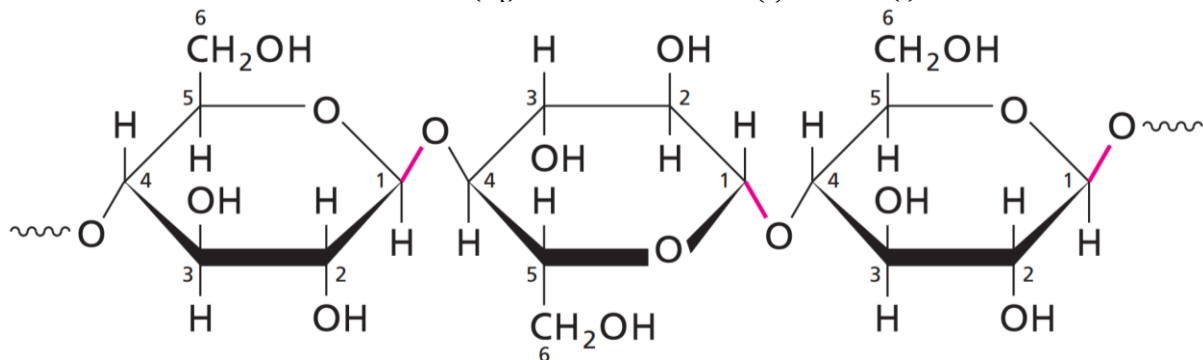
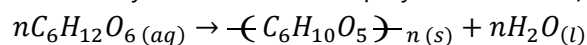
- In **condensation polymerisation**, the functional groups of the two monomers react, forming a new bond and releasing water.
- Example:
  - Proteins are condensation polymers made from amino acids.
  - Amino acids** contain the *amine group* ( $\text{NH}_2$ ) and *carboxylic acid group* ( $\text{COOH}$ ).



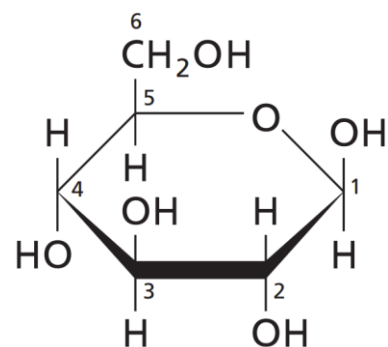
- A hydrogen from the *amine* end of the molecule combines with the hydroxyl group on the *acid* end of another molecule to create water.
- The carboxylic acid group ( $-\text{COOH}$ ) combines with an amine group ( $-\text{NH}_2$ ) to form an amide link ( $-\text{CO}-\text{NH}-$ ).
- Continued condensation polymerisation produces a protein.

### 1.2.5 Describe the structure of cellulose and identify it as an example of a condensation polymer found as a major component of biomass

- Cellulose is the most abundant polymer on Earth and is a major component of biomass, which is a renewable resource. Biomass is carbon-based matter, and serves as a source of chemically modified cellulose-based polymers, such as rayons, cellulose nitrate and acetate.
- Cellulose is a biopolymer formed by the condensation polymerisation of  $\beta$ -glucose monomers.

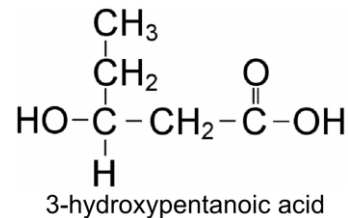
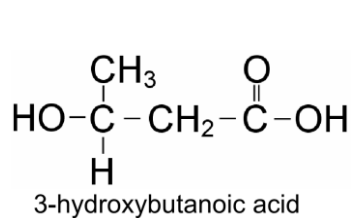


- Cellulose is a very long condensation polymer containing thousands of  $\beta$ -glucose units in long chains.
- The  $\beta$ -glucose monomers are linked by a  **$\beta$ -1,4 glycosidic bond**.
- Cellulose has a **linear** structure because the *bulky*  $\text{CH}_2\text{OH}$  groups on  $\text{C}_5$  are on alternate sides of adjoining glucose units.
- The  $\text{OH}$  groups form *hydrogen bonds* that hold cellulose chains together. This creates long, **rigid** cellulose fibres which account for the strength of wood as a building material.
- The *reduced availability* of  $\text{OH}$  groups, due to their involvement in hydrogen bonding between chains, makes cellulose **insoluble in water**. The structure of cellulose exposes few  $\text{OH}$  groups to water molecules.



**1.2.6 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 naturally occurring polymers found in living organisms.
- Biopolymer: Biopol
  - This biopolymer is called **PHBV (poly-3-hydroxybutyrate-poly-3-hydroxyvalerate)**.
    - It is a co-polymer of polyhydroxybutyrate (PHB) and polyhydroxyvalerate (PHV).
    - The monomer of PHB is 3-hydroxybutanoic acid (*common name* 3-hydroxybutyric acid).
    - The monomer of PHV is 3-hydroxypentanoic acid (*common name* 3-hydroxyvaleric acid).



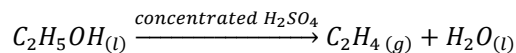
- Production:
  - This polymer is produced industrially by bacteria (*Ralstonia eutrophus* or *Alcaligenes eutrophus*) growing in tanks with a carbon-based food source, high in glucose or valeric acid.
  - The bacteria manufacture the PHBV which is stored in their cell walls as granules for later use as an energy source.
  - The polymer is then isolated and purified.
- Uses in relation to properties:
  - Biopol is mainly used in *medical applications* (e.g. surgical stitches and tissue scaffolding) as it is **biocompatible** (not rejected by the body's immune system) and **biodegradable** (products decompose naturally and no surgery is needed to remove them).
    - The use of biopolymers in medicine will mean more lives can be saved due to biopolymer transplants and fewer allergic reactions.
  - Biopol is also used to make *disposable items* (e.g. bottles, razors and shampoo containers) as it is **biodegradable** and **non-toxic**. However, this is uncommon now, due to the high cost of production.
- Recent developments:
  - Recently, the gene for producing Biopol polymer strands from the *Alcaligenes eutrophus* bacteria was extracted and implanted into *E. coli* using genetic engineering techniques. *E. coli* bacteria are much easier to grow than other bacteria, and thus are cheaper.
  - Scientists have also attempted to genetically engineer plants such as cress so that they produce biodegradable plastics rather than storing starch. This results in a much cheaper process, although it is still more expensive than petrochemical polymers.
- Evaluation:
  - Biopol is currently much more expensive than petrochemical plastics, so research is being carried out to genetically modify bacteria to control the plastic that they form. There is a growing demand for it where biodegradability and biocompatibility are important.
  - It has an advantage over petroleum-based polymers of being **renewable**, as it is formed from a microorganism. Biodegradable polymers may eventually replace petroleum-based polymers, reducing our dependence on fossil fuels and allowing them to last longer.



## 1.3 Ethanol - Use and Manufacture

### 1.3.1 Describe the dehydration of ethanol to ethylene and identify the need for a catalyst in this process and the catalyst used

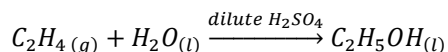
- The **dehydration** of ethanol involves the removal of a water molecule from ethanol, forming ethylene.



- Ethanol is dehydrated by heating it with a catalyst (**concentrated  $H_2SO_4$** ), which breaks the  $C - OH$  and  $C - H$  bonds, allowing the formation of a double bond and water. The catalyst also provides an alternate pathway with a lower activation energy.
  - Sulfuric acid is chosen because it is a strong dehydrating agent (absorbs water).

### 1.3.2 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

- The **hydration** of ethanol involves the addition of a water molecule to ethylene, forming ethanol.



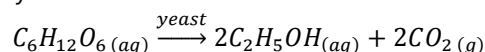
- Hydration also needs heat and a catalyst (**dilute  $H_2SO_4$** ) which opens the double bond and allows water to attach. Water itself is not reactive enough to break the ethylene double bond.

### 1.3.3 Describe and account for the many uses of ethanol as a solvent for polar and non-polar substances

- Ethanol is a clear, colourless liquid that has a lower boiling point than water. It is volatile and its vapours form combustible mixtures with air.
- Uses:
  - The major uses of ethanol are as a **motor fuel supplement** and as a **solvent**.
  - Ethanol is used as a solvent in cosmetics (e.g. perfumes) and toiletries, medicinal preparations (e.g. antiseptics) and food colourings and dyes.
  - It is also an industrial solvent for paints, oils and fatty acids.
- Ethanol is able to act as a solvent for polar and non-polar substances due to its unique molecular structure.
- The  $OH$  group is the **polar hydroxyl end**, which interacts with other polar molecules through *dipole-dipole forces* or *hydrogen bonds*. This favours the solubility of polar substances (e.g. glucose, carboxylic acids) in ethanol. Ethanol dissolves in water in all proportions due to the strong hydrogen bonding between the two liquids.
- The  $CH_3CH_2$  group is the **non-polar alkyl chain end**, which interacts with non-polar substances through *dispersion forces*. This favours the solubility of non-polar substances (e.g. hydrocarbons, oils) in ethanol. Non-polar iodine also readily dissolves in ethanol.

### 1.3.4 Present information from secondary sources by writing a balanced equation for the fermentation of glucose to ethanol

- Fermentation** is a process in which glucose is broken down to ethanol and carbon dioxide by the action of enzymes present in yeast.

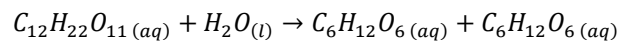


**1.3.5 Describe conditions under which fermentation of sugars is promoted**

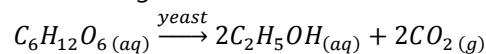
- The conditions under which fermentation is promoted:
  - A **suitable grain or fruit** (plant material with a high content of starch or simple sugars ) is mashed up with water.
  - The presence of **yeast**.
  - The **exclusion of air** (*anaerobic* environment).
  - The **temperature** is kept at about **37°C**.
  - The **ethanol concentration** is kept below **15%**, as yeast cannot function effectively above this concentration.
  - Approximately **neutral pH**.

**1.3.6 Summarise the chemistry of the fermentation process**

- Yeast is first added to mashed grain and water.
- Enzymes (biological catalysts) in the mixture convert any starch or sucrose ( $C_{12}H_{22}O_{11}$ ) into glucose or fructose.



- The yeast use their enzymes to convert glucose or fructose into ethanol and carbon dioxide.



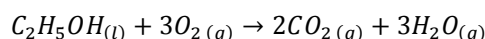
- Yeast can produce ethanol concentrations of up to about 15%, after which the yeast die and fermentation stops. Fractional distillation is required to obtain higher ethanol concentrations (95%). This produces common industrial or laboratory alcohol. To obtain 100% ethanol, more complex distillation procedures are needed to completely remove water, due to the strong hydrogen bonding between ethanol and water.

**1.3.7 Process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane**

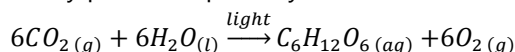
- In the production of sugar (sucrose) from sugarcane, a by-product is a concentrated solution of sucrose called molasses. This can be used to produce ethanol by fermentation:
  - The harvested sugarcane is crushed to extract the juices that contain sucrose.
  - The sucrose is extracted and crystallised, leaving the remaining liquor (molasses) with a high percentage of sucrose.
  - Water is added to the molasses syrup to reduce the sucrose concentration, and acid is added to prevent bacterial growth.
  - The mixture in the fermentation tank is adjusted to the desired temperature (37°C) and yeast is added.
  - Fermentation begins and the carbon dioxide gas that evolves is collected and sold to other industries.
  - After a few days the fermentation is complete, and the mixture is passed through rectifying columns to purify it.
  - The final mixture is distilled to produce 95% ethanol.

### 1.3.8 Outline the use of ethanol as a fuel and explain why it can be called a renewable resource

- Ethanol is able to undergo combustion, so it can be used as a fuel.



- Ethanol is a renewable resource as it is manufactured from carbohydrates such as glucose and starch that are produced by photosynthesis in plants. The products of its combustion ( $CO_2$  and  $H_2O$ ) are the reactants needed by plants for photosynthesis.



### 1.3.9 Assess the potential of ethanol as an alternative fuel and discuss the advantages and disadvantages of its use

- Potential of ethanol as an alternative fuel:
  - As supplies of petroleum dwindle, the development of renewable fuels such as ethanol becomes an important area of research.
  - Ethanol is a liquid, which makes it an easily transportable fuel that is a possible alternative fuel for automobiles.
- Advantages of using ethanol as a fuel:
  - It is a **renewable** resource that is derived from biomass.
  - It undergoes **complete combustion** more readily than fossil fuels:
    - The *oxygen atom* in the ethanol molecule ensures that less oxygen is needed for complete combustion. Ethanol also contains *less carbon than octane*, the major component of petrol. It produces only  $CO_2$  and  $H_2O$  as by-products.
    - Thus, ethanol is a **cleaner** and **more efficient** fuel that has reduced greenhouse gas emissions.
- Disadvantages of using ethanol as a fuel:
  - Ethanol has a **lower heat of combustion** than petrol so it does not release as much energy on complete combustion. Cars can travel further with the same amount of octane than ethanol, so ethanol is **more expensive** than petrol.
  - Engines must be **modified** to run on high ethanol mixtures (e.g. E25).
  - Large areas of arable **land** are needed to grow crops to use in the production of ethanol, at the expense of other farming industries. This leads to environmental problems such as soil erosion, deforestation, fertiliser runoff and salinity.
  - Disposal of **fermentation wastes** in the production of ethanol also presents major environmental issues.
- Evaluation:
  - Currently, ethanol has potential as an alternative fuel and a future replacement for fossil fuels, particularly for transport. However, further research into developing more efficient methods of ethanol production is required before it can become an economically viable proposition.
- Note: Ethanol has been proposed as a fuel based on the fact that it is 'greenhouse neutral', i.e. the  $CO_2$  produced when it burns is balanced by the  $CO_2$  used in photosynthesis to produce crops to be later converted to ethanol. However, significant energy input is required for the production of fertilisers and the distillation process. This comes from the combustion of fossil fuels, which leads to the release of carbon dioxide. Nevertheless, the combustion of ethanol does have a lower greenhouse impact compared with the combustion of petrol.

### 1.3.10 Process information from secondary sources to summarise the use of ethanol as an alternative car fuel, evaluating the success of current usage

- Ethanol is mainly used (mixed with petrol) as a fuel to **supplement petrol supplies**. Petrol containing 10% ethanol can be used in normal petrol engines without engine modification.
- Brazil is the world's largest producer of ethanol. Since the 1970s, its major fuel for cars has been ethanol.
  - However, Brazil has struggled with the higher costs of producing ethanol compared with petrol, and subsidies are needed before it is economically viable.
- In the US and Canada, a biofuels program has been adopted, which grants tax concessions to ethanol producers. Ethanol is used in a fuel called *gasohol* (10% ethanol, 90% gasoline).
- In Australia, ethanol is generally considered an **uneconomic proposition** due to the high costs of production.
  - Mainly, Australia lacks the arable land to grow sufficient sugar cane crops to make ethanol an important contributor to liquid fuel demands.
  - Subsidies and tax concessions have been set up to encourage the production of ethanol to be added to petrol (mainly to reduce oil consumption). There is increasing acceptance of **ethanol/petrol blends** (e.g. **E10**, which contains 10% ethanol) that have no detrimental effect on vehicles.
  - It is expected that, in the future, as the price of petrol increases, ethanol/petrol blends will be more widely used in Australia.

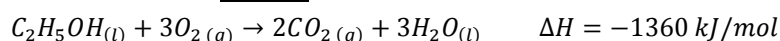
### 1.3.11 Define the molar heat of combustion of a compound and calculate the value for ethanol from first-hand data

- The **molar heat of combustion** of a substance is the heat liberated when one mole of the substance undergoes *complete combustion* with oxygen at standard temperature and pressure, with the final products being carbon dioxide gas and *liquid* water.
  - The molar heat of combustion is the positive quantity of the enthalpy change for the combustion process.

$$\Delta H = -mC\Delta T$$

- |  |  |
|--|--|
| ▪ $\Delta H$ = change in heat (J)        | ▪ $m$ = mass of system (kg)  |
| ▪ $\Delta T$ = change in temperature (K) | ▪ $C$ = specific heat capacity of substance ( $J\ kg^{-1}\ K^{-1}$ ) |

- The molar heat of combustion for ethanol:



### 1.3.12 Solve problems, plan and perform a first-hand investigation to carry out the fermentation of glucose and monitor mass changes

- Aim: To ferment a sucrose solution and monitor the mass changes involved.
- Equipment: balance, conical flask, sucrose, table salt, dried yeast, limewater  $Ca(OH)_2(aq)$ .
- Method:
  - The fermentation mixture of water, sugar, salt and yeast were placed into a conical flask, swirled to mix and then weighed.
  - Another conical flask was half filled with limewater and weighed.

3. Both containers were stoppered and connected by a rubber hose. The yeast beaker was placed in a water bath at a constant temperature (37°C).
  4. The appearance and weight of the fermentation mixture and limewater were recorded daily for a week.
- Results:
    - The yeast flask became milky, foamy and smelt of alcohol, proving that *ethanol* was produced.
    - Limewater turned cloudy. This proved that *carbon dioxide gas* was produced.
$$\text{Ca(OH)}_2\text{(aq)} + \text{CO}_2\text{(g)} \rightarrow \text{CaCO}_3\text{(s)} + \text{H}_2\text{O(l)}$$
    - As the mass of the yeast flask steadily decreased each day (due to the  $\text{CO}_2$  inevitably escaping), the limewater flask also gained approximately the same mass.
  - Risk Assessment: Safety glasses were worn throughout this experiment.

### 1.3.13 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

- Aim: To determine and compare the heats of combustion of **ethanol, methanol** and **1-butanol** (these are short-chained alkanols and so are most likely to undergo complete combustion). The method used to determine the heat of combustion of fuels is calorimetry, which involves determining the heat released or absorbed by a reaction by measuring the temperature change of the surroundings:  $\Delta H = -mC\Delta T$
- Equipment: ethanol, methanol, 1-butanol, tin can (better thermal conductor than a glass beaker), balance, thermometer, matches.
- Method:
  1. The mass, temperature and volume of water and the mass of each alkanol were recorded.
  2. Each alkanol, in a spirit burner, was used to heat 150 mL of water in a tin can. A thermometer was used to stir the water and measure the temperature.
  3. After 10 minutes, the spirit burner was capped and immediately reweighed, and the final temperature was recorded.
- Results: In order of *increasing*  $\Delta H$ : methanol, ethanol, 1-butanol
- Discussion:
  - As molecular mass increases, the number of  $\text{C} - \text{C}$  and  $\text{C} - \text{H}$  bonds increases and more bonds need to be created in the products ( $\text{H}_2\text{O}$  and  $\text{CO}_2$ ). Since bond formation releases energy, this leads to an increase in  $\Delta H$ .
  - The experimental value of  $\Delta H$  may have been less than the theoretical value because:
    - *Chemical reason:* The molar heat of combustion refers only to complete combustion under standard temperature and pressure. The yellow flames and soot that formed indicated that the combustion was incomplete (i.e. less than maximum energy is released).
    - *Physical reason:* Heat was lost from the tin can to the surrounding air or the tripod, which would reduce accuracy.
  - To obtain more accurate experimental data:
    - Use a can container (conducts heat better) instead of a glass beaker.
    - Ensure that the container is as close to the flame of the spirit burner as possible.
    - Use a draught shield to minimise heat loss.
- Risk Assessment:
  - Alkanols are flammable so the bulk supply was kept well away from the burner and matches.

## 1.4 Energy from Redox Reactions

### 1.4.1 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 into a neutral atom.
- Active metals will displace less active metal ions from solution. The more active metal atom loses one or more electrons and becomes a positive ion. The electrons lost are transferred to the ions of the less active metal, resulting in them becoming metal atoms.

– e.g. Zinc metal will displace copper ions from solution:



- Solid *Zn* metal dissolves to produce  $\text{Zn}^{2+}$  ions in solution. The  $\text{Cu}^{2+}$  ions in solution are converted to solid *Cu* metal.
- The *Zn* metal is the reductant (reducing agent), i.e. electron donor, that reduces the  $\text{Cu}^{2+}$  ions to *Cu* metal. The  $\text{Cu}^{2+}$  ions form the oxidant (oxidising agent), i.e. electron acceptor, that oxidises the *Zn* metal to  $\text{Zn}^{2+}$  ions.
- *The electrons lost by Zn atoms undergoing oxidation are used to reduce  $\text{Cu}^{2+}$  ions to Cu atoms.*

### 1.4.2 Identify the relationship between displacement of metal ions in solution by other metals to the relative activity of metals

- Referring to the table standard reduction potentials on the HSC Chemistry Data Sheet, a metal higher up in the series is more reactive and will displace a metal ion lower down from solution.
- Therefore, a spontaneous redox reaction will occur if the reductant (species undergoing oxidation) is higher in the table of standard reduction potentials than the oxidant (species undergoing reduction).
- The further apart the ions are (the greater the difference in activity between the two metals), the more vigorous the displacement reaction (and thus more energy released).
- Reactions between acids and metals are **exothermic**. The higher the metal in the activity series, the greater the heat liberated in its reaction with an acid.

### 1.4.3 Account for changes in the oxidation state of species in terms of their loss or gain of electrons

- For monatomic ions, the **oxidation state** of the element is the charge on the ion (including sign).
  - It is a number given to an atom to indicate the number of electrons it has lost or gained.
- Rules for oxidation states:
  - All atoms in **elemental** form have oxidation number *zero* (e.g.  $\text{Cl}_2$ , *Na*,  $\text{H}_2$ ,  $\text{O}_2$ , *Cu*,  $\text{P}_4$ ).
  - **Neutral** molecules have oxidation number *zero* (e.g.  $\text{H}_2\text{O}$ , *NaCl*).
  - **Monatomic** ions have oxidation number equal to their *charge* (e.g.  $\text{Cu}^+ = 1$ ,  $\text{S}^{2-} = -2$ ).
  - **Polyatomic** ions have oxidation number equal to their *charge*, and the *sum* of the oxidation states of the atoms equals this number (e.g.  $\text{OH}^- = -1$ ,  $\text{PO}_4^{3-} = -3$ ,  $\text{SO}_4^{2-} = -2$ ).
  - **Oxygen** always has oxidation number  $-2$  (except in peroxide,  $\text{O}_2^{2-}$ , where it is  $-1$ ).
  - **Hydrogen** always have oxidation number  $+1$  (except in metal hydrides, e.g. sodium hydride, *NaH*, where it is  $-1$ ).

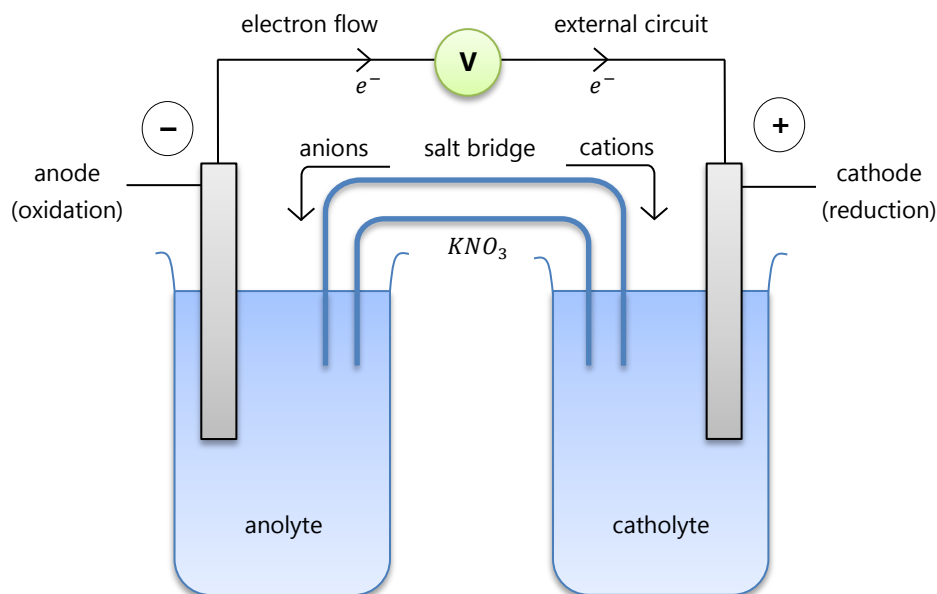
- In **general**:
  - Oxidation is an **increase** in oxidation state (loss of electrons).
  - Reduction is a **decrease** in oxidation state (gain of electrons).

#### 1.4.4 Describe and explain galvanic cells in terms of oxidation/reduction reactions

- A **galvanic cell** (*electrochemical cell*) is a device that allows electricity to be generated from a spontaneous redox reaction.
- It consists of two half-cells, each containing an electrode in an electrolyte solution. Oxidation occurs in one half-cell and reduction in the other.
- The electrodes are physically separated, but connected by an external circuit for the transfer of electrons from the anode to the cathode. This flow of electrons produces electricity.
- In any commercial galvanic cell, the two active chemicals must not be allowed to come into contact, otherwise they would react directly and no electricity would be produced. The role of the electrolyte in cells is to keep the active chemicals apart while allowing migration of ions through the cell.

#### 1.4.5 Outline the construction of galvanic cells and trace the direction of electron flow

#### 1.4.6 Define the terms anode, cathode, electrode and electrolyte to describe galvanic cells



- The **anode** is the electrode at which oxidation occurs.
- The **cathode** is the electrode at which reduction occurs.
- The **electrodes** are the conductors of the cell that get connected to the external circuit.
- The **electrolyte** is the substance which in solution or molten conducts electricity (all salt solutions are electrolytes).
- The **salt bridge** is usually filter paper *soaked in* potassium nitrate,  $KNO_3$  ( $K^+$  and  $NO_3^-$  do not form any precipitates with other ions).
  - The purpose of the **salt bridge** is to facilitate the migration of ions from one half-cell to another to complete the circuit and maintain electrical neutrality.
  - If the salt bridge is removed, the voltage falls to zero and no current flows.

- A **voltmeter** can be used to measure the voltage (*potential difference*) between two half-cells. If the voltmeter shows a positive voltage, it means the anode (where oxidation occurs) has the greater ability to produce electrons.
- As galvanic cell reactions proceed, there are several observations that can be made:
  - The size/mass of the anode decreases
  - Deposits of metal form on the cathode
  - The anolyte colour becomes darker and the catholyte colour fades

#### 1.4.7 Solve problems and analyse information to calculate the potential $E^\ominus$ requirement of named electrochemical processes using tables of standard potentials and half-equations

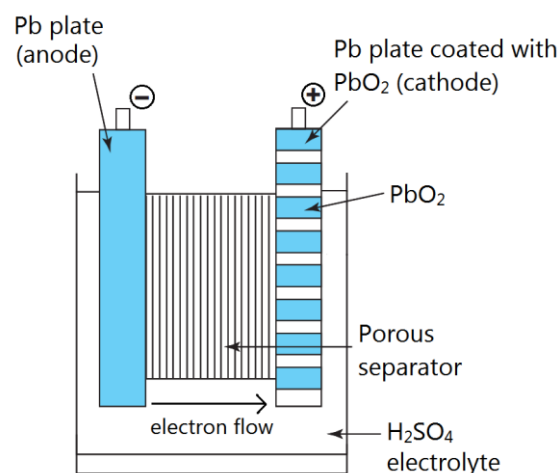
- **Standard reduction potential** ( $E^\ominus$ ) is a measure of the relative tendency of a substance to undergo reduction compared to the standard hydrogen electrode (0 V).
  - This is measured under standard laboratory conditions (SLC):
    - Temperature: 25°C;
    - Pressure: 100 kPa;
    - Solution concentration: 1 mol L<sup>-1</sup>
- The **standard cell potential** is the sum of the standard reduction potential and the standard oxidation potential:

$$E^\ominus_{\text{cell}} = E^\ominus_{\text{reduction}} + E^\ominus_{\text{oxidation}}$$

- Note:
  - To obtain  $E^\ominus_{\text{oxidation}}$ , simply reverse the sign of the  $E^\ominus_{\text{reduction}}$ .
  - Doubling the half-equation does *not* alter  $E^\ominus$ .
- A positive cell potential ( $E^\ominus_{\text{cell}}$ ) indicates a spontaneous redox reaction will occur in the forward direction.
- The potential of a cell decreases as the reaction proceeds because the reactant is used up, so it produces less current. Thus, batteries go flat when one of the reactants is all used up. No further chemical reaction is possible so no more current is produced.

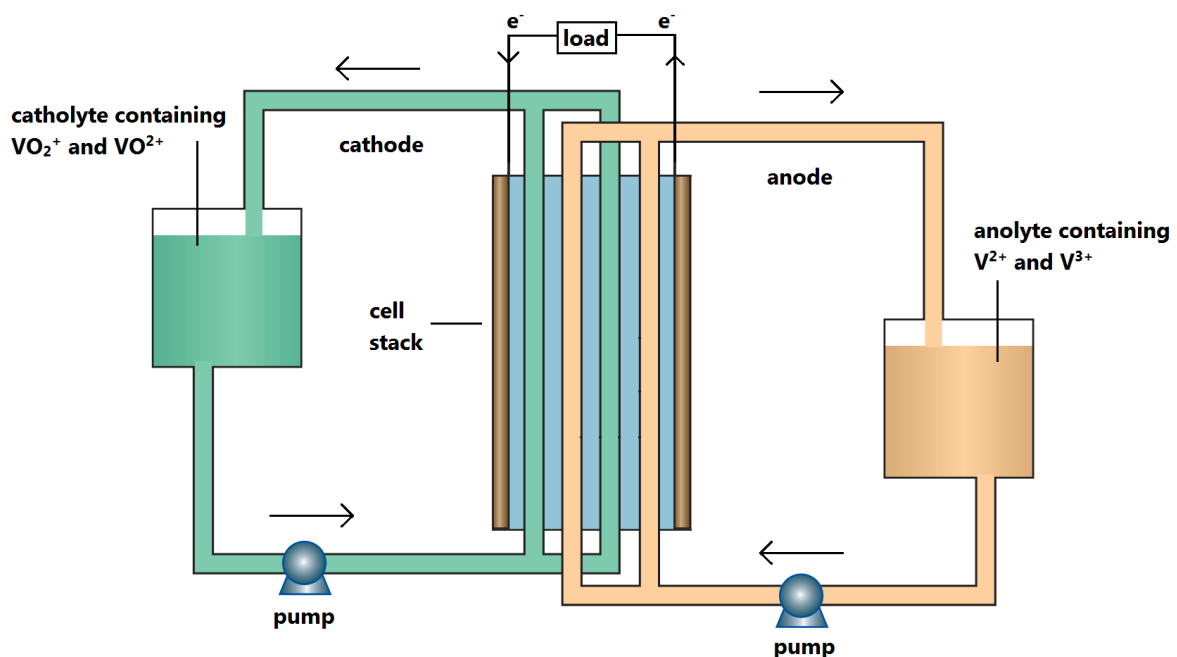
#### 1.4.8 Gather and present information on the structure and chemistry of a lead-acid cell and evaluate it in comparison to a vanadium redox cell in terms of chemistry, cost and practicality, impact on society and environmental impact

- **Lead-acid cell:**
  - In a lead-acid cell, six cells (each 2V) are arranged in series to produce a 12V battery (therefore, a battery is simply a series of cells).
  - The lead-acid cell can be recharged by application of an external current. This is possible because the product of the reaction ( $PbSO_4$ ) is insoluble and stays in contact with the electrodes.
  - The battery is used during start-up to provide the energy for the car's starter motor. It is gradually recharged during driving using electrical energy from the car's alternator.





- Chemistry:
  - **Anode:**  $Pb_{(s)} + SO_4^{2-} \rightarrow PbSO_{4(s)} + 2e^-$
  - **Cathode:**  $PbO_{2(s)} + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_{4(s)} + 2H_2O_{(l)}$
  - **Electrolyte:**  $5 \text{ mol L}^{-1} H_2SO_4$
- Cost & Practicality:
  - The batteries are **expensive** due to the lead content.
  - The battery is **reliable, long-lasting** and can be **recharged** externally multiple times.
  - The batteries are **bulky** and **heavy**, limiting their portability.
  - They have the **lowest energy density** of most commonly used rechargeable batteries.
- Impact on society:
  - The lead-acid battery is important for **car start-up motors** as it provides a large burst of current to start an engine.
  - It is also a useful **storage battery** for remote locations and emergency lighting. It can be recharged by connecting to solar panels or electric generators.
- Environmental Impact:
  - Lead-acid batteries are recycled to retrieve the lead, as **lead** metal is a heavy metal that is toxic to organisms in the environment and causes anaemia in humans.
  - The concentrated  $H_2SO_4$  electrolyte is highly acidic and can cause severe damage if spilled. Sealed lead-acid cells prevent acid fumes from causing corrosion.
- Vanadium redox cell:
  - A vanadium redox cell is a redox flow battery that consists of two vanadium electrolyte tanks which are pumped through a battery stack, where the chemical energy stored in the solutions is converted to electrical energy. The potential difference between the two half-cells leads to electron flow in the external circuit.
  - The cell is recharged by passing an electric current through it and also by reversing the solution flow, which reverses the two half-reactions.
  - The cell can also be recharged by replacing the spent electrolytes with fresh ones, since there are no changes to electrodes during operation.



- Chemistry:
  - **Anode** (*graphite felt*):  $V^{2+}_{(aq)} \rightarrow V^{3+}_{(aq)} + e^{-}$
  - **Cathode** (*graphite felt*):  $VO_2^{+}_{(aq)} + 2H^{+} + e^{-} \rightarrow VO^{2+}_{(aq)} + H_2O_{(l)}$
  - **Anolyte**:  $VSO_4$  solution
  - **Catholyte**:  $(VO_2)_2SO_4$  solution
- Cost & Practicality:
  - There is a **high cost** to the vanadium redox cell until it is fully commercialised. However, vanadium is a plentiful and hence **cheap** metal.
  - The battery is recharged at a low voltage but can deliver a **high voltage** on discharge.
  - It is important that the oxidant and reductant do not mix, which requires a separate compartment for each solution, making it even **less portable** than the lead acid battery.
- Impact on society: The vanadium redox cell has several important applications including:
  - **Replacement for lead-acid batteries** used to power up car motors, especially in remote areas. This is important because lead-acid batteries face the environmental problem of disposing toxic lead metal.
  - **Power source** for electric vehicles. Electric cars are increasingly being used as petrol prices increase and supplies of petrol diminish in the near future.
  - **Electrochemical storage of solar and wind energy**. This is possible because the vanadium battery can be recharged at low voltages, acting as an emergency backup battery system.
- Environmental Impact:
  - The vanadium redox cell may replace the lead-acid battery, hence avoiding the disposal of toxic lead metal to the environment.
  - The vanadium solutions can be indefinitely **recycled** so it is **safe and non-polluting**, and waste is minimised.
- Comparison of the two cells:
  - **Similarities**
    - Both cells are rechargeable
    - Both have  $SO_4^{2-}$  in the electrolyte
  - **Differences**
    - The lead-acid cell consists of one compartment, whereas the vanadium redox cell has 2 compartments separated by a porous membrane.
- Evaluation of the two cells:
  - Overall, the lead-acid battery delivers the required voltage but its use is disadvantaged by lead which can pollute the environment.
  - The vanadium redox battery is safe and environmentally friendly but still in its developmental stage.

### 1.4.9 Perform a first-hand investigation to identify the conditions under which a galvanic cell is produced

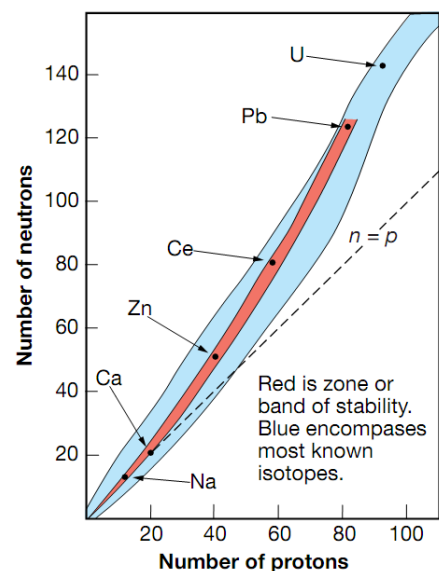
### 1.4.10 Perform a first-hand investigation and gather first-hand information to measure the difference in potential of different combinations of metals in an electrolyte solution

- **Aim:** To find the order of the metals from the strongest to weakest reductant using galvanic cells.
- **Equipment:** 150 mL beakers, strips of filter paper to make salt bridges, electrical leads with clips, DC voltmeter, piece of emery paper, various electrodes and electrolytes.
- **Method:**
  1. A  $Zn | Zn^{2+} || Cu^{2+} | Cu$  galvanic cell was set up. A  $Zn$  electrode was placed in one beaker with  $ZnSO_4(aq)$  and a  $Cu$  electrode in another beaker with  $CuSO_4(aq)$ . For each half-cell, the electrodes were thoroughly cleaned with emery paper to remove corrosion and contaminants.
  2. The salt bridge was made from a strip of filter paper soaked in  $KNO_3$  solution. A clean strip of filter paper was used for each cell to ensure that the ions in solution for the previous beaker did not remain and react with the new ions (i.e. prevents possible precipitation).
  3. The potential difference was recorded for each cell.
  4. The  $Cu^{2+} | Cu$  half-cell was used as a standard for comparing the other metal ion/metal half-cells:  $Mg | Mg^{2+}$ ;  $Fe | Fe^{2+}$ ;  $Sn | Sn^{2+}$ ;  $Pb | Pb^{2+}$ ;  $Ag | Ag^+$ .
- **Results:**  $Mg$  was found to be the strongest reductant and  $Cu$  was the strongest oxidant.

## 1.5 Nuclear Chemistry

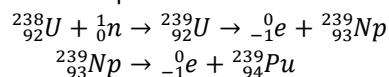
### 1.5.1 Distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable

- A **radioactive** isotope (*radioisotope*) has an unstable nucleus which spontaneously emits radiation ( $\alpha$ ,  $\beta$  or  $\gamma$ ) and undergoes a transmutation (change in composition).
- A **stable** isotope does not emit radiation as it has a stable nucleus.
- An isotope is unstable (radioactive) if:
  - **Atomic number** is greater than 83 ( $Z > 83$ ): These isotopes undergo nuclear fission to form smaller, more stable nuclei. An alpha decay results:
 
$${}_{92}^{238}U \rightarrow {}_2^4He + {}_{90}^{234}Th$$
  - **Ratio of neutrons to protons** is outside the *zone of stability* in a graph of no. of neutrons vs. no. of protons.
    - $Z < 20$ : stable  $n:p$  ratio is 1:1
    - $Z \approx 50$ : stable  $n:p$  ratio is 1.3:1
    - $Z \approx 80$ : stable  $n:p$  ratio is 1.5:1
  - High  $n:p$  ratio -  $B^-$  decay occurs
  - Low  $n:p$  ratio -  $B^+$  or  ${}_1^0e$  decay occurs
  - Nucleus contains too much energy (i.e. metastable): It will undergo gamma emission.

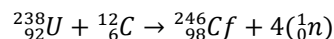


### 1.5.2 Describe how transuranic elements are produced

- **Transuranic elements** are artificially produced elements with atomic numbers greater than that of uranium ( $Z > 92$ ). Uranium has the largest value of the naturally occurring elements.
- Transuranic elements are produced by bombardment of nuclei with neutrons or other nuclei, in nuclear reactors or particle accelerators
  - Neutron bombardment:
    - Early transuranic elements were synthesised by **neutron bombardment** (supplied by a **nuclear reactor**) of heavy elements.
    - Neptunium ( $Z = 93$ ) and plutonium ( $Z = 94$ ) can be synthesised in nuclear reactors by the neutron bombardment of uranium-238. The unstable U-239 formed decays by beta emission to form neptunium-239 and plutonium-239.

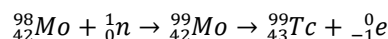


- Fusion reactions:
  - The production of larger transuranic elements is achieved by bombarding heavy nuclei with **high speed positive particles** (e.g. helium or carbon nuclei) produced in particle accelerators, such as **linear accelerators** and **cyclotrons**.
  - Californium-246 is formed by bombarding uranium-238 with carbon in a linear accelerator.

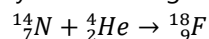


### 1.5.3 Describe how commercial radioisotopes are produced

- Commercial radioisotopes are produced in nuclear reactors or particle accelerators.
  - Nuclear reactors supply neutrons which are bombarded at a target to produce **neutron-rich** radioisotopes. *Technetium-99m* (medical radioisotope) is produced by neutron bombardment of molybdenum-98.

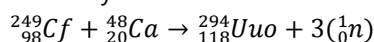
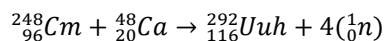


- Particle accelerators accelerate light positive particles to high speeds, which are then collided with heavy nuclei. This produces **neutron-deficient** radioisotopes. Linear accelerators accelerate particles in a straight line, while cyclotrons accelerate particles in a spiral path. *Fluorine-18* is prepared in a cyclotron by bombarding nitrogen-14 with helium nuclei.



### 1.5.4 Process information from secondary sources to describe recent discoveries of elements

- Element 116, ununhexium (Uuh), was synthesised by Russian scientists in 2000 by bombarding curium-248 with calcium-48.
- Element 118, ununoctium (Uuo) is the most recently produced element, and the heaviest element known to man. It was produced in 2002 by the fusion of californium-249 and calcium-48.



### 1.5.5 Identify instruments and processes that can be used to detect radiation

- Photographic film: (*Note: this is not an instrument*)
  - Radioactivity can be detected by the darkening of photographic film.
  - **Radiation badges** are worn by laboratory workers handling radioactive substances, and the amount of darkening of the film is a measure of the amount of radiation that the worker has received.
- Cloud chamber:
  - A cloud chamber contains supersaturated water or alcohol vapour cooled with dry ice.
  - As radiation travels through their air and vapour, it ionises surrounding air molecules. The vapour molecules condense onto these ions, creating small droplets or cloud trails that reveal the path of the ionising radiation.  $\alpha$  particles form straight dense tracks;  $\beta$  particles form thinner zigzag tracks;  $\gamma$  rays form even fainter tracks.
- Scintillation counter:
  - When certain substances (e.g.  $ZnS$ ) are irradiated with  $\alpha$ ,  $\beta$  or  $\gamma$  rays, they emit a flash of light (scintillation) which can be collected and amplified in a photomultiplier. The electrical signal generated is then counted electronically to measure the amount of radiation.
- Geiger-Muller counter:
  - This device uses ionising properties of radiation, and is only able to measure  $\beta$  radiation.
  - The  $\beta$  ray enters the Geiger tube, collides with a gas molecule (e.g. argon) and ionises it, knocking an electron out of it.
  - The high voltage accelerates this electron so that it ionises more argon atoms in its path, constituting an electrical pulse which is amplified and measured by an amplifier or counter.

### 1.5.6 Identify one use of a named radioisotope in industry and in medicine

- Industry: **Cobalt-60** (Co-60) is used to irradiate food to prolong its shelf life.
- Medicine: **Technetium-99m** (Tc-99m) is used in the diagnosis of disease.

### 1.5.7 Describe the way in which the above named industrial and medical radioisotopes are used and explain their use in terms of their properties

- Cobalt-60:
  - Use:
    - Co-60 is used to *irradiate food materials* to minimise spoilage and extend shelf life, and *sterilise medical supplies* such as dressings and bandages. Food on a conveyor belt is gamma irradiated by passing it through a chamber containing a safely shielded Co-60 source.
  - Properties:
    - Co-60 is **chemically inert** and is a **potent gamma emitter**. Gamma rays can easily penetrate hermetically sealed packaging and the contents, killing harmful microbes such as bacteria, viruses and fungi. They have sufficient energy to destroy bacteria but not enough to make food radioactive.
    - Co-60 has a reasonably **long half-life of 4-6 years**, to minimise replacement.
  - However, there are concerns that gamma radiation can destroy vitamin content in food and may lead to the formation of harmful compounds in the food. In addition, workers must be protected from irradiation.

- **Technetium-99m:**

- Use:
  - Tc-99m is widely used for *medical diagnosis*. The Tc-99m is attached to a biological molecule that concentrates in the organ to be investigated. A scintillation counter measures the distribution of Tc-99m which can be used to detect and pinpoint blood clots, constrictions and other circulation disorders.
- Properties:
  - Tc-99m is particularly suitable for medical diagnosis due to its **short half-life** of 6 hours. It rapidly decays and so causes minimal damage to the patient.
  - Tc-99m emits **low energy gamma radiation**, which causes minimal damage to healthy cells, but can still be detected in the body by a gamma ray sensitive camera.
  - Tc-99m is **quickly eliminated** from the body.
  - Technetium is **relatively reactive**, so it can be reacted to form a compound with chemical properties that leads to concentration in the organ of interest such as the heart, liver, lungs or thyroid.
- As Tc-99m has such a short half-life, it must be continuously made from the decay of molybdenum-99.

### **1.5.8 Use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine**

- **Benefits:**

- The main benefits of radioisotopes are largely in the field of medicine.
  - Radioisotopes have provided a range of **non-invasive diagnostic techniques**
  - Radiotherapy provides effective treatment of many cancerous tumours, especially in sensitive organs (e.g. brain).
- Radioisotopes also have the ability to:
  - Make monitoring equipment more **sensitive** and **precise** than earlier equipment.
  - Carry out tasks more **efficiently** and **reliably** (e.g. gamma ray sterilisation of medical supplies, which is efficient and effective compared to other sterilisation methods).
  - Perform tasks that were not otherwise possible (e.g. examine buildings and machinery for structural faults).

- **Problems:**

- Radiation from radioisotopes is harmful to humans and all other life forms. It can cause undesirable reactions in living tissue and upset the delicate balance among the complex chemical reactions occurring in living cells.
- Continued exposure to radiation can lead to **diseases** such as tissue damage, cancer and genetic damage (which leads to deformities in offspring). Workers who work with radioactive elements must be continually protected and avoid any form of irradiation.
- Nuclear reactors (the source of neutrons) produce **nuclear waste** which must be disposed of safely. The storage of radioactive material also presents a problem, as it must be kept in shielded containers to prevent radiation leaks.