

9.2 – Production of Materials:

Δ. Construct word and balanced formulae equations of all chemical reactions as they are encountered in this module:

• *BASIC reactions to remember:*

– **Acid** reactions:

- acid + base \longrightarrow salt + water
- acid + metal \longrightarrow salt + hydrogen gas
- acid + carbonate \longrightarrow carbon dioxide gas + salt + water

– Complete **combustion**:

- hydrocarbon + oxygen $\xrightarrow{\Delta}$ water + carbon dioxide

– **Displacement** reactions:

- $Y + X \text{ (anion)} \longrightarrow X + Y \text{ (anion)}$; where $Y > X$ on *activity series*.

• *Alkene/alkane reactions:*

– **Cracking** of pentane:

- pentane $\xrightarrow{\Delta}$ ethylene + propane
- $C_5H_{12} \text{ (g)} \xrightarrow{\Delta} C_2H_4 \text{ (g)} + C_3H_8 \text{ (g)}$

– **Hydrogenation** of ethylene:

- ethylene + hydrogen \xrightarrow{Pt} ethane
- $C_2H_4 \text{ (g)} + H_2 \text{ (g)} \xrightarrow{Pt} C_2H_6 \text{ (g)}$

– **Hydration** of ethylene:

- ethylene + water $\xrightarrow{H_3PO_4}$ ethanol
- $C_2H_4 \text{ (g)} + H_2O \text{ (l)} \xrightarrow{H_3PO_4} C_2H_5OH \text{ (l)}$

– **Halogenation** (more specifically, **Chlorination**) of ethylene:

- ethylene + chlorine \longrightarrow 1,2-dichloroethane
- $C_2H_4 \text{ (g)} + Cl_2 \text{ (g)} \longrightarrow C_2H_4Cl_2 \text{ (l)}$

– **Hydrohalogenation** (more specifically, **Hydrofluorination**) of ethylene:

- ethylene + hydrogen fluoride \longrightarrow fluoroethane
- $C_2H_4 \text{ (g)} + HFl \text{ (g)} \longrightarrow C_2H_5Fl \text{ (g)}$

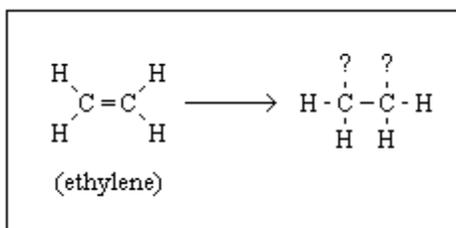
- Reaction of **cyclohexene** with **bromine water**:
 - cyclohexene + bromine + water \longrightarrow 2-bromo-1-cyclohexanol + hydrogen bromide
 - $\text{C}_6\text{H}_{10}(\text{l}) + \text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \longrightarrow \text{C}_6\text{H}_{10}\text{BrOH}(\text{l}) + \text{HBr}(\text{aq})$
- *Fermentation and other ethanol-based reactions:*
 - **Dehydration** of ethanol:
 - ethanol $\xrightarrow{\text{H}_2\text{SO}_4}$ ethylene + water
 - $\text{C}_2\text{H}_5\text{OH}(\text{l}) \xrightarrow{\text{H}_2\text{SO}_4} \text{C}_2\text{H}_4(\text{g}) + \text{H}_2\text{O}(\text{l})$
 - **Combustion** of ethanol:
 - ethanol + oxygen \longrightarrow carbon dioxide + water
 - $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \longrightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})$
 - **Fermentation** of glucose:
 - glucose $\xrightarrow{\text{yeast}}$ ethanol + carbon dioxide
 - $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \xrightarrow{\text{yeast}} 2\text{C}_2\text{H}_5\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g})$
- *Electrochemistry:*
 - **Displacement** of copper from solution due to zinc:
 - zinc + copper sulfate \longrightarrow zinc sulfate + copper
 - $\text{Zn}(\text{s}) + \text{CuSO}_4(\text{aq}) \longrightarrow \text{ZnSO}_4(\text{aq}) + \text{Cu}(\text{s})$
 - **Ionic equation** of this reaction:
 - zinc + copper(II) ion + sulfate ion \longrightarrow zinc(II) ion + sulfate ion + copper
 - $\text{Zn} + \text{Cu}^{2+} + \text{SO}_4^{2-} \longrightarrow \text{Zn}^{2+} + \text{SO}_4^{2-} + \text{Cu}$
 - **Net ionic equation** of this reaction:
 - zinc + copper(II) ion \longrightarrow zinc(II) ion + copper
 - $\text{Zn}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \longrightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu}(\text{s})$
 - **Half-equations** of this equation:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^-$
 - $\text{Cu}^{2+} + 2\text{e}^- \longrightarrow \text{Cu}$

– **Catalytic Cracking:**

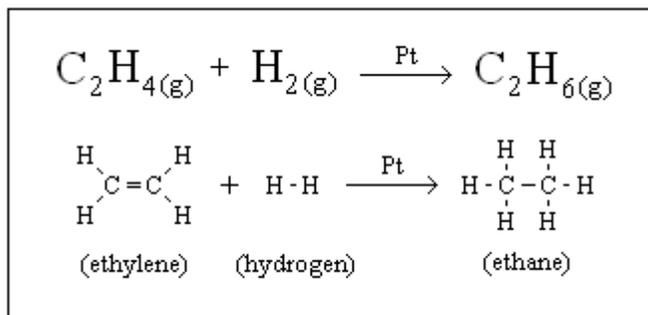
- In this process, carried out in a ‘cat-cracker’, long *alkane* molecules (C15 - C25) are broken into just two molecules, an alkane and an alkene.
- This form of cracking uses a CATALYST to break the alkanes.
- The catalyst used are *zeolite* crystals:
 - Zeolites are aluminosilicates (compounds made of aluminium, silicon and oxygen), with small amounts of metal ions attached.
- The reaction is carried out at 500°C, in the absence of air, with pressure just above atmospheric pressure.
- This process uses less heat than THERMAL cracking, but it cannot decompose large molecules *completely* into ethylene, so it is insufficient in meeting the demands of the industry.

– **Thermal Cracking:**

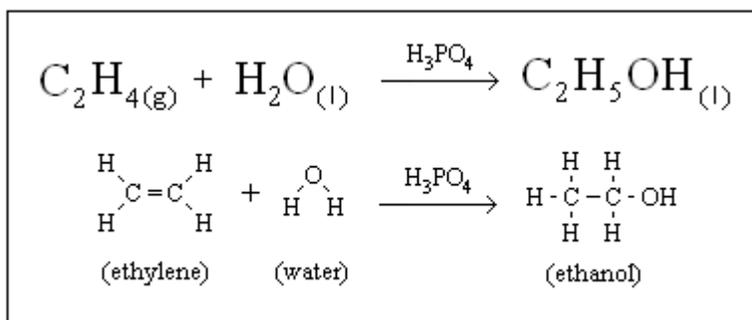
- Also called ‘steam’ cracking.
 - This process does not use a catalyst, only very high temperatures.
 - The long-chain alkanes are passed through metal tubes at temperatures of 700°C to 1000°C, at pressure above atmospheric.
 - The alkanes are decomposed *completely* into ethylene and other short chains.
 - The use of steam is that it allows for easy flow of hydrocarbon gases, it dilutes the mixture to create smooth reactions, and it removes carbon deposits in the metal tubes.
- *Identify that ethylene, because of the high reactivity of its double bond, is readily transformed into many useful products:*
 - Ethylene has a highly reactive double-bond; It is a site of very HIGH ELECTRON DENSITY. One of the bonds readily breaks, creating two new bonding sites on the molecule:



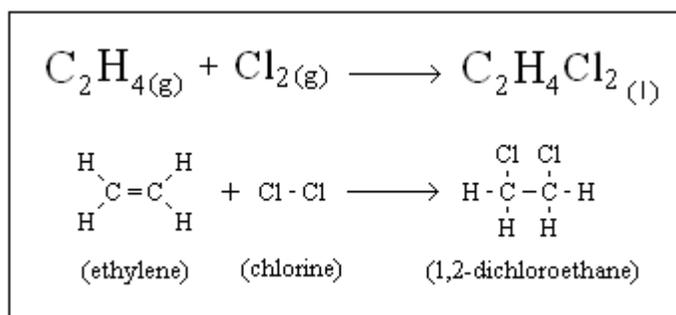
- ADDITION reactions are a type of reaction ethylene can undergo; in these reactions, one bond in the double bond is broken, and the two atoms in a diatomic molecule are 'added' on.
- There are many types of addition reactions:
 - **Hydrogenation:** Hydrogen is reacted with ethylene, using a platinum catalyst at 150°C. The product is ethane.



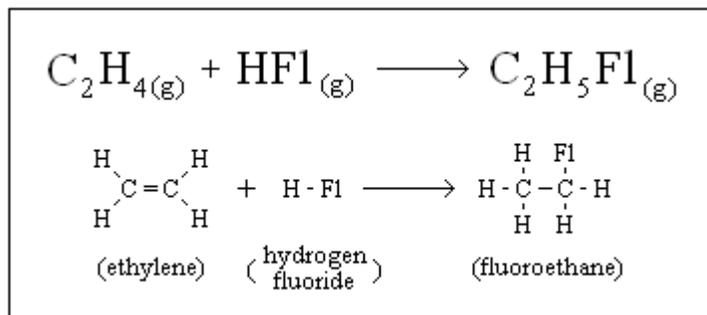
- **Hydration:** Ethylene is reacted with water, using phosphoric acid as a catalyst, to produce ethanol. This is an industrially important reaction.



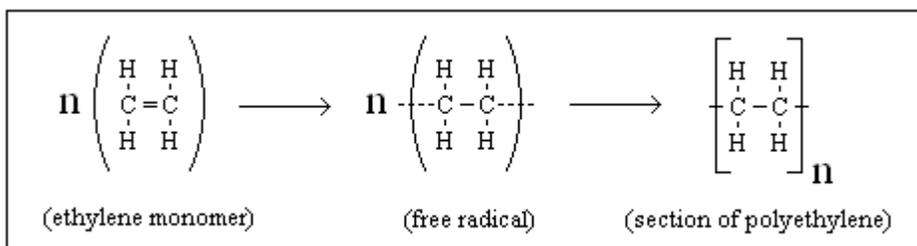
- **Halogenation:** Reactive molecules from the halogen group (F₂, Cl₂ and Br₂) can all react with ethylene. **EG:** Chlorine molecule reacting with ethylene forms 1,2-dichloroethane.

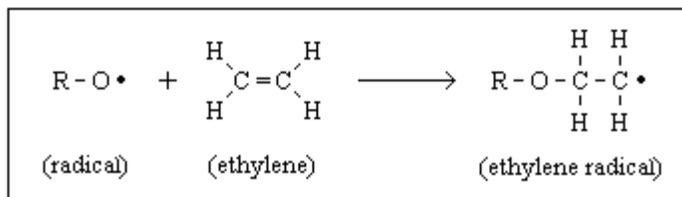


- **Hydrohalogenation:** In this reaction, a hydrohalogen (such as HCl or HFl) and ethylene react to form a halo-ethane. **EG:** HFl reacting with ethylene forms fluoroethane.

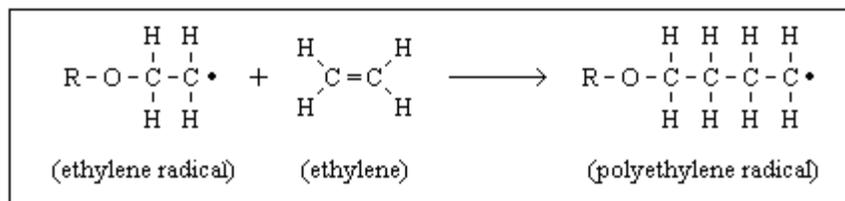


- The **MAIN** advantage of the double bond is that ethylene can undergo polymerisation, a very important reaction that will be discussed later.
- *Identify that ethylene serves as a monomer from which polymers are made:*
 - **Polymerisation** is the chemical reaction in which many identical small molecules combine to form one very large molecule.
 - The small identical molecules are called **MONOMERS**, and the large molecule is called a **POLYMER**.
 - Because of its reactive double bond, ethylene is able to undergo polymerisation; ethylene, a monomer, forms the polymer poly(ethylene).
- *Identify polyethylene as an addition polymer and explain the meaning of this term:*
 - In an **addition polymerisation** reaction, no additional molecules (e.g. water) are produced – there is no gain or loss of atoms, the double bond simply ‘opens’ and monomers attach.
 - Polyethylene is an addition polymer, as the ethylene molecules combine with each other in the following way:

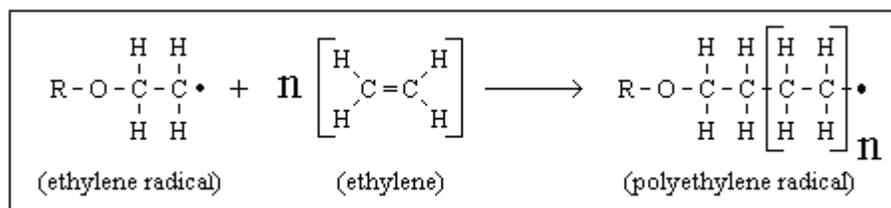




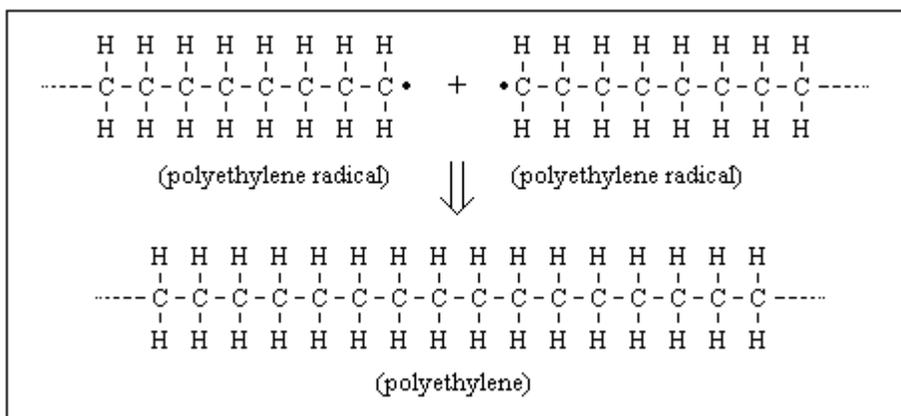
- **PROPAGATION:** Another ethylene monomer attaches to this radical, opening another bonding site, then another attaches, and so on, rapidly increasing the length of the chain. One of these reactions:



Repeating this reaction many times gives a general formula:



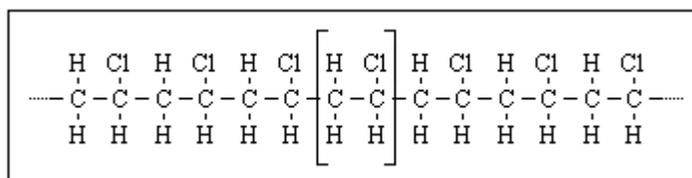
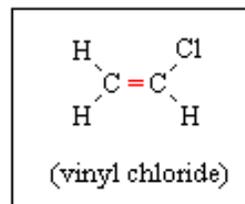
- **TERMINATION:** The reaction stops (terminates) when two such chains collide and the two radicals react, forming a longer chain. This is a random process, so the length of polyethylene chains can vary greatly. (The peroxide initiator is eventually engulfed by the reaction, and so is no longer present at termination):



- Identify vinyl chloride and styrene as commercially significant monomers by both their systematic and common names:

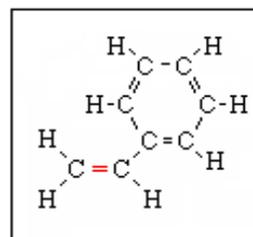
– **Vinyl Chloride:**

- SYSTEMATIC NAME: Chloroethene.
- FORMULA: C_2H_3Cl or $CH_2=CHCl$
- It is an ethylene molecule with one of its hydrogen atoms substituted with a chlorine atom.
- It can form polyvinyl chloride, a very important polymer.
- Diagram of polyvinyl chloride:

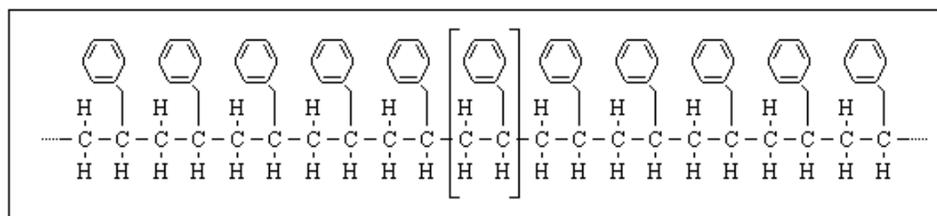
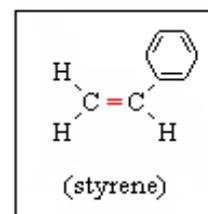


– **Styrene:**

- SYSTEMATIC NAME: Phenylethene.
- FORMULA: C_8H_8 or $CH_2=CHC_6H_5$
- Styrene is an ethylene molecule with one of its hydrogen atoms replaced by a benzene ring.
 - A benzene ring is a six-carbon ring with alternating double-bonds. The double bonds within benzene are not reactive; but the double bonds in alkenes are reactive.
- It forms polystyrene.
- Diagram of polystyrene:



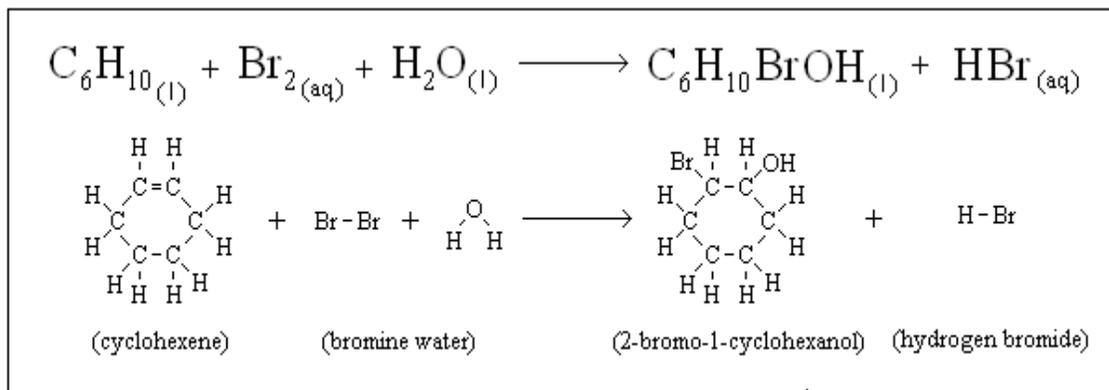
OR



- *Describe the uses of the polymers made from the above monomers in terms of their properties:*
 - **Low-Density Polyethylene (LDPE):**
 - Uses Related to Properties:
 - Plastic cling wrap; because it is flexible, clear and non-toxic.
 - Disposable shopping bags; because it is cheap and relatively strong.
 - Milk bottles; as it is non-toxic, cheap, un-reactive and recyclable.
 - **High-Density Polyethylene (HDPE):**
 - Uses Related to Properties:
 - Kitchen utensils and containers; as it is strong and non-toxic.
 - Rubbish bins; it is rigid, only slightly flexible and hard.
 - Pipes and other building materials; it is rigid, hard, and un-reactive.
 - **Polyvinyl Chloride (PVC):**
 - Uses Related to Properties:
 - Garden hoses; it can contain UV inhibitors; it is relatively un-reactive, flexible, and durable. Can be softened with plasticisers.
 - Pipes and guttering; it is very rigid and hard, and un-reactive. It is also easily shaped.
 - **Crystal Polystyrene:**
 - Uses Related to Properties:
 - CD cases and cassette tapes; used because polystyrene is clear, hard, rigid, easily shaped, and is a good insulator.
 - Screw driver handles and kitchen cupboard handles; very durable and strong, hard and inflexible.
 - **Expanded Polystyrene:**
 - Uses Related to Properties:
 - Packaging, and disposable cups; it is light (full of air), cheap, and it is a thermal insulator.
 - Sound-proofing; it is a shock absorbent material, light, easily shaped.

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

- In this experiment an alkene (*cyclohexene*) and its corresponding alkane (*cyclohexane*), were placed in a solution of yellow bromine water.
- **RESULT:** It was observed that cyclohexene turned the bromine water colourless, whereas the cyclohexane solution remained yellow.
- Thus ONLY cyclohexene reacted with the bromine water, and thus the alkene was said to be more reactive than its corresponding alkane; this is due to the double bond of the alkene.
- Reaction:



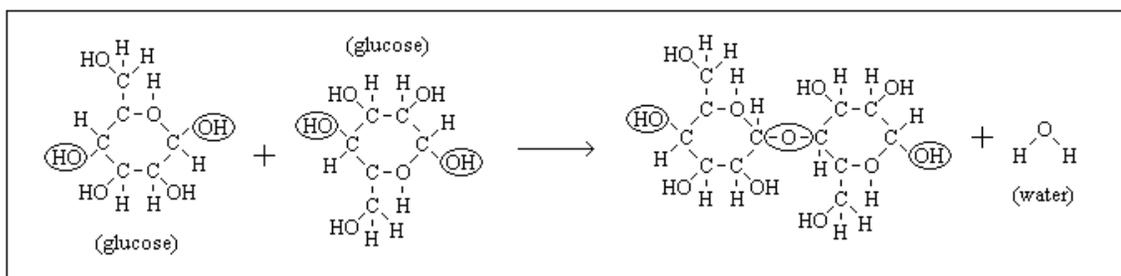
- **JUSTIFY** the method:
 - Cyclohexene and cyclohexane were used, instead of ethylene or propene because C1 to C4 are gases at room temperature, and would be hard to manage; cyclohexene is liquid at room temperature.
 - Also cyclohexene/ane was used instead of hexene/ane because cyclic hydrocarbons are more stable than their linear counterparts.
- **LIMITATIONS** of the method:
 - The alkane reacted slightly, as UV radiation caused slow substitution reactions.
- **SAFETY** precautions:
 - Bromine water is highly toxic if ingested, and is slightly corrosive.
 - Cyclohexene and cyclohexane are both poisonous if ingested, and both give off fumes, as they are highly volatile and highly flammable.

- **PRACTICAL** – *Analyse information from secondary sources such as computer simulations, molecular model kits or multimedia resources to model the polymerisation process:*
 - In this experiment, **molecular modelling kits** were used to show how polyethylene is produced through the polymerisation of ethylene.
 - The class was divided into groups, and each group was provided with a kit.
 - 3 ethylene monomers were created by each group, with *black* balls representing carbons and smaller, *white* balls representing hydrogen.
 - Then the monomers were ‘polymerised’: each group combined their monomers with every other group until a large chain was created – a section of polyethylene.
 - **JUSTIFY** the method:
 - The models created a 3D representation of the chemical process, which led to greater understanding of polymerisation.
 - The use of ball-and-stick models, depicting the double-bond with flexible rubber rods, greater increased understanding of the process.
 - **LIMITATIONS** of the method:
 - The model only provided a very limited section of a polyethylene molecule, as there were limited numbers of kits.
 - The use of catalysts (such as Zeigler-Natta catalysts) was not shown in the process, and thus it was not completely accurate.

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

- **RECALL:**
 - **Addition** polymers form NO extra molecules when their monomers join together.
 - This type of polymerisation reaction occurs due to a double-bond opening, creating 2 new bonding sites.
- *Discuss the need for alternative sources of the compounds presently obtained from the petrochemical industry:*
 - There is an overwhelming need for alternative sources of compounds that are presently derived from the petrochemical industry (i.e. *crude oil*).
 - This is because crude oil is a fossil fuel, and is hence a non-renewable resource.
 - Based on current usage statistics, crude oil reserves could be completely used up within a few decades.
 - Compounds obtained from the petrochemical industry have two uses:
 - The production of **energy**: 84% of crude oil is used to produce energy. This includes petrol and diesel for cars, heating oil, jet-engine oil and LPG.
 - The production of **materials**: The other 16% is used to produce polymers, pharmaceuticals, and other extremely important chemicals.
 - Some of the materials created from crude oil cannot be derived by any other ways (or would be much too expensive to synthesise), so once crude oil is exhausted, there will be no way to produce them.
 - It has been argued that alternative fuels be created so that crude-oil can be reserved for use by the petrochemical industry to create materials.
 - The increasing cost of crude oil in this current day and age is another factor.
 - Also, many countries that contribute a significant portion of the world's crude oil are very economically and politically unstable, with fragile infrastructure, and supply from these countries can be very erratic.
 - One of the most appealing replacements for crude-oil derived compounds is cellulose; this is because it contains all the carbon-chain structures needed for the production of materials, and it is so remarkably abundant on Earth.

- *Explain what is meant by a condensation polymer:*
 - A **condensation** polymer is a polymer that produces EXTRA molecules (usually water) when its monomers combine.
 - Examples include natural polymers such as cellulose, starch, protein, DNA, and manufactured polymer fabrics such as silk, polyester and nylon.
- *Describe the reaction involved when a condensation polymer is formed:*
 - In **condensation**, the monomers react *differently* than in addition reactions.
 - There is *no* double-bond that opens (as in addition); the FUNCTIONAL GROUPS of the two monomers react together, forming a new bond and water.
 - **EG - Cellulose:**
 - Cellulose is a natural polymer formed through the polymerisation of glucose
 - **Glucose**, $C_6H_{12}O_6$, is the monomer in this polymer.
 - The reaction occurs between 2 hydroxyl groups, forming a *glycosidic* bond:

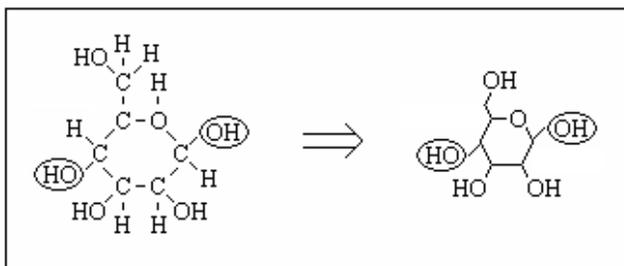


- As can be seen, the reaction sites are the hydroxyl (OH⁻) groups on the first and fourth carbons (C-1 and C-4).
 - Each glucose molecule has 2 reaction sites; that is why it can polymerise.
 - One C-OH bonds to another C-OH, forming a C-O-C bond (*glycosidic bond*).
 - The left over H⁺ and OH⁻ combine, forming water.
- *Describe the structure of cellulose and identify it as an example of a condensation polymer found as a major component of biomass:*
 - Cellulose is a naturally occurring condensation polymer (a **biopolymer**)
 - It is the single most abundant polymer on Earth, making up about 50% of the total *biomass* of the planet (biomass is the mass of all organisms in a given area).
 - It is long polymer chain made of repeating glucose monomer units, which FLIP for every alternate glucose, as can be seen in the above diagram.

- Above, the structure of glucose is quite cluttered. To demonstrate a section of a cellulose chain, a simplified form of glucose will be used.

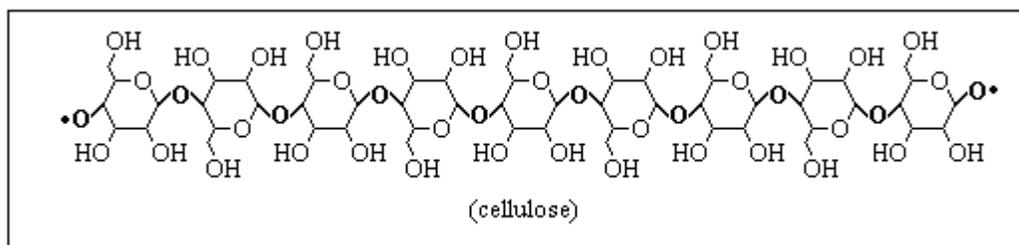
- Glucose; in short-form:

- It is assumed that at every corner, there is a carbon atom.
- Hydrogen atoms are not shown, but are also



assumed to be there, and are deduced by knowing that carbon makes 4 bonds.

- Hence, the structure of cellulose can be shown as:



- As can be seen, it is a very linear molecule, due to its straight chains.
- *Identify that cellulose contains the basic carbon-chain structures needed to build petrochemicals and discuss its potential as a raw material:*
 - The BASIC carbon-chain structures that are used to make petrochemicals are short-chained alkenes such as **ethylene** (2C), **propene** (3C) and **butene** (4C).
 - Glucose, the basic structure in cellulose, is a 6C molecule.
 - Hence it has to potential to be transformed into the above compounds.
 - The Potential of Cellulose as a Raw Material:
 - Although theoretically, cellulose can provide limitless amounts of renewable raw materials, this is currently too expensive and impractical.
 - This is because in order to derive ethylene, etc., from cellulose, firstly, cellulose must be broken into glucose (using either bacterial digestion or acidic decomposition), then fermented (with yeast) into ethanol and then dehydrated (using H₂SO₄) into ethene; this is a lengthy and expensive process.
 - Hence, cellulose has great potential, but is currently not economical.

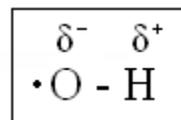
- **REPORT** – Use available evidence to gather and present data from secondary sources and analyse progress in the recent development and use of a named biopolymer. This analysis should name the specific enzyme(s) used or organism used to synthesise the material and an evaluation of the use or potential use of the polymer produced related to its properties:
 - **Name of Biopolymer:** Biopol™
 - It is made of *polyhydroxybutyrate* (PHB) and *polyhydroxyvalerate* (PHV).
 - **Organism Used:**
 - *Alcaligenes eutrophus* (a bacterium).
 - **Production:**
 - In industrial production, *A. Eutrophus* is grown in an environment *favourable* to its *growth* to create a very large population of bacteria (such as high nitrates, phosphates and other nutrients).
 - When a sufficiently large population has been produced, the environment is changed to one that is high in *glucose*, high in valeric acid and low in *nitrogen*.
 - This unnatural environment induces the production of the polymer by the bacterium; the polymer is actually a natural fat storage material, created by the *A Eutrophus* in adverse conditions.
 - Large amounts of a chlorinated hydrocarbon, such as *trichloromethane* are added to the bacteria/polymer mix; this dissolves the polymer.
 - The mixture is then filtered to remove the bacteria.
 - The polymer is extracted from the hydrocarbon solvent as a powder, which is then melted or treated further to create a usable polymer.
 - **Properties:**
 - It is BIODEGRADABLE and BIOCOMPATIBLE
 - It is non-toxic, insoluble in water, permeable to oxygen, resistant to UV light, acids and bases, high melting point, high tensile strength.
 - **Uses in Relation to Properties:**
 - It has many medical applications (e.g. biocompatible stiches that dissolve or are absorbed by the body).

- Disposable containers for shampoo, cosmetics, milk bottles, etc., as it only takes 2 years to decompose back into natural components.
- Disposable razors, cutlery, rubbish bags, plastic plates, etc.
- **Advantages:**
 - It is biodegradable, unlike polyethylene and other petroleum derived plastics, and so will help to reduce levels of rubbish in landfills.
 - It is compatible with organisms (biocompatible); it is not rejected by the body's immune system and so can be used safely.
 - It is a renewable resource.
- **Disadvantages:**
 - It is currently very expensive, and currently the demand is not high enough for it to be economically viable.
- **Future 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.
 - Nutrient sources are starting to be derived from waste materials, such as molasses and other agricultural wastes. This greatly reduces costs.

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

- **RECALL:**

- A POLAR covalent bond is a bond where one of the atoms in it is more electronegative than the other, and so the bond has a slight charge.
- **Electronegativity** is the ability of an atom to attract electrons; the more electronegative an atom, the *stronger* it will hold onto electrons in a *chemical bond*.
- The order of electronegativity, from most electronegative to least, for relevant atoms is: *fluorine, oxygen, chlorine, nitrogen, carbon* and then *hydrogen*.
- For example, a bond between oxygen and hydrogen is a polar bond because oxygen holds onto negative electrons stronger; thus, in this bond, oxygen is slightly negative.



- **Solubility Rules:**

- Polar substances dissolve other polar substances: This is because the slightly negative end is attracted to the slightly positive end of another polar bond, forming a slight intermolecular bond.
 - Non-polar substances dissolve other non-polar substances: This is due to very weak dispersion forces between molecules.
- 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 is the chemical process whereby a water molecule is removed from ethanol, forming ethylene.

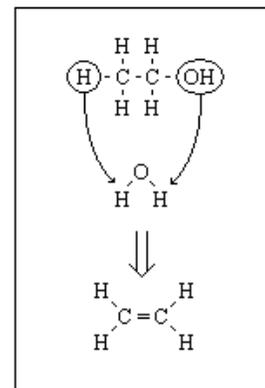
- **Dehydration** of ethanol:

- ethanol $\xrightarrow{\text{H}_2\text{SO}_4}$ ethylene + water
 - $\text{C}_2\text{H}_5\text{OH}_{(l)} \xrightarrow{\text{H}_2\text{SO}_4} \text{C}_2\text{H}_4_{(g)} + \text{H}_2\text{O}_{(l)}$

- An acid catalyst (concentrated sulfuric acid) is needed

because the acid breaks the C-OH and C-H bonds, allowing the formation of a double-bond and water (it also reduces the activation energy).

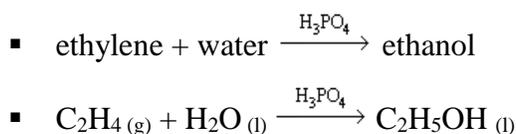
- Sulfuric acid is the chosen acid, because it is also a powerful dehydrating agent.



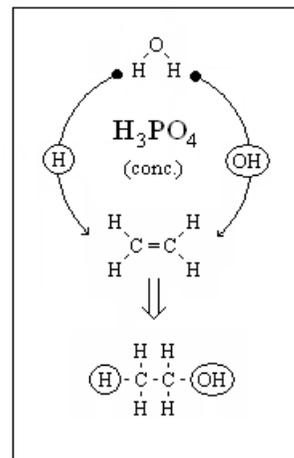
- Describe the addition of water to ethylene resulting in the production of ethanol and identify the need for a catalyst in this process and the catalyst used:

– The *hydration* of ethylene is the chemical process whereby a water molecule is added to ethylene, forming ethanol.

– **Hydration** of ethylene:



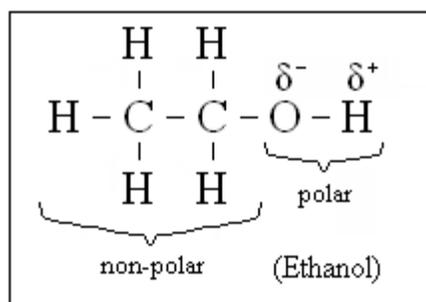
– In this case, the acid catalyst (concentrated phosphoric acid) opens the double bond, allowing water to attach, forming ethanol.



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

– See **RECALL** above.

– *Ethanol* is able to act as a solvent for polar, non-polar and some ionic substances due to its unique molecular structure:



– As can be seen, ethanol is not completely polar or completely non-polar:

- The **OH** group: This section is polar, and as a result, can form polar bonds with other polar substances, such as water.
- The **CH₃CH₂** group: C-H and C-C bonds are non-polar, and hence this section is non-polar. It can share dispersion forces with other non-polar substances, and dissolve them; for e.g. heptane.

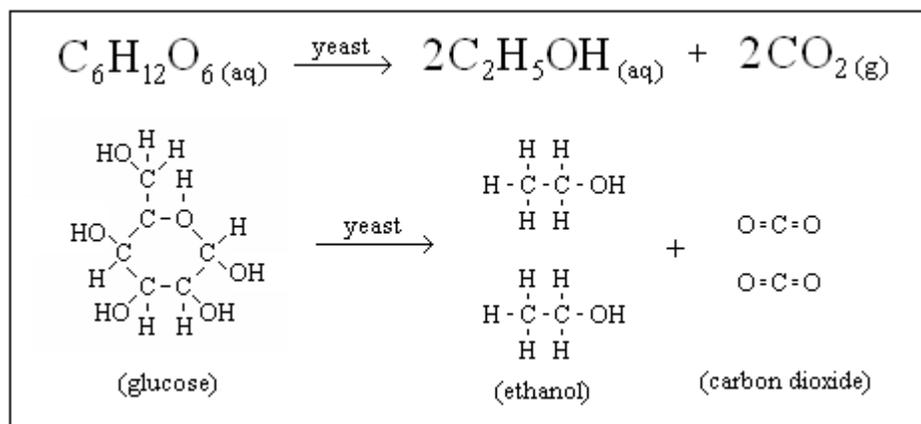
– Hence it is a widely used solvent for perfumes, dyes, pharmaceuticals, etc.

- *Outline the use of ethanol as a fuel and explain why it can be called a renewable resource:*
 - **Combustion** is the reaction whereby a hydrocarbon reacts with oxygen to form carbon dioxide and water vapour, releasing energy.
 - Ethanol is able to undergo combustion, so it can be used as a fuel:
 - $\text{C}_2\text{H}_5\text{OH}_{(l)} + 3\text{O}_{2(g)} \longrightarrow 2\text{CO}_{2(g)} + 3\text{H}_2\text{O}_{(g)}$
 - Despite its short chain, ethanol is a liquid (due to strong polar bonds).
 - This makes it an easily transportable fuel, and thus has been used for many years for outdoor camping, hikers, etc.
 - It has also been used as a fuel-additive in automobiles, up to about 20% ethanol.
 - As a **renewable** resource:
 - Ethanol can be a renewable resource because it can be derived from non-fossil fuel sources, such as the fermentation of glucose.
 - This glucose can be derived from bacterial decomposition of cellulose (a renewable very abundant material) or from starch (mainly from corn crops).
- *Assess the potential of ethanol as an alternative fuel and discuss the advantages and disadvantages of its use:*
 - Potential of Ethanol:
 - 80% of the world's demand for transportation fuels is petroleum derived.
 - However, as the price of petroleum continues to rise, the concept of other fuels as alternatives becomes more attractive.
 - Approximately 8 million vehicles worldwide run on ethanol/petrol blends.
 - 30% of Brazilian automobiles run on at least 25% ethanol fuels.
 - Many other countries such as China and South Africa are investing money in researching the potential of ethanol as a fuel.
 - In Australia, sugar cane and wheat have been fermented to produce ethanol, but here, it is currently an uneconomic proposition.
 - ADVANTAGES of ethanol:
 - It is a *renewable* resource.
 - It is “greenhouse” *neutral*; that is, the CO_2 absorbed by the crop (e.g. corn) can match the CO_2 produced by combustion (if very efficient).

- Because ethanol has *less carbon* than octane (the major component of petrol), as well as the fact it already contains an oxygen atom, it requires less oxygen to *completely* combust; hence it is a CLEANER and MORE EFFICIENT fuel.
- Produces only carbon dioxide and water as a by-product.
- DISADVANTAGES of ethanol:
 - Engines must be *modified* to run on fuel containing more than 20% ethanol.
 - Engines *wear down* faster due to the need for higher engine compression ratios needed for ethanol combustion.
 - Large areas of *land* are required to grow crops that will be harvested for ethanol production; land that can be used for other purposes.
 - Disposal of fermentation wastes presents major environmental issues.
- *Process information from secondary sources to summarise the use of ethanol as an alternative car fuel, evaluating the success of current usage:*
 - There are a few forms in which ethanol can be used as an alternative car fuel; these include *ethanol/petrol mixtures*, *very pure ethanol fuels*, and *ethanol-powered fuel cells*:
 - Ethanol/Petrol Mixtures: Significant quantities of 10% ethanol are sold in some parts of Australia; however, there has not been much success as the public holds suspicions about the effect of ethanol on their engines.

However, in other countries, ethanol/petrol mixtures are very successful. In the United States, many states require a minimum of 10% ethanol in all fuel sold. In Sweden, 85% ethanol mixtures are common. Brazil requires that ALL car engines are able to accept at least 25% ethanol. Thus in certain countries, use of ethanol as a fuel is quite successful.
 - Pure Ethanol Fuels: “Pure” ethanol is ethanol with AT MOST 1% water. It is a very clean fuel. Engines must be modified to deal with such high levels of ethanol. It is currently being used in Brazil and Argentina as a complete alternative to gasoline. A quarter of all Brazilian cars run on pure ethanol. It has proven to be a very efficient fuel.
 - Ethanol Fuel-Cells: This is still in an experimental stage; it is the proposition that fuel cells be used to run cars; success of such a scheme is still not known.

- Describe the conditions under which fermentation of sugars is promoted:
 - **Fermentation** is the biochemical process in which *glucose* is turned into ethanol and carbon dioxide by the action of enzymes produced by microbes (esp. yeast).
 - The conditions under which fermentation is promoted are:
 - Presence of suitable grain or fruit made into a pulp with water.
 - Presence of yeast cultures.
 - The exclusion of air (*anaerobic* environment).
 - The temperature is kept at about 37°C.
- Present information from secondary sources by writing a balanced equation for the fermentation of glucose to ethanol:
 - **Fermentation** of glucose:



- Summarise the chemistry of the fermentation process:
 - Yeast is added to mashed grain and water.
 - The yeast and other microbes break down the large carbohydrates (e.g. starch or sucrose) into simple sugars (glucose or fructose) which are then fermented.
 - sucrose + water \longrightarrow glucose + fructose
 - $\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \longrightarrow \text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) + \text{C}_6\text{H}_{12}\text{O}_6(\text{aq})$
 - In an oxygen-free atmosphere, the yeast use their enzymes to break down the sugars, forming ethanol and CO_2 as products.
 - $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \xrightarrow{\text{yeast}} 2\text{C}_2\text{H}_5\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g})$
 - When ethanol concentration reaches 15%, the yeast die and fermentation STOPS.
 - Distillation is used to obtain higher ethanol concentrations (95-100%).

- *Process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane:*
 - The **industrial production** of ethanol from sugar-cane uses a few more chemicals (some of which are toxic) and processes compared to ethanol produced for consumption; also sugarcane is higher in simple sugars compared to corn starch.
 - This is a summary of the process:
 - The sugar-cane crop is harvested; the whole plant is then crushed and grinded to create a cellulose/sugar pulp.
 - The pulp is heated to 100°C, and dilute sulfuric acid is added. This hydrolyses the cellulose and sucrose into glucose molecules.
 - The mixture is filtered to separate the glucose solution from the solid residues of lignin and unbroken cellulose.
 - The solids residue is further hydrolysed with stronger acids and filtered again.
 - Calcium hydroxide is added to the sugar solution remaining to neutralise the sulfuric acid; an insoluble salt (precipitate) of calcium sulfate is formed.
 - The solution is filtered again to remove solid calcium sulfate particles.
 - The solution is then placed in an oxygen-free tank, warmed to 37°C, and suitable yeast cultures are added.
 - After 15% concentration is reached, the solution is distilled to produce high concentration industrial grade ethanol.
- *Define the molar heat of combustion of a compound and calculate the value for ethanol from first-hand data:*
 - The **molar heat of combustion** is the heat energy released when one *mole* of a substance undergoes complete combustion with oxygen at a pressure of 101.3 kPa (or 1 atmosphere), with the final products being CO₂ and H₂O.
 - Formula for change in heat:

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

ΔH = Change in HEAT; in joules (J)

ΔT = Change in TEMPERATURE; in Kelvin (K)

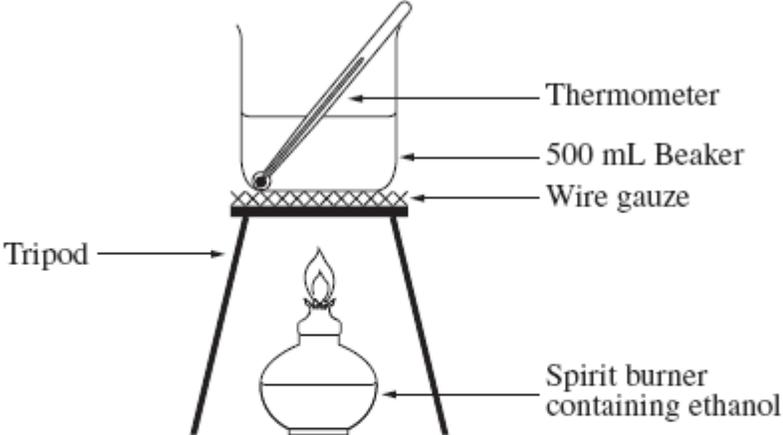
m = Mass of system; in kilograms (kg)

C = Specific heat capacity of substance; in (J kg⁻¹ K⁻¹)

- For the calculation of the molar heat of combustion of ethanol, the following first hand values, were used (from 2001 HSC, Q17):

The following extract is from the practical report of one student.

Apparatus used:



Lab data:

Mass of water	=	250.0 g	Copyright © Board of Studies NSW
Initial mass of burner	=	221.4 g	
Final mass of burner	=	219.1 g	
Initial temperature of water	=	19.0°C	
Final temperature of water	=	59.0°C	

- In this case, the formula for ΔH is applied to the water (the “system”):
 - $\Delta T = 59 - 19 = 40 \text{ K}$
 - $m = 250 \text{ g} = 0.25 \text{ kg}$
 - $C = 4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$ (This value is a constant; given in exams)
- Therefore: $\Delta H = -0.25 \times 4.18 \times 10^3 \times 40$

$$= -41800 \text{ joules (J)}$$

$$= -41.8 \text{ kilojoules (kJ)}$$
- But the change in mass of the burner was 2.3 grams, therefore only 2.3 grams of ethanol was combusted.
- Moles = mass / molar mass = $2.3 / 46 = 0.05 \text{ mol}$
- Therefore, $-41.8 \text{ kJ} / 0.05 \text{ mol} = -836 \text{ kJ/mol}$
- Hence, the experimental molar heat of combustion of ethanol is **-836 kJ/mol**.

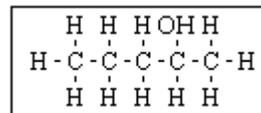
- Identify the IUPAC nomenclature for straight-chained alkanols from C1 to C8:

- **Alkanols** are a group of alkanes where one or more hydrogens have been replaced by the *hydroxyl* (–OH) functional group
- When naming alkanols, there are specific rules:
 - The number of carbons determines the prefix of the name:

#C's	1	2	3	4	5	6	7	8
Prefix	methane-	ethane-	propane-	butane-	pentane-	hexane-	heptane-	octane-

- If there is only ONE hydroxyl group, the “e” is dropped from the prefix and the suffix “-ol” is added. The carbon the hydroxyl is on must also be stated; this is written before the prefix with a “dash”. The carbons, depending on how long the chain is, are numbered from 1 to 8.

- **E.G.** This alkanol has 5 carbons, but only one hydroxyl, so its prefix is “pentan-”, and its suffix is “-ol”. Also, the hydroxyl is on the 2nd carbon



(the number is taken either from the left OR the right; the SMALLER number must be taken). HENCE this alkanol is **2-pentanol**

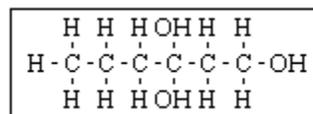
- INCORRECT naming would be 4-pentanol.

- If there is more than one hydroxyl group, the suffixes are (1-4):

No. of OH's	1	2	3	4
Suffix	-ol	- <u>di</u> ol	- <u>tri</u> ol	- <u>tetra</u> ol

For more than one carbon, the “e” at the end of the prefix is NOT dropped. The positions of the OH groups must be stated. If there are 2 hydroxyls on the same carbon, then the number is written twice, with a comma in between:

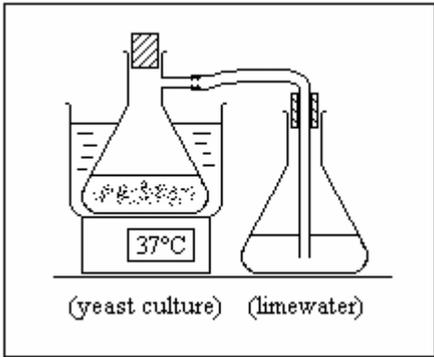
- **E.G.** This alkanol has 6 carbons, and 3 hydroxyl groups so its prefix is “hexane-” and its suffix is “-triol”. Also, one hydroxyl is on



the 1st carbon, while the other 2 are on the 3rd carbon. HENCE, the IUPAC name for this alkanol is **1,3,3-hexanetriol**.

- INCORRECT naming would be 4,4,6-hexanetriol.

- **PRACTICAL** – *Process information from secondary sources such as molecular model kits, digital technologies or computer simulations to model the addition of water to ethylene and the dehydration of ethanol:*
 - **Molecular modelling kits** were used to model:
 - the addition of water to ethylene (hydration).
 - the removal of water from ethanol (dehydration).
 - “Ball-and-stick” kits were used, where *black* balls represented carbons, smaller, *white* balls representing hydrogen, and *red* balls represented oxygen.
 - Firstly, an ethylene molecule was created, and a water molecule created:
 - Then, the water molecule was split into a H^+ ion and an OH^- ion.
 - The double-bond of ethylene was opened, and the ions were attached where there were free bonding sites; the resultant molecule was ethanol.
 - Secondly, a separate ethanol molecule was created:
 - The hydroxide group (OH^-) and a hydrogen was removed from the ends.
 - They were combined, and water was formed; the two open bonding sites of the ethanol were joined, and ethylene was formed.
 - **JUSTIFY** the method:
 - The models created a 3D representation of the chemical process, which led to greater understanding of dehydration and hydration processes.
 - The use of ball-and-stick models, depicting the double-bond with flexible rubber rods, greatly increased understanding of chemical reactions.
 - **LIMITATIONS** of the method:
 - Both were severely simplified representations of chemical processes, which had many multiple steps and consisted of a series of aqueous (dilute sulfuric acid) or solid catalysts.
- **PRACTICAL** – *Solve problems, plan and perform a first-hand investigation to carry out the fermentation of glucose and monitor mass changes:*
 - In this experiment, **sucrose** solution was fermented to form ethanol and carbon dioxide. The yeast cells first split sucrose into two glucose molecules using the *invertase* enzyme .

- A 250 mL side-arm conical flask with a rubber stopper was used. A plastic hose was connected to the side arm, and the end of the hose was placed in another conical flask in a solution of *limewater*. No gas was allowed to escape the apparatus:
- 
- The diagram shows a side-arm conical flask on the left, partially submerged in a water bath. A label below the water bath indicates a temperature of 37°C. The flask is labeled '(yeast culture)'. A plastic hose is connected to the side arm of the flask and extends to the right, where it is inserted into a second conical flask labeled '(limewater)'. The entire setup is enclosed in a rectangular box.
- 100 ml of 0.15 M *sucrose* solution was placed in the conical flask. ONE gram of *active yeast* was placed into the sucrose, along with a pinch of **sodium biphosphate** (Na_2HPO_4) as a yeast nutrient. This was mixed thoroughly.
 - The stopper firmly put on, and the flask was WEIGHED with an electronic scale.
 - The apparatus was then set up as shown, with the yeast beaker in a water bath at a constant temperature (37°C).
 - Both flasks were weighed daily for 5 days.
 - **RESULTS:**
 - The yeast flask turned foamy and smelt clearly of alcohol, while the limewater turned cloudy; this proved that CO_2 and ethanol were produced, and that fermentation occurred.
 - The mass of the yeast flask also steadily decreased by about half a gram each day; this is due to the carbon dioxide escape; the limewater flask also gained approximately the same mass.
 - **JUSTIFY** the method:
 - A “closed” system (where no gas was allowed to escape) was used to ensure an accurate experiment.
 - Limewater was employed to prove CO_2 was produced.
 - The water bath ensured that the most optimal fermentation occurred.
 - **LIMITATIONS** of method:
 - The combined masses of both flasks steadily decreased as well; this was due to inevitable leakages of gas.
 - The atmosphere in the flasks was not anaerobic (oxygen-free) and this could have hampered the fermentation process.

- **PRACTICAL** – *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:*
 - The 3 alkanols used were: **methanol, ethanol, and 1-propanol**
 - Each alkanol was placed in a spirit burner; the original mass recorded, and then was used to heat 200 mL of water (at 25°C) in a tin can.
 - A thermometer was used to stir the water as well as measure the temperature
 - Once the temperature rose by 10 degrees (Kelvin or Celsius, it doesn't matter; they both use the same scale) the spirit burner was capped and immediately reweighed.
 - **RESULTS:**
 - The ΔH (change in heat) was calculated for each alkanol by using the formula $\Delta H = -mC\Delta T$. This was then calculated per gram, and then per mole, to give the heat of combustion per gram, as well as the molar heat of combustion.
 - Methanol has the lowest value, followed by ethanol, and then 1-propanol.
 - NOTE: This is *not* because of the extra bonds in longer hydrocarbon chains, but rather more bonds need to be created in the products (H₂O and CO₂); recall that:
 - ◆ **creating** bonds **releases** energy.
 - ◆ **breaking** bonds **absorbs** energy.
 - **JUSTIFY** the method:
 - A tin can was used as it is a better thermal conductor than a glass beaker.
 - Methanol, ethanol and 1-propanol were used as they are the shortest alkanols and thus are the most likely to undergo complete combustion.
 - **LIMITATIONS** of method:
 - Molar heat of combustion refers **ONLY** to complete combustion; the yellow flames and soot formed indicated that the combustion was incomplete. Thus the experimental data gathered is inaccurate.
 - Also, much heat was lost to the air, as there was not 100% efficiency of heat transfer from flame to tin can.
 - Heat was also radiated from the can to the air; insulation would reduce this.

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

- **RECALL:**

- **Ionic** equations are chemical equations where the ionic compounds are split into their ions, displaying their charges; e.g. **salts** and **acids** can be split.
- **EG:** The reaction between sulfuric acid and magnesium:
 - *Chemical equation:* $\text{H}_2\text{SO}_4 (\text{aq}) + \text{Mg} (\text{s}) \longrightarrow \text{MgSO}_4 (\text{aq}) + \text{H}_2 (\text{g})$
 - *Ionic equation:* $2\text{H}^+ + \text{SO}_4^{2-} + \text{Mg} \longrightarrow \text{Mg}^{2+} + \text{SO}_4^{2-} + \text{H}_2$
- As can be seen, the ionic compounds, sulfuric acid, and magnesium sulfate were split. Hydrogen gas is COVALENT, so it cannot be split.
- The states (solid, liquid, etc.) do not need to be written for ionic equations.
- **NET ionic** equations are ionic equations where the *spectator ions* are removed; spectator ions are ions (usually polyatomic ions) that remain unchanged throughout the reaction.
- Looking at the above acid-metal reaction, the sulfate ion (SO_4^{2-}) is the same on both sides of the equation; it remains unchanged, hence:
 - *Net ionic equation:* $2\text{H}^+ + \text{Mg} \longrightarrow \text{Mg}^{2+} + \text{H}_2$

- *Explain the displacement of metals from solution in terms of transfer of electrons:*

- A **displacement** reaction is a reaction in which a more reactive metal changes a less reactive metal's IONS into solid ATOMS. That is, the less reactive metal's ions are "displaced" out of solution and neutralised into atoms.
- **EG:** When *zinc* metal is placed in *copper* sulfate solution, the zinc will displace the copper ions, forming zinc sulfate and solid copper:
 - *Chemical equation:* $\text{Zn} (\text{s}) + \text{CuSO}_4 (\text{aq}) \longrightarrow \text{ZnSO}_4 (\text{aq}) + \text{Cu} (\text{s})$
 - *Ionic equation:* $\text{Zn} + \text{Cu}^{2+} + \text{SO}_4^{2-} \longrightarrow \text{Zn}^{2+} + \text{SO}_4^{2-} + \text{Cu}$
 - *Net ionic equation:* $\text{Zn} + \text{Cu}^{2+} \longrightarrow \text{Zn}^{2+} + \text{Cu}$
- Displacement reactions are actually ELECTRON TRANSFER reactions, where one substance donates electrons to another; however, this is not clear until you look at the *half-equations* of the reaction.

- **Half-equations** are another way of displaying chemical reactions; the net ionic equation is split into two “halves” (usually, but not always, the *same* element from both sides of the net ionic equation is taken on its own as a half-equation).
- From above, the two half equations are:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+}$
 - $\text{Cu}^{2+} \longrightarrow \text{Cu}$
- HOWEVER, these are incomplete, as the electrical charges on both sides of the equation are not balanced. Hence, a true depiction of the 2 half-reactions:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^{-}$
 - $\text{Cu}^{2+} + 2\text{e}^{-} \longrightarrow \text{Cu}$
- **Explanation:** For zinc to ionise, it has to give up 2 electrons from its outer shell. But for the copper ion to solidify (neutralise), it has to gain 2 electrons. Hence, the net reaction is that zinc DONATES (or ‘transfers’) 2 electrons to copper.
- Therefore, displacement reactions are electron transfer reactions.
- **Δ OXIDATION & REDUCTION:**
 - *Oxidation* and *reduction* reactions (or REDOX reactions), are the scientific way of saying ‘electron-transfer reactions’.
 - The terms “oxidation” and “reduction” refer to the two separate half-equations of a redox reaction; in one half, oxidation occurs, and reduction in the other.
 - To identify whether a half-reaction is oxidation or reduction:

OXIDATION	REDUCTION
Gain of OXYGEN	Loss of OXYGEN
Loss of HYDROGEN	Gain of HYDROGEN
!! Loss of ELECTRONS !!	!! Gain of ELECTRONS !!
Increase in OXIDATION STATE	Decrease in OXIDATION STATE

NOTE: *Oxidation states will be explained later...*

- Quick way to memorise which is which; remember the **OIL-RIG**:
 - **O**xidation **I**s **L**oss, **R**eduction **I**s **G**ain of ELECTRONS.
- Hence, the 2 half-equations above can be labelled as oxidation or reduction.
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^{-}$ (Oxidation; zinc LOSES electrons)
 - $\text{Cu}^{2+} + 2\text{e}^{-} \longrightarrow \text{Cu}$ (Reduction; copper GAINS electrons)

- The species that is oxidised is the reductant (thus, zinc is the reductant)
- The species that is reduced is the oxidant (thus, copper is the oxidant)
- There are many types of *redox* reactions, a few of which are:
 - **Displacement** reactions; e.g. magnesium and silver nitrate:
 - $\text{Mg}_{(s)} + 2\text{AgNO}_{3(aq)} \longrightarrow \text{Mg}(\text{NO}_3)_2(aq) + 2\text{Ag}_{(s)}$
 - $\text{Mg} + 2\text{Ag}^+ + 2\text{NO}_3^- \longrightarrow \text{Mg}^{2+} + 2\text{NO}_3^- + 2\text{Ag}$
 - $\text{Mg} + 2\text{Ag}^+ \longrightarrow \text{Mg}^{2+} + 2\text{Ag}$ (2NO_3^- is the spectator ion)
 - ◆ $\text{Mg} \longrightarrow \text{Mg}^{2+} + 2e^-$ (Oxidation)
 - ◆ $2\text{Ag}^+ + 2e^- \longrightarrow 2\text{Ag}$ (Reduction)
 - **Acid/Metal** reactions; e.g. sulfuric acid and zinc:
 - $\text{H}_2\text{SO}_{4(aq)} + \text{Zn}_{(s)} \longrightarrow \text{ZnSO}_{4(aq)} + \text{H}_{2(g)}$
 - $2\text{H}^+ + \text{SO}_4^{2-} + \text{Zn} \longrightarrow \text{Zn}^{2+} + \text{SO}_4^{2-} + \text{H}_2$
 - $2\text{H}^+ + \text{Zn} \longrightarrow \text{Zn}^{2+} + \text{H}_2$ (SO_4^{2-} is the spectator ion)
 - ◆ $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2e^-$ (Oxidation)
 - ◆ $2\text{H}^+ + 2e^- \longrightarrow \text{H}_2$ (Reduction)
 - **Metal/Non-metal** reactions; e.g. reacting sodium and chlorine gas:
 - $2\text{Na}_{(s)} + \text{Cl}_{2(g)} \longrightarrow 2\text{NaCl}_{(s)}$
 - $2\text{Na} + \text{Cl}_2 \longrightarrow 2\text{Na}^+ + 2\text{Cl}^-$ (No spectator ion in this case)
 - ◆ $2\text{Na} \longrightarrow 2\text{Na}^+ + 2e^-$ (Oxidation)
 - ◆ $\text{Cl}_2 + 2e^- \longrightarrow 2\text{Cl}^-$ (Reduction)
 - **Alkali metal/water** reactions; e.g. reacting potassium and water:
 - $2\text{K}_{(s)} + 2\text{H}_2\text{O}_{(l)} \longrightarrow 2\text{KOH}_{(aq)} + \text{H}_{2(g)}$
 - $2\text{K} + 2\text{H}_2\text{O} \longrightarrow 2\text{K}^+ + 2\text{OH}^- + \text{H}_2$
 - ◆ $2\text{K} \longrightarrow 2\text{K}^+ + 2e^-$ (Oxidation)
 - ◆ $2\text{H}_2\text{O} + 2e^- \longrightarrow 2\text{OH}^- + \text{H}_2$ (Reduction)
 - This is slightly different as there are TWO elements in the reduction half.
 - **Metal combustion** reactions; e.g. burning magnesium in oxygen:
 - $2\text{Mg}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{MgO}_{(s)}$
 - $2\text{Mg} + \text{O}_2 \longrightarrow 2\text{Mg}^{2+} + 2\text{O}^{2-}$
 - ◆ $2\text{Mg} \longrightarrow 2\text{Mg}^{2+} + 2e^-$ (Oxidation)
 - ◆ $\text{O}_2 + 2e^- \longrightarrow 2\text{O}^{2-}$ (Reduction)

- *Identify the relationship between displacement of metal ions in solution by other metals to the relative activity of metals:*
 - In the above metal displacement reaction, between zinc and copper sulfate, the reaction proceeded ONLY because **zinc** was more reactive than **copper**.
 - If you placed copper in a zinc sulfate solution, nothing would happen.
 - Hence, only a *more* reactive metal will displace a *less* reactive metal.
 - Using this fact, a table of reactivity, or '**metal activity series**' can be formed, with the more reactive metals on the left, and the less reactive metals on the right.
 - THE METAL ACTIVITY SERIES:

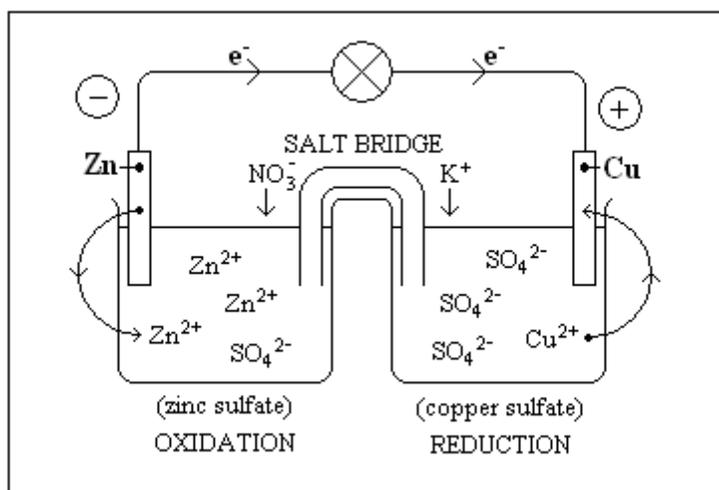
K→Na→Li→Ca→Mg→Al→Zn→Fe→Sn→Pb→H→Cu→Ag→Pt→Au
 - This 'series' was deduced through experimentation; it should be learnt.
 - Thus, a metal on the series can displace out of solution ANY metal on its *right*, but cannot displace any metal on its *left*; hydrogen is included as a standard.
 - What the 'metal activity series' implies:
 - The metals on the left are very reactive and hence LOSE electrons easily, and are thus likely to be **oxidised**; most of the time they are *reductants*.
 - The metals on the right are very unreactive; *but* when they are ions, they GAIN electrons very easily, and thus are easily **reduced**; most likely *oxidants*.
- *Account for the changes in the oxidation state of species in terms of their loss or gain of electrons:*
 - '**Oxidation state**', or number, is another name for the VALENCY of an element.
 - It is defined as the *charge* an element (in a compound) would have if all bonded atoms and electron pairs were removed from it.
 - RULES FOR CALCULATING OXIDATION STATES:
 - All atoms in their *elemental* form are given an oxidation number of zero (e.g. Zn, H₂, P₄, S₈ are all given an oxidation number of 0).
 - **Neutral** molecules are given an oxidation number of zero (e.g. H₂O, NaCl).
 - **Monatomic** ions are given an oxidation number equal to their charge, including the sign (e.g. Cu⁺ = 1, S²⁻ = -2).

- **Polyatomic** ions are also given an oxidation number equal to their *charge*, including the sign (e.g. $\text{OH}^- = -1$, $\text{PO}_4 = -3$, $\text{NH}_4^+ = 1$, $\text{SO}_4^{2-} = -2$), and the SUM of the oxidation states of the atoms equals this number.
- **Oxygen** has an oxidation number of -2 in all compounds, except in peroxides, where it is equal to -1 (peroxide is the anion O_2^{2-}).
- **Hydrogen** has an oxidation number of +1, except in metal hydrides, where it has an oxidation number of -1 (e.g. in sodium hydride, NaH).
- Using these rules, the oxidation states of elements in compounds can be found.
- **EG:** Find the oxidation number of *manganese* in the permanganate ion (MnO_4^-):
 - It is a polyatomic ion with a net charge of -1.
 - Hence; $\text{Mn} + 4 \times \text{O} = -1$

$$\text{Mn} + 4(-2) = -1$$

$$\text{Mn} = 8 - 1 = 7$$
 - Therefore, manganese has an oxidation state of +7 in KMnO_4 .
- The POINT of all this is that sometimes it is difficult to identify whether a reaction is oxidation or reduction; oxidation states provide a new method:
 - **Oxidation** is INCREASE in oxidation number.
 - **Reduction** is DECREASE in oxidation number.
- Relating this back to the metal displacement reactions:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^-$ (Oxidation)
 - $\text{Cu}^{2+} + 2\text{e}^- \longrightarrow \text{Cu}$ (Reduction)
- It can be seen that the oxidation state of **zinc** changes from (0 \rightarrow +2); this *increase* signifies an oxidation, while the oxidation state of **copper** changes from (+2 \rightarrow 0); this *decrease* shows it is a reduction.
- Thus, relating this back to transfer of electrons:
 - An increase in oxidation number means that electrons have been lost, and the oxidation number is increasing (moving towards the “positive” numbers) due to the loss of negative electrons.
 - A decrease in oxidation number means that electrons have been gained, and the oxidation number is decreasing (moving towards the “negative” numbers) due to a gain of negative electrons.

- Describe and explain galvanic cells in terms of oxidation/reduction reactions:
 - A **galvanic cell** is a device or an apparatus that allows ELECTRICITY to be produced from a chemical reaction (specifically, redox reactions).
 - Electricity is simply a flow of electrons. Redox reactions are *electron-transfer* reactions; if this electron flow can be exploited, electricity could be produced.
 - In a galvanic cell, to utilise the electron flow, the redox reaction is split into its two half-reactions: There are two **half-cells**; OXIDATION takes place in one cell and REDUCTION in the other.
 - A conducting wire and *salt bridge* connects the two half-cells and completes the circuit; as electrons have to flow from the oxidation cell to the reduction cell, a flow of electrons is produced in the wire, and hence electricity is produced.
 - Galvanic cells are explained in more detail below...
- Outline the construction of galvanic cells and trace the direction of electron flow:
 - As *galvanic cells* use a redox reaction to make electricity, the metal displacement reaction of zinc and copper sulfate can be used as an example (*again...*)
 - The two half-equations of the reaction are:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^-$ (Oxidation)
 - $\text{Cu}^{2+} + 2\text{e}^- \longrightarrow \text{Cu}$ (Reduction)
 - This is the set-up of a *galvanic cell* using these 2 reactions:



- This type of galvanic cell is also called a Daniell Cell.
- GALVANIC CELL SET-UP:
 - There are two cells, each containing a solution of the metal-sulfate; one cell contains *zinc sulfate*, the other cell *copper sulfate*.
 - In the zinc sulfate, there is a solid **zinc electrode**, connected by a wire to a solid **copper electrode**, which is in the copper sulfate solution.
 - A salt bridge, soaked in *potassium nitrate* solution, connects the two cells.
- The CHEMICAL REACTIONS:
 - In the zinc-sulfate cell, **oxidation** is occurring, as SOLID zinc is oxidised to zinc IONS, which then flow into the zinc sulfate solution. The electrons that are released flow into the wire:
 - $\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^{-}$ (Oxidation)
 - In the copper-sulfate cell, **reduction** is occurring, as copper IONS are reduced to SOLID copper, when then build up on the copper electrode. Electrons are received through the wire, which then reduce the ions:
 - $\text{Cu}^{2+} + 2\text{e}^{-} \longrightarrow \text{Cu}$ (Reduction)
- NOTE: The oxidation and reduction cells can be on the left OR the right, it does not matter, although oxidation is conventionally on the right.
- As the *zinc* is slowly oxidised, and more zinc ions build-up, the zinc sulfate solution builds up in POSITIVE charge (more Zn^{2+} than SO_4^{2-}).
- Similarly, as the *copper* ions are reduced, the copper sulfate solution builds in NEGATIVE charge (more SO_4^{2-} than Cu^{2+}).
- However, this will affect the flow of electrons; electrically neutral solutions are needed for optimal electricity production. Hence the role of the salt bridge:
 - The **salt bridge** completes the circuit, but also has another function.
 - The salt bridge maintains **electrical neutrality**; this means that it keeps the charges in both the half-cells at zero, by allowing the flow of ions.
 - The salt bridge is soaked in **potassium nitrate** solution: Thus, as the positive charge builds up in the left cell, NEGATIVE nitrate ions migrate towards the cell to neutralise the charge; as the negative charge builds up in the right cell, the POSITIVE potassium ions move towards the cell to neutralise it as well.

- *Define the terms anode, cathode, electrode and electrolyte to describe galvanic cells:*
 - An **ELECTRODE** is anything through which electrical current passes; in the context of galvanic cells, they are the metal conductors placed in the *electrolytes*.
 - An **ELECTROLYTE** is any solution that can conduct electricity; all salt solutions are electrolytes (but not all salts are soluble).
 - The terms **anode** and **cathode** refer to the electrodes that are placed in the solution; to identify which is the anode and which is the cathode:
 - **AN OX** – Anode is OXIDISED (it is the “negative” side).
 - **RED CAT** – Cathode is REDUCED (it is the “positive” side).
 - Hence, the zinc was the anode, and the copper was the cathode.
 - In galvanic cells, electrons flow from *anode* to *cathode*.
- *Solve problems and analyse information to calculate the potential E° requirement of named electrochemical processes using tables of standard potentials and half-equations:*
 - The total **voltage** (or EMF; electromotive force) a galvanic cell can produce is determined by the substances taking part in the redox reaction.
 - The above cell can also be represented as: [Zn | Zn²⁺ || Cu²⁺ | Cu]:
 - Where Zn | Zn²⁺ represents a metal/metal ion couple.
 - The double line || represents the salt bridge.
 - Electrode/electrolyte couples have a **FIXED** voltage, no matter how many moles of each substance is present.
 - This “fixed voltage” is termed the **standard reduction potential** (or E°), and is given in a table in the exam. For example, in such a table it has:
 - Zn²⁺ + 2e⁻ → Zn (**-0.76V**)
 - Cu²⁺ + 2e⁻ → Cu (**0.34V**)
 - However, in the cell, the zinc reaction is: Zn → Zn²⁺ + 2e⁻, the *reverse* of the above reaction; so the SIGN of E° is **FLIPPED**. Hence, for our reaction, the E° for Zn | Zn²⁺ is +0.76V (not -0.76V), and the E° for Cu²⁺ | Cu is 0.34V.
 - **THUS** the total E° value for this cell is the sum, which is 0.34 + 0.76 = 1.1 volts.

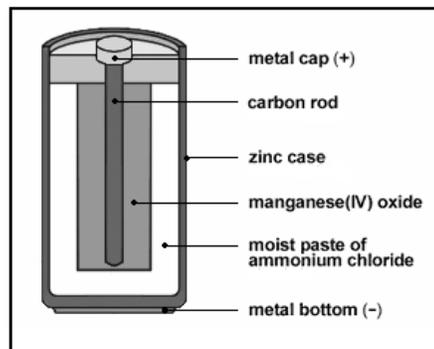
- **PRACTICAL** – *Perform a first-hand investigation to identify the conditions under which a galvanic cell is produced:*
 - A galvanic cell was produced in the lab in the same set-up as above; that is, in the form of a DANIELL CELL.
 - A 2 cm strip of **zinc** and **copper** were cut from metal strips. Using wire leads and crocodile clips, the zinc strip was connected to the NEGATIVE terminal of a voltmeter, and the copper strip connected to the POSITIVE terminal.
 - The zinc was then placed in 50 mL of 1M solution of **zinc sulfate**, and the copper in 50 mL of 1M solution of **copper sulfate**.
 - A strip of filter paper was soaked in **potassium nitrate**; the two cells were then connected using this ‘salt bridge’.
 - **RESULTS:** The voltmeter showed a reading of 0.4 volts. When more electrolyte was added, the voltage stayed at 0.4 volts; thus the voltage is determined ONLY by the metals used, and has nothing to do with the amount of copper or zinc.
 - **JUSTIFY** the method:
 - Copper and zinc were used as they are readily available, non-toxic metals.
 - 1M solution was used as the ratio of moles of the salts was 1:1
 - A potassium nitrate salt bridge was used as potassium and nitrate ions do not react with zinc, copper or sulfate ions.
- **PRACTICAL** – *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:*
 - The same experiment above was performed again, except a range of difference electrode electrolyte couples were used.
 - **RESULTS:**
 - [Zn | Zn²⁺ || Cu²⁺ | Cu]: TOTAL voltage = 0.4 V
 - [Mg | Mg²⁺ || Cu²⁺ | Cu]: TOTAL voltage = 0.95 V
 - [Al | Al³⁺ || Cu²⁺ | Cu]: TOTAL voltage = 0.2 V
 - [Fe | Fe²⁺ || Cu²⁺ | Cu]: TOTAL voltage = 0.5 V

- **REPORT** – Gather and present information on the structure and chemistry of a zinc-carbon dry cell and evaluate it in comparison to a silver-oxide button cell in terms of: **1. Chemistry** **2. Cost and practicality** **3. Impact on society and** **4. Environmental impact:**

– **The DRY CELL** (or Leclanché Cell):

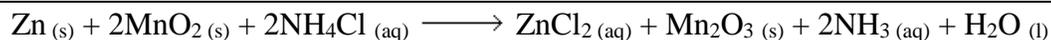
▪ STRUCTURE:

- The dry cell is made of a *carbon rod* surrounded by a mixture of **manganese(IV) oxide** and carbon (in the form of *graphite*); this is the cathode. This is then surrounded by a paste of **ammonium chloride** which acts as the electrolyte. All of this is contained in a **zinc shell**, which is the anode.

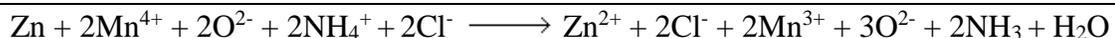


▪ CHEMISTRY:

- The complete *chemical equation* is shown as:



- The *ionic equation* is:



- But there is also another reaction: $2\text{NH}_4^+ \rightleftharpoons 2\text{NH}_3 + 2\text{H}^+$
- This occurs on the left hand side; hence 2NH_3 and 2Cl^- are spectator ions:
- Thus the *net ionic equation* is:



- Splitting this into redox **half-cells**:

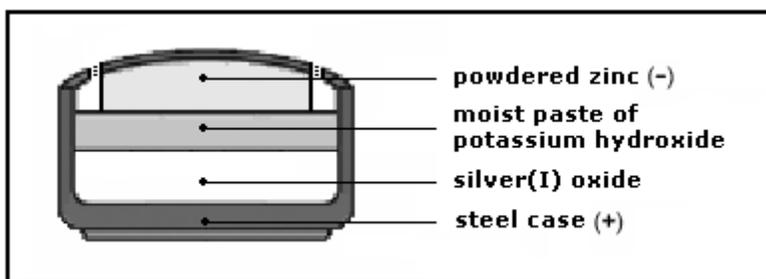


- **Zn** is oxidised: ($0 \rightarrow +2$) and **Mn** is reduced: ($+4 \rightarrow +3$).

- The **SIMPLIFIED** galvanic cell representation is:



- COST and PRACTICALITY:
 - The dry cell is relatively cheap.
 - It is very practical to manufacture as there is little wastage of materials; all the materials (including the casing) take part in the reaction.
 - It is light and portable, and can be used in small appliances.
 - It has a short shelf-life however, as the acidic NH_4^+ slowly corrodes the zinc.
 - IMPACT on SOCIETY:
 - It was the first commercially produced battery, and so it had a HUGE impact on society; it made portable devices such as torches, radios and clocks possible.
 - It is very widely used, as it is a cheap, portable source of steady electricity.
 - ENVIRONMENTAL IMPACT:
 - Very minimal environmental impact.
 - The manganese(III) product is readily oxidised back to manganese(IV), which is stable and insoluble; it is harmless.
 - Ammonium salts and carbon are also harmless; small quantities of zinc pose no environmental risk.
- **The Silver-Oxide BUTTON CELL:**
- STRUCTURE:
 - The silver-oxide button-cell is made of layers of chemicals within a steel case. There is powdered **silver(I) oxide** at the bottom; this is the cathode. At the top is powdered **zinc**; this is the anode. They are separated by a paste of alkaline **potassium hydroxide** which acts as the electrolyte and a catalyst. The steel case does not take part in the reaction.

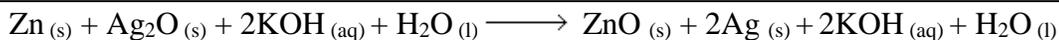


▪ CHEMISTRY:

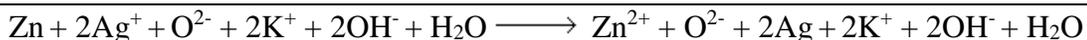
- The overall *chemical equation* is:



- However, this ignores the role of the potassium hydroxide; a more complete chemical equation (with aqueous KOH as catalyst) is:

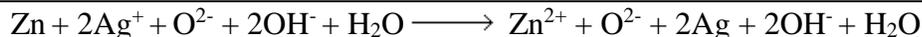


- The *ionic equation* is:

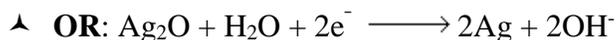
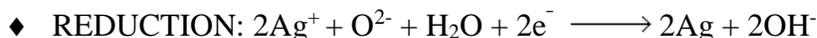
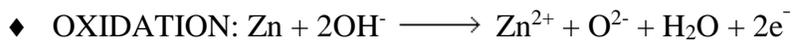


- ◆ NOTE: The water and OH⁻ need to be shown for the half-equations.

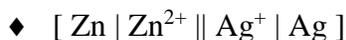
- The *net ionic equation* (without K⁺ ions) is:



- Splitting this into redox **half-cells**:



- **Zn** is oxidised: (0 → +2) and **Ag** is reduced: (+1 → 0).
- THUS, KOH takes part in the equation as a catalyst, by splitting into its ions, but at the end of the reaction, the ions reform.
- The SIMPLIFIED galvanic cell representation is:



▪ COST and PRACTICALITY:

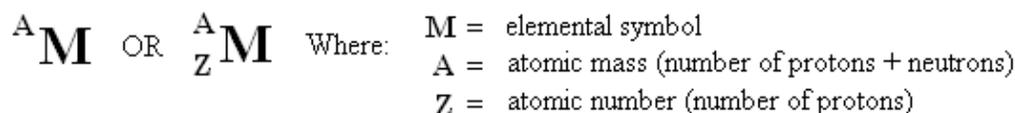
- Silver oxide button cells are very **expensive**, due to the high cost of silver.
- However, even small cells are able to provide large amounts of electricity with a very constant voltage for a long period of time; so the benefits balance out the costs of the silver.
- It is non-rechargeable.
- The steel case does not take part in the reaction, and there is very little chance of leakage.

- IMPACT on SOCIETY:
 - The very small size of the cell, and high constant voltage allows it to have many applications, such as in wristwatches (where they last for many years), calculators and digital cameras.
- ENVIRONMENTAL IMPACT:
 - Environmental impact is minimal.
 - The *zinc*, *zinc oxide*, *silver*, and *silver oxide* are all stable, insoluble and non-toxic compounds.
 - *Potassium hydroxide* is strongly alkaline; however, it is in quite a dilute form as an electrolyte, and small amounts are not harmful.
- **EVALUATING** the dry-cell in relation to the button cell:
 - In terms of chemistry, the dry-cell and the button cell have very similar reactions; however, the button cell is able to produce larger and more constant voltage supply in relation to size; this is because **silver** has a higher reduction potential than **manganese(IV)**. Also the alkaline environment of the button cell encourages the reaction to occur at a constant rate, for long periods.
 - In terms of cost and practicality, the dry cell is more practical in most situations as it is cheaper. However, some situations require smaller cells that are able to last much longer than the short life of the dry cell, such as in watches. Also, the button cell is much less likely to leak, and thus is a more reliable battery.
 - In terms of impact on society, the dry cell has had a far greater impact than the button cell. This is due to the historical significance of the Leclanché cell, the first battery ever produced. The dry cell made portable electrical devices possible; however, the button cell has allowed the size of electrical devices to reduce greatly, as some devices these days are even smaller than dry cells.
 - Both cells have very minimal environmental impact, and hence are advisable to be used over other more polluting cells, such as mercury cells.

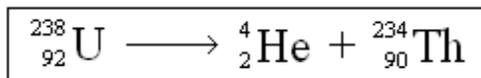
5. Nuclear chemistry provides a range of materials:

- **RECALL:**

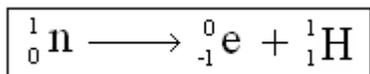
- **Isotopes** are atoms of the same element with different numbers of NEUTRONS; but they have the same number of PROTONS.
- In *nuclear chemistry* (chemistry dealing with nuclear reactions), isotopes are shown in the following form:



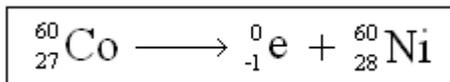
- E.G. chlorine-35 is written as ${}^{35}\text{Cl}$ and rubidium-85 as ${}^{85}\text{Rb}$
- There are three types of radiation: α (alpha), β (beta) and γ (gamma) radiation:
 - **Alpha Decay:** Alpha radiation is made of ‘helium nuclei’ (2 protons and 2 neutrons) that are ejected from unstable large nuclei (too heavy). For example, the decay of uranium-238:



- **Beta Decay:** Beta radiation is made up of electrons ejected from an unstable nucleus (too many neutrons); BUT nuclei do not contain electrons. Hence, the underlying reaction is the decomposition of a *neutron*:



When a neutron decomposes, it forms an **electron**, which is immediately ejected as beta radiation, and a **proton** (‘hydrogen nucleus’), which is captured by the nucleus. Thus, beta decay results in an **increase** in atomic number (IMPORTANT). For example, the beta decay of cobalt-60 results in an increase of atomic number, creating nickel-60:



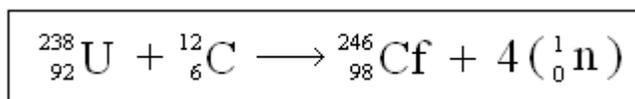
- There is no such thing as “**gamma** decay”; gamma radiation, high energy electromagnetic waves, are emitted in addition to some beta or alpha decays.

- *Distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable:*
 - **Radioactivity** is the spontaneous emission of RADIATION from certain atoms
 - For some elements (e.g. carbon), some of their isotopes are stable (such as carbon-12), and others are radioactive (such as carbon-14).
 - There are 2 *conditions* used to predict whether an atom will be radioactive:
 - Atomic Number: All atoms (including all their isotopes) with more than 83 protons ($Z > 83$) are radioactive. That is, all atoms with atomic number greater than *bismuth* are radioactive and undergo decay.
 - Proton-Neutron Ratio: The ratio of protons to neutrons determines whether an atom will be stable or not. Anything *outside* the ratios below is radioactive:
 - $Z < 20$, the stable ratio of protons to neutrons is **1:1**
 - Around $Z = 30$, the stable ratio is about **1:1.3**
 - Around $Z = 80$, the stable ratio is **1:1.5**
- *Describe how transuranic elements are produced:*
 - **Transuranic** elements are elements with atomic numbers greater than uranium; that is $Z > 92$ (more than 92 protons).
 - All transuranic elements are artificially produced.
 - Transuranic elements are produced in two ways:
 - **Neutron Bombardment** (in nuclear reactors): In nuclear reactions, the fission chain-reaction (of uranium-235 or other elements) produces large amounts of neutrons. When atoms are placed inside the reactor, they are bombarded by these neutrons. Occasionally the atom **ABSORBS** one of these neutrons; however, it is unstable, and undergoes *beta decay* (see above). Hence the proton number increases, and a transuranic element can be created.
 - **EG:** Uranium-238 is not fissile (it can not undergo the nuclear chain-reaction); when it is placed in the reactor, the following reaction occurs:

$${}_{92}^{238}\text{U} + {}_0^1\text{n} \longrightarrow {}_{92}^{239}\text{U} \longrightarrow {}_{-1}^0\text{e} + {}_{93}^{239}\text{Np}$$
 - Thus, neptunium-239, the first transuranic element, is formed.
 - This method is used to produce the first few of the transuranic elements.

- **Fusion Reactions** (in particle accelerators): The production of larger transuranic elements is achieved by colliding heavy nuclei with high-speed positive particles (such as helium or carbon nuclei). The positive particles need to be at very high speeds to overcome the positive repulsive force of the heavy nuclei and fuse with them. Particle accelerators are used to bring these particles to the high speeds required.

➤ **EG:** Uranium-238 is fused with a carbon nucleus:



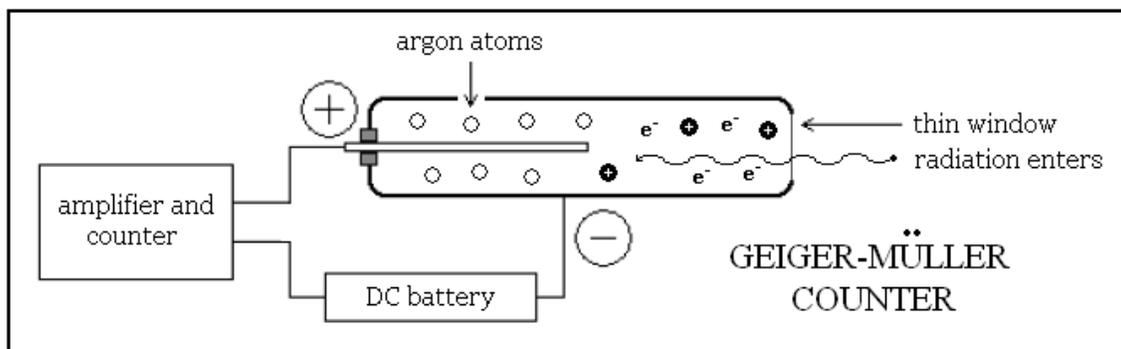
➤ As a result, californium-246, a large transuranic element, is formed.

- *Process information from secondary sources to describe recent discoveries of elements:*

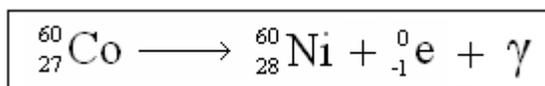
– Four new elements have been discovered in the 21st century. They are listed below. Note that their strange names are just temporary until the IUPAC decides on permanent names:

- **Ununhexium:** Also known as “eka-polonium”, element 116 was synthesised in December, 2000, by the Joint Institute for Nuclear Research (Dubna, Russia). It was produced through the fusion of curium-248 and calcium-48. The atom decayed 48 milliseconds later.
- **Ununpentium:** Also known as “eka-bismuth”, element 115 was synthesised in February, 2004, by the scientists from the Joint Institute for Nuclear Research (Dubna, Russia) and the Lawrence Livermore National Laboratory (America). It was produced through the fusion of americium-243 and calcium-48. The atom then underwent ALPHA decay, forming element 113, a new element.
- **Ununtrium:** Also known as “eka-thallium”, element 113 was also synthesised in February, 2004, through the alpha decay of *ununpentium*.
- **Ununoctium:** Also known as “eka-radon”, element 118 is the most recently produced, and the heaviest element known to man. It was produced by the fusion of californium-249 atoms and calcium-48.

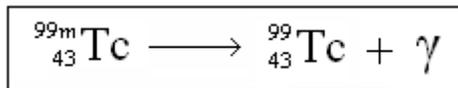
- *Describe how commercial radioisotopes are produced:*
 - **Commercial** radioisotopes are isotopes that are produced on a regular basis for medical, industrial or other use.
 - Many are produced by neutron bombardment within nuclear reactors, as explained above; at the **Lucas Heights** nuclear reactor in Sydney, the Australian Nuclear Science and Technology Organisation (**ANSTO**) produces a range of neutron-rich isotopes for commercial use:
 - *Technitium-99m* (an important medical radioisotope) is produced by neutron bombardment of molybdenum-98.
 - *Cobalt-60* (used in industry and medicine) is produced by neutron bombardment of the stable cobalt-59.
 - *Americium-241* (a domestically used isotope; in smoke alarms) is produced by neutron bombardment of plutonium-241.
 - Other isotopes are produced in particle accelerators, such as the **National Medical Cyclotron**, near the Royal Prince Alfred hospital. Particle accelerators accelerate nuclei to incredible speeds, and 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. Radioisotopes produced include:
 - *Iodine-131* (used to diagnose thyroid disorders).
 - *Carbon-11, nitrogen-13, oxygen-15* (all used in PET scans).
- *Identify instruments and processes that can be used to detect radiation:*
 - **Geiger-Müller Counter:**
 - This device consists of a metal tube filled with argon gas, connected to a DC power supply.
 - As radiation enters, it ionises the gas, splitting the atoms into electrons and positive nuclei that complete the circuit within the metal tube; the stronger the radiation, the more ionisation that occurs.
 - The amplifier releases a series of clicks or displays an electronic reading to signify that radiation is present. The counter thus display a number in terms of intensity of radiation.



- **Photographic Film:**
 - Photographic film is a sheet of plastic coated with silver halide salts.
 - These salts are sensitive to electromagnetic radiation (e.g. light or X-rays), and darken when they are exposed to radiation.
 - People who work with radioactive materials often wear badges containing photographic film; the amount of darkening shows how much they have been exposed to radiation.
- **Scintillation Counter:**
 - Some substances give off light when they are struck by high-energy radiation.
 - A photo-receptor cell senses these flashes of light that occur, and from this measures the number of decay events that are occurring.
- *Identify one use of a named radioisotope in industry and in medicine:*
 - **Industry:** Cobalt-60 is used to irradiate food to prolong its shelf-life.
 - **Medicine:** Technetium-99m can be used to identify the location of tumours.
- *Describe the way in which the above named industrial and medical radioisotopes are used and explain their use in terms of their chemical properties:*
 - **Cobalt-60:**
 - USE: The irradiation of food materials.
 - CHEMICAL PROPERTY: It is chemically inert, and hence it can be safely housed within machinery without fear of any unwanted reactions, such as oxidation or reduction. It is also a strong gamma emitter.



- **HOW IT WORKS:** Food on a conveyer belt is passed through a chamber containing cobalt-60 housed within machinery. Gamma rays are extremely effective in damaging large biological molecules (e.g. DNA) because they are high-energy waves that can destroy chemical bonds. This kills harmful microbes in food, making them safer to eat, and last longer.
 - **Advantages:** Gamma rays have sufficient energy to destroy bacteria but not enough to make food radioactive; also cobalt-60 has a half-life of 5.3 years so it can last very long.
 - **Disadvantages:** Gamma radiation can also destroy useful nutrients in food; workers must be protected from irradiation.
- **Technetium-99m:**
- **USE:** A cancer diagnostic tool (identifies location of tumours).
 - **CHEMICAL PROPERTY:** Technetium-99m can be changed to a number of oxidation states. This allows for the production of a wide range of biologically active chemicals; it can be chemically bonded to an organic substance such as glucose and injected into the body. It emits low energy gamma rays.



- **HOW IT WORKS:** Technetium-99m is bonded to an organic compound and inserted into the body. Tc-99m is *metastable* (as denoted by the **m**); this means that its nucleus is in an *excited* state. It releases gamma radiation to release this energy. Hence it is a source of pure gamma radiation, which is then used by imaging machinery to diagnose diseases.
- **Advantages:** It has a very short half-life of 6 hours, and hence causes minimal damage to the patients tissues. It emits low energy gamma radiation that can be picked up by machinery, but does not damage cells to a great extent. It is quickly eliminated by the body. Tc-99m is relatively reactive, and can be joined to many compounds.
- **Disadvantages:** As it has such a short half-life it must be continuously made. Healthy cells may also killed.

- *Use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine:*
 - BENEFITS of radioisotopes:
 - **Industrial** benefits include the ability to make monitoring equipment that is more sensitive, precise and reliable than previously possible. It allows for more efficient processes (such as sterilisation and food irradiation) and previously impossible things (examining faults in construction and machinery).
 - **Medical** benefits include a new wide range of non-invasive diagnostic techniques that would not be possible on sensitive organs (brain, etc). Radiation therapy is also a greatly positive new treatment.
 - PROBLEMS with radioisotopes:
 - **Nuclear reactors**, which are the source of neutrons, produce considerable amounts of nuclear waste, which we have no way of disposing safely, and which last for thousands of years.
 - The storage of **radioactive** material presents a problem, as they must be kept in shielded containers to prevent radiation leakages.
 - Doses of **radiotherapy** must be extremely carefully controlled, to balance between the benefits of killing cancer cells, and the risk of harm.
 - Nuclear technicians and other workers must be continually **protected** and avoid any form of irradiation, as disease such as cancer or radiation poisoning can result from this.