Natasha T.

Production of Materials: HSC Notes

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

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

Production

Industrially, ethene (also known as ethylene) is extracted from petroleum by the "**cracking**" of various fractions isolated from petroleum refinery.

- Before cracking is undertaken, petroleum (a mixture of hydrocarbons) is refined by distilling into fractions – some useful others not. The fractions of little value (such as naphtha and LPG) are cracked to form useful products.
- In the cracking process, long-chain hydrocarbons are split into shorter ones through the breaking of strong carbon-carbon bonds.
- Ethene is considered a by-product of the cracking process as the purpose is to produce petrol rather than produce ethene specifically. Nevertheless, ethene is **produced in large quantities**.

2 ways to 'crack' petroleum products into ethene

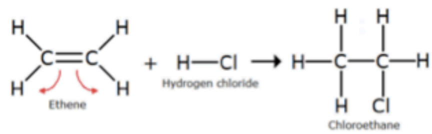
- **Thermal cracking** involves high temperatures (450°-750°C) and pressures (~700kPa). These conditions ensure there is enough energy to break the carbon-carbon bonds without the need for a catalyst.
- **Catalytic cracking** involves the use of a catalyst (usually zeolites) which reduces the amount of energy required to break carbon-carbon bonds (it lowers the activation energy). Hence, lower temperatures (~500°C) and pressures can be used (cheaper to maintain).

For example, $C_{12}H_{26}$ (dodecane) --> C_8H_{18} (octane) + C_4H_8 (butene)

Identify that ethylene, because of its high reactivity of the double bonds, can be readily transformed into many useful products.

Reactivity

Ethene is highly reactive due to its unsaturated structure (its double bond). This means it is readily transformed into many useful products via the **addition reaction.**



For example, a number of useful polymers can be formed from ethane:

- Ethene is a **monomer** – a small molecule that can be reacted with others to form a long chain molecule (a **polymer**). The polymer made from the ethene monomer is polyethylene.
- Ethene can also be used to make other monomers via a substitution reaction where some of the H-atoms are replaced by others. These monomers can then be polymerised to make the corresponding polymer. For example:

Starting chemical	Can make these monomers	Polymerisation process	Can make these polymers
Ethene	Ethylene (ethene)	Addition reaction	LDPE
			HDPE
	Vinyl chloride (chloroethene)	Addition reaction	PVC
	Styrene (phenylethene)	Addition reaction	Polystyrene

- Thus, ethene can be used to make a number of commercially significant addition polymers including polyethylene (HDPE and LDPE – see below), polyvinylchloride (PVC) and polystyrene.

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

Addition Polymer: the breaking of a double bond and 'adding' in two or more atoms (only occurs in alkenes)

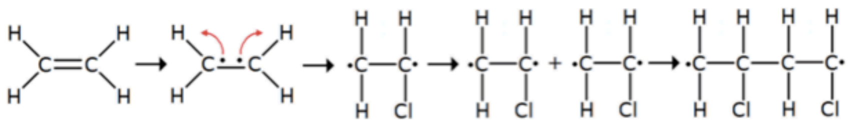
For example, $C_2H_4 + H_2$ ----> C_2H_6 (ethane)

For example, C2H4 + Br2 ----> $C_2H_4Br_2$ 1,2- dibromoethane

Polyethylene

Polyethylene (PE) is a commercially significant **addition polymer** – a polymer formed by the addition polymerisation process. In this process unsaturated monomers combine via the opening up of the double bond to form the polymer without losing any atoms or forming any other products.

- In PE, ethene's double bond opens up, allowing the addition of two more opened up monomers on either side of the original monomer:
- The above diagram is an oversimplification – the actual production of PE is much more complicated. It can result in the formation of low density or high density polyethylene (LDPE or HDPE, respectively).



Compare the reactivity of appropriate alkenes with corresponding alkanes in bromine water

Independent Variable:

- concentration of solution (use of cyclohexane and cyclohexene)

Controlled Variables:

- Same volume of solutions (10ml of each; cyclohexane and cyclohexene as well as bromine water)
- Same sized test-tube
- Same exposure to temperature

Based on the experiments conducted, it was found that cyclohexene was indeed more reactive than cyclohexane as after mixing both the cyclohexene and bromine water together in a test-tube, the solution had turned colourless after gently shaking the test-tube. Based on this result, it can be concluded that cyclohexene is indeed more reactive than cyclohexane as it is more reactive due to the presence of the double bond.

Outline the steps in the production of polyethylene as an example of a commercially and industrially important polymer

There are two known types of productions of polyethylene. These include Low Density Polyethylene and High Density Polyethylene.

High Density Polyethylene

HDPE takes place in low pressures (1-3 atm) and temperatures (~60°C), along with a catalyst, usually a **Ziegler-Natta catalyst** (a mixture of titanium chloride & trialkylaluminium compound). The resultant molecule is summarised below:

Structure	Unbranched molecules, packed together in an orderly fashion → stronger dispersion forces 
Properties	More crystalline: high melting point, high density, relatively hard and tough, less transparent (crystalline regions scatter and refract light and appear translucent or white)
Uses	Toys, garbage bins, kitchen utensils, milk bottles

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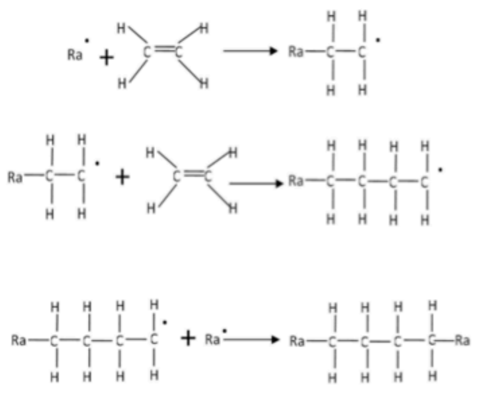
Low Density Polyethylene

LDPE is produced using high temperatures (~ 300°C) and pressures (1000 – 3000 atmospheres) with an initiator (such as peroxide)

- During the **initiation** step, U.V. light or heat is used to decompose the initiator into free radicals (atoms or molecules with unpaired electrons – highly reactive). These free radicals add across the double bond of an ethylene monomer via addition reactions to create a monomer free radical.
- In the **propagation step** the monomer free radical continues to react with ethylene monomers.
- This process continues until it is stopped with another initiator molecule during **termination.**
- The resultant polyethylene is summarised below:

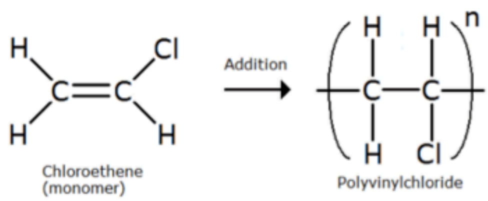


Structure	Extensively branched molecules, widely spaced apart → weak intermolecular forces
Properties	Light weight, low density, low rigidity, elastic, low hardness and toughness.
Uses	Disposable plastic bags, plastic takeaway boxes, plastic trays, cling wrap.

Identify the following as commercially significant monomers by both their systematic and common names:

- *Vinyl Chloride*
- *Styrene*

Polyvinylchloride (PVC)

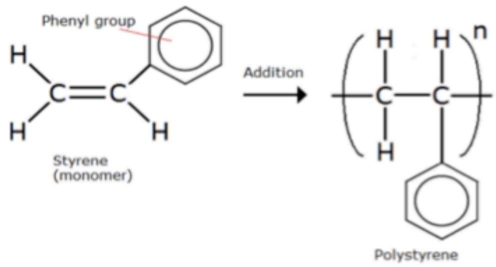


PVC is the polymer of the monomer C_2H_3Cl. The monomer's common name is 'vinyl chloride' and systematic name is 'chloroethene'.

Often with additives, PVC is used to make:

- **Pipes / guttering / credit cards:** PVC is suitable as it is hard, brittle/non-flexible and water resistant. For credit cards, pigment is added to make it visually appealing. As PVC degrades in UV light and has a low melting point, UV absorber and heat stabiliser are added for pipes and guttering.
- **Electrical conduit / electrical coating:** PVC is suitable as it is hard, brittle/non-flexible, and an electrical insulator. UV absorber is added to prevent breakdown in UV light.
- **Food packaging:** PVC is suitable as it is moderately resistant to chemical attack. The UV absorber additive is required.
- **Flexible hoses / gloves:** PVC is suitable as it is water resistant and moderately resistant to chemical attack. Since PVC is hard and brittle/inflexible, a plasticiser additive is needed to increase flexibility whilst a UV absorber and pigment additive are also needed.

Polystyrene (PS)



PS is the polymer of the monomer C_8H_8. The monomer's common name is 'styrene' and systematic name is 'ethenyl benzene'.

PS (often treated) is used to make

- **Car battery cases / tool handles:** PS is suitable in crystal form as it is rigid, hard, and lightweight while additives increase impact resistance. The crystal form of PS is also an electrical insulator which is especially useful for car batteries.
- **Insulated food packaging:** This use requires PS that has been treated by blowing hot air into molten PS. This form (called 'expanded PS') is suitable as it is moderately resistant to chemical attack, is a good heat insulator (e.g. for coffee cups) and is lightweight.
- **CD packaging / drinking glasses:** Crystal form PS is used as it has a high refractive index, high rigidity and hardness and is lightweight.
- **Protective packaging:** Expanded PS is used because it is soft, flexible and lightweight

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

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

Society's fossil fuels are non-renewable and most likely will run out during the next 100 years so it is important for scientists to come up with new alternatives that can be used to produce energy and materials such as polymers.

Biomass is considered an alternative replacement source for petroleum as the major component of biomass is cellulose, which can be converted into ethylene.

Explain what is meant by a condensation polymer:

Condensation Polymer*:* polymers that form by the elimination of a small molecule (usually water) when pairs of monomers join together.

Describe the reaction involved when a condensation polymer is formed

Cellulose is a condensation polymer consisting of around 10,000 units of glucose that act as monomers ($C_6H_{12}O_6$). The monomer formula can be written as: $HO-C_2H_{10}O_4-OH$.

The polymerisation occurs by the elimination of a water molecule between each monomer pair. For example:

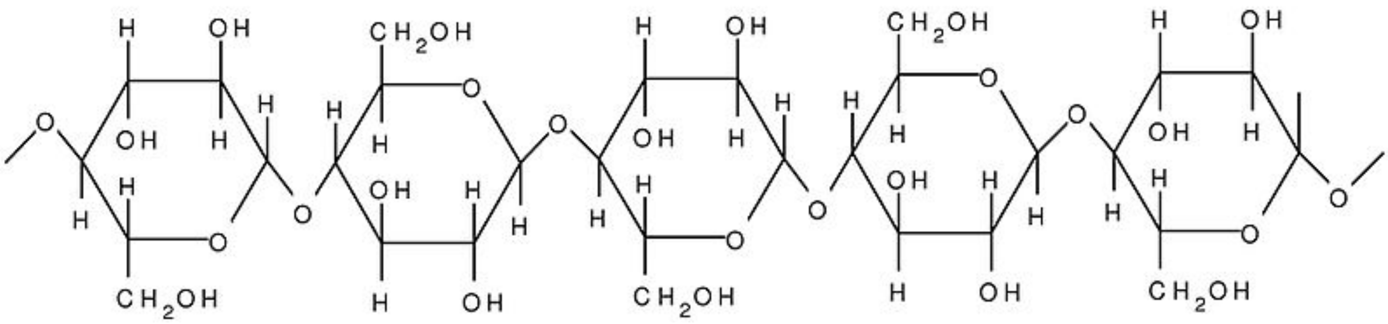
- $HO-C_2H_{10}O_4-OH$ $HO-C_2H_{10}O_4-OH$ $HO-C_2H_{10}O_4-OH$ $HO-C_2H_{10}O_4-OH$ $HO-C_2H_{10}O_4-OH$ $HO-C_2H_{10}O_4-OH-$

The removal of water can be written as:

- $HO-C_2H_{10}O_4-$~~OH H~~$O-C_2H_{10}O_4-$~~OH H~~$O-C_2H_{10}O_4-$~~OH H~~$O-C_2H_{10}O_4-$~~OH H~~$O-C_2H_{10}O_4-$~~OH H~~$O-C_2H_{10}O_4-OH-$

=

$O-C_2H_{10}O_4-O-C_2H_{10}O_4-O-C_2H_{10}O_4-O-C_2H_{10}O_4-O-C_2H_{10}O_4-O-C_2H_{10}O_4-O-C_2H_{10}O_4-$



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

In cellulose, each glucose unit has 4 carbon atoms joined together in a chain. Thus it contains the basic carbon chain structure needed to make starting molecules for petrochemicals which are also carbon based (e.g. ethene, propene, butene). There are advantages and disadvantages to the use of cellulose as a raw material.

Assess the reliability of using cellulose as a raw material for the petrochemical industry	
Advantages:	***Disadvantages:***
- renewable source of energy as cellulose can be found in plants - large quantity of biomass available - can decompose fairly easily	- expensive as technology needed must be modified in order to accumulate for the amount energy required to extract cellulose from biomass. - Large plots of free land needed to grow plants - Lands must be cleared for plant growth

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Use available evidence to gather and present data from secondary sources and analyse the progress in recent development and sue of a named biopolymer. This analysis should name the specific enzymes used or the organism used to synthesis the material and an evaluation of the use or potential use of the polymer produced related to its properties.

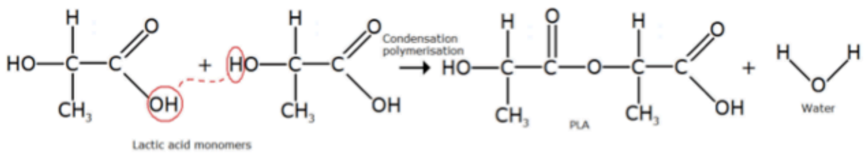
Polylactic Acid (PLA)

Progress

- 1890'S –PLA first discovered
- 1932 – First low molecular weight polymer of lactic acid was made.
- 1954 – Process for synthesising PLA was patented. Due to relatively high cost of acquiring the monomer, little further research and development was conducted until the 1980's.
- 1987-1992 – Cargill Inc. (USA) developed a pilot plant for PLA production.
- 1996 – PLA was commercialised.
- 2002 – By this time the Nebraska and Iowa facilities were using corn starch to produce large quantities of PLA.

Synthesis

- To convert sugar into lactic acid microorganisms such as **Lactobacillus bacteria** or fungi such as **Rhizopus oryzae** are used. They use the fermentation process.
- To convert lactic acid to PLA **Alcaligenes Eutrophus** (a type of bacteria) is used.
- Steps in PLA production:
  - Starch is extracted (e.g. from corn)
  - Dextrose (a sugar) is processed from starch
  - Dextrose is converted into lactic acid, by fermentation with **Lactobacillus bacteria**
  - PLA is produced by condensation polymerisation of lactic acid. ***Eutrophus*** bacteria is used as a catalyst.



Potential Use

PLA is currently used for a number of applications.

Loose-fill packaging as well as food packaging

Property	Application
Biodegradable	Preparation of bioplastic – used in compost bags and disposable tableware.
Oil and grease resistant	Useful as kitchen utensils, plates, dishes, bowls, etc.
High tensile strength	Numerous biomedical applications such as sutures, stents, dialysis media and drug delivery devices.

- Advantages of the use of PLA
  - It is **renewable** as it is produced from renewable resources like corn and starch.
  - As it is biodegradable it does not remain in landfills for a long time in contrast to other plastics (e.g. polyethylene) which can last for centuries.

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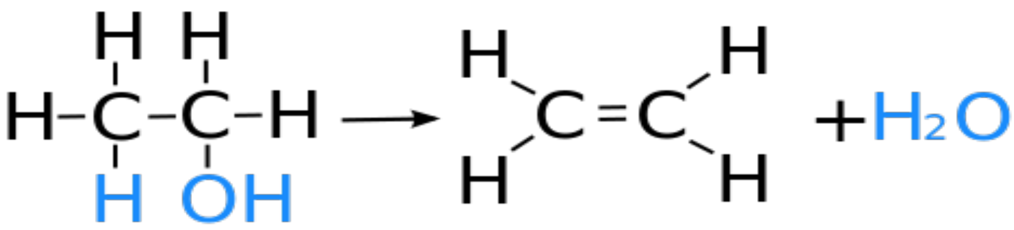
3. *Other resources, such as ethanol are readily available from renewable resources such as plants*

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

Dehydration*:* the removal of water molecules from a substance

Ethanol can be dehydrated thus can be formed into ethylene and water by heating it using a concentrated sulfuric acid catalyst.

C_2H_5OH ----> C_2H_4 + H_20



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.

Hydration*:* the adding of water molecules to the substance.

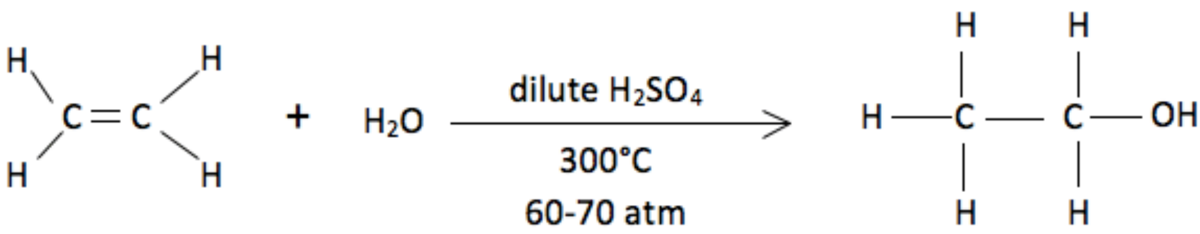
This is done by using a dilute sulphuric acid as a catalyst or phosphoric acid.

A dilute sulphuric acid is used to help lower the activation energy as water will not attack the double bond present in the ethylene molecule.

The hydration of ethylene is an example of an *addition reaction.*

******This method is a non-renewable source as ethene is non-renewable.***

C_2H_4 + H_2O ----> C_2H_5OH



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

Ethanol is a very polar molecule due to its hydroxyl (OH) group, with the high electronegativity of oxygen allowing hydrogen bonding to take place with other molecules. Ethanol therefore attracts polar and ionic molecules. The ethyl (C_2H_5) group in ethanol is non-polar. Ethanol therefore attracts non-polar molecules thus ethanol can dissolve both polar and non-polar substances. In industrial and consumer products, ethanol is the second most important solvent after water. Ethanol is the least toxic of the alcohols (it is only poisonous in large amounts), which makes it more suitable for use in industry and consumer products. Ethanol is a common solvent in:

- Cosmetics (such as perfumes).
- Medicinal preparations (such as antiseptics).
- Some cleaning agents.

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Describe conditions under which fermentation of sugars is promoted

Fermentation: *a process in which glucose monomers present in cellulose are broken down into ethanol and carbon dioxide by the action of enzymes present in yeast.*

The equation can be written as:

$$C_6H_{12}O_6 \xrightarrow{37°C} 2C_2H_5OH + 2CO_2\ (g)$$

Bubbles of carbon dioxide are given off, using the process of fractional distillation, about 95% of pure ethanol can be collected within school laboratories however in order to extract pure 100% ethanol, more elaborate distillation processes are required.

Conditions under which fermentation is promoted:

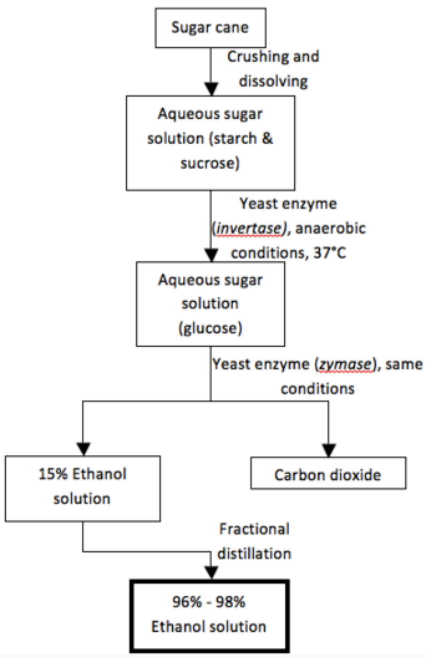
Condition	Reason
Moist environment	Survival of yeast
Yeast present	To produce the enzymes which catalyse the reaction
Low O_2 concentration	The reaction is anaerobic (does not involve oxygen). If too much oxygen is present the glucose will be converted to carbon dioxide and water instead. Any ethanol that is produced would be oxidised to ethanoic acid.
Alcohol concentration less than 15%	Concentrations higher than this will kill the yeast
Warm temperature (~37°C)	Accelerates the fermentation process. Excess heat could kill the yeast.

Summarise the processes involved in the industrial production of ethanol from sugar cane.

The enzymes used industrially are produced by yeast and are extremely sensitive to environmental conditions. Hence the above conditions must be strictly abided by.

Steps in the industrial production of ethanol from sugar cane:

- Sugar Cane is first crushed and mixed with water.
- Yeast is then added and air is removed. The mixture is kept at ~37°C.
- Enzymes produced by the yeast (*invertase*) catalyse reactions turning sugars (starch, sucrose) into glucose
- Other yeast enzymes (*zymase*) then catalyse reaction to turn glucose into ethanol and CO_2.
- The resultant 15% ethanol solution is then fractionally distilled to produce a 96%-98% ethanol mixture.



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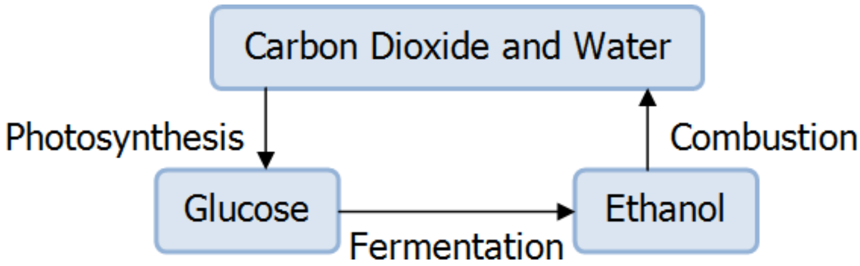
Outline the use of ethanol as a fuel and explain why it is called a renewable source.

Ethanol can be used as a potential fuel in the near future as it is known as a ****renewable source**** that can be extracted from glucose found in biomass material. Ethanol has the ability to combust readily in the presence of oxygen thus producing carbon dioxide and water. It is also important to note that mildly acidic conditions must be used to prevent the growth of pathogens from occurring.

$$C_2H_5OH + 3CO_{2\,(g)} \text{------>} CO_{2\,(g)} + 3H_2O_{\,(l)}$$

When oxygen is present with ethanol, complete combustion can occur therefore no carbon and carbon monoxide is produced. When glucose is fermented and ethanol is combusted due to the presence of oxygen, the products of the ethanol combustion can be converted back into glucose thus the process starts again.



Summarise the use of ethanol as an alternative car fuel and evaluate the success of the current usage of ethanol as a fuel and list its advantages and disadvantages of using ethanol as an alternate fuel source:
As ethanol is a liquid that can readily burn, it is also an easily transportable liquid thus can therefore be used as an alternative liquid fuel for automobiles. It has the potential to be an alternative fuel to current non-renewable fuels like petrol as it can be burnt to produce carbon dioxide, water and energy. To assess this potential both the positive and negative aspects of use of ethanol must be considered.

USING ETHANOL AS AN ALTERNATE FUEL SOURCE:	
Advantages:	***Disadvantages***:
- Renewable source - Ability to reduce greenhouse emissions as products of fermentation are recycled by the combustion reaction of ethanol with the presence of oxygen. - Highly combustible - When ethanol is added to automobiles (10-20%), the amount of greenhouse gases is reduced (carbon monoxide and hydrocarbons)	- Large areas of agricultural land must be devoted to growing suitable crops - Disposal of waste products form the production of ethanol can pose a major environmental problem. - Motor vehicles will need to be modified in order to accompany the full amount of ethanol usage in vehicles (100%). - More expensive than petrol

In Australia, current automobiles that are non-modified can only accept 10-20% of ethanol contained in fuels whilst in Brazil, 40% of ethanol can be used in conjunction with with fuel as most automobiles are modified.

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Define the molar heat of combustion of a compound and calculate that value of ethanol from first-hand data:

Molar Heat of Combustion: *amount of energy released per mole of fuel which has undergone complete combustion at 100kPa at 24.8℃*

***** Molar heat of Combustion for ethanol is always 1360kJ/mol**

Molar Heat of Combustion Equation:

$\Delta H = -mC\Delta T$

Where:

m = mass of H_2O (in grams)

C = Specific heat capacity of H_2O = 4.18 J $k^{-1}g^{-1}$

Δ T= change in temperature of H_2O in °C or °K after a known amount of compound is burnt

Example 1: If 3.6g of ethanol is combusted in excess of oxygen to raise the temperature of 200g of water by 35℃, what is the molar heat of combustion?

Ethanol = 1360kJ/mol
= C_2H_5OH
= 46g

∴ no. of moles = $\frac{3.6g}{46g}$
= 0.078260869 moles

ΔH = -200g × 4.18 × 35°C
= 29,260J
= 29.26kJ/mol

∴ Heat of combustion of ethanol = $\frac{29.26}{0.07826089}$
= 373.8781101
= 373.88kJ/mol

Example 1

Example 2: A student uses a spirit burner containing methanol to heat a 250mL beaker full of water. Initially the spirit burner weighs 139.4g, but after heating the water from 21 to 27°C the spirit burner weighs 138.7g. Find the molar heat of combustion of methanol.

ΔH = -250 × 4.18 × (27°C - 21°C)
= 6270J
= 6.27kJ/mol

Mass of ethanol = 139.4 - 138.7
= 0.7g

No. of moles = $\frac{0.7g}{32g}$
= 0.021875 moles

∴ molar heat of combustion = $\frac{6.27kJ/mol}{0.021875 \text{ moles}}$
= 286.6285714
= 286.63kJ/mol

Example 2

Example 3: The molar heat of combustion of propanol is 2020kJ/mol. What mass of propanol is combusted to heat 0.2 L of water by 8°C?

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

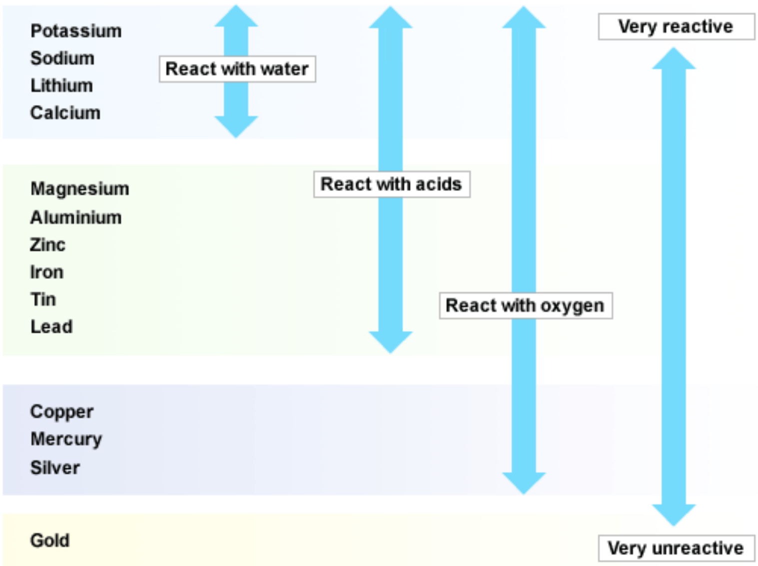
Explain the displacement of metals from solution in terms of electron transfer

Displacement Reaction: *the transfer of electrons between a metal and a metal ion. The ability to lose or gain electrons depends on the metals ionisation energy, the more reactive a metal, the more it will displace a less reactive one.*

Identify the relationship between displacement of ions in solution by other metals to the relative activity of metals.

Activity Series: *a series of metals arranged from most (easily oxidised) to least reactive (least easily oxidised) (left → right)*

A metal will always displace the ions of any metal towards the right hand side.



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

Oxidation*: loss of electrons (OIL = Oxidation is loss)*

Reduction*: gain of electrons (RIG = Reduction is gain)*

Redox Reaction*: reaction including both the oxidation-reduction reaction*

Cation*: positive ion*

Anion*: negative ion*

The oxidation state of an atom or species is its charge present. For example, the oxidation state for iron is $2+$ while the oxidation state of Oxygen is $2-$

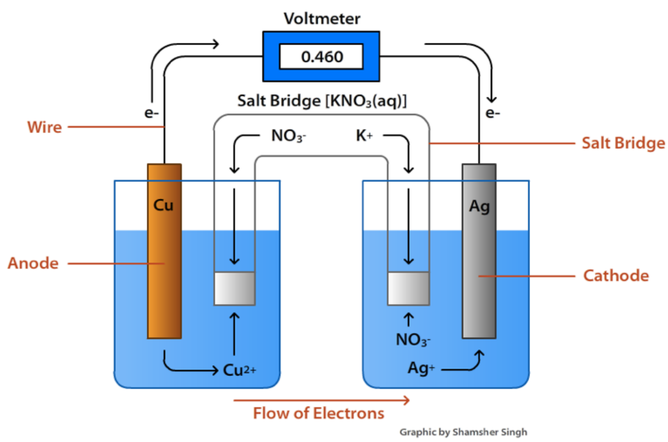
Describe and explain galvanic cells in terms of oxidation- reduction reactions

Galvanic Cell: *a device that uses a redox chemical reaction to generate electricity*

As the transfer of electrons can occur in redox reactions, the transfer of elections can help to produce electricity due to the external wire connected between two half cells. As a result, electrons travel through the wire circuit thus generates electricity.

Outline the construction of galvanic cells and trace the direction of electron flow:

- Two electrodes are used (anode and cathode)
- Suitable electrolyte
- Salt bridge (used for the migration of ions between one beaker and another)
- Two beakers
- External wire circuit
- Voltmeter (used to measure charge flowing through)



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The flow of electron consists of the more reactive metal losing its electrons in order to become stable thus passing it onto the least reactive metal for it to become stable.

Identify conditions in which galvanic cells are produced

A successful galvanic cell requires the following conditions:

- Two different metal electrodes
- Two separate solutions within each beaker
- Two electrodes submerged in the two separate solutions to allow for the flow of electrons to occur
- A salt bridge connecting two beakers (allows for the migration of ions)

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

Anode*: where oxidation of a metal occurs (AN OX = Oxidation occurs at the Anode)*

Cathode*: where reduction of a metal ion occurs (RED CAT = Reduction occurs at the Cathode)*

Electrode*: an electrical conductor used to generate an electric current*

Electrolyte*: solution that contains ions in which help to generate an electric current*

Measure the difference in potential of different combinations of metals in an electrolytic solution:

Example 1:

$Fe_{(s)}$ --------> $Fe_{(aq)}$ + 2e-

(anode reaction)

+

$Cu_{(aq)}$ + 2e- ------> $Cu_{(s)}$

(cathode reaction)

=

$Cu_{(aq)}$ + $Fe_{(s)}$ -----> $Cu_{(s)}$ + $Fe_{(aq)}$

(redox reaction)

Example 2:

$Zn_{(s)}$ -------> $Zn_{(aq)}$ + 2e-

(anode reaction)

+

$Cu_{(aq)}$ + 2e- -------> $Cu_{(s)}$

(cathode reaction)

=

$Cu_{(s)}$ + $Zn_{(aq)}$ -----> $Cu_{(aq)}$ + $Zn_{(s)}$

(redox reaction)

Example 3:

$Mg_{(s)}$ ------> $Mg_{(aq)}$ + 2e-

(anode reaction)

+

$2H_{(aq)}$ + 2e- -------> $H2_{(g)}$

(cathode reaction)

=

$Mg_{(s)}$ + $2H_{(g)}$ ---------> $Mg_{(aq)}$ + $H2_{(g)}$

(redox reaction)

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Compare the structure of either a dry cell or lead- acid cell and evaluate it in comparison to one of the following:

- *Button cell*
- *Fuel cell*
- *Vanadium- redox cell*
- *Lithium cell*
- *Liquid junction photovoltaic device (Gratzel Cell)*

Dry Cell Battery:

The Dry Cell battery is a commonly used galvanic cell in society. A Dry Cell battery can generate electricity through the redox reaction thus can only occur if the positive terminal is connected with a negative terminal (completes the circuit). A Dry-Cell battery consists of a zinc case and graphite rod separated by a paste of Manganese Oxide (MnO_2) and, NH_4Cl and carbon

Dry Cell Battery (Leclanché cell)

Voltage: 1.5V

Anode (-): Zinc (outer casing)

Anode Half Equation:

$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^{-}$

Cathode (+): Carbon (graphite) rod, which is highly conductive, surrounded by solid MnO_2

Cathode Half Reaction:

$2MnO_{2(s)} + 2NH_4^{+}{}_{(aq)} + 2e^{-} \rightarrow Mn_2O_{3(s)} + 2NH_{3(aq)} + H_2O_{(l)}$

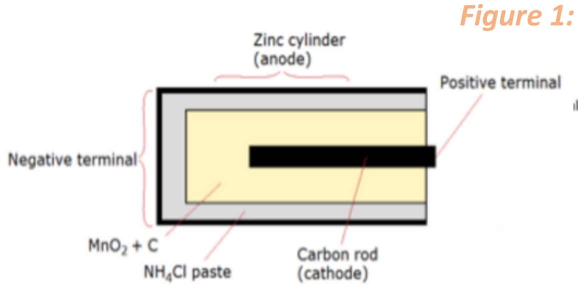
[The Mn is being reduced from oxidation state +4 to +3]

Electrolyte: $NH_4Cl_{(aq)}$ (ammonium chloride paste)

Overall Reaction:

$2MnO_{2(s)} + 2NH_4Cl_{(s)} + Zn_{(s)}$ à $Mn_2O_{3(s)} + H_2O_{(l)} + Zn(NH_3)_2Cl_{2(s)}$

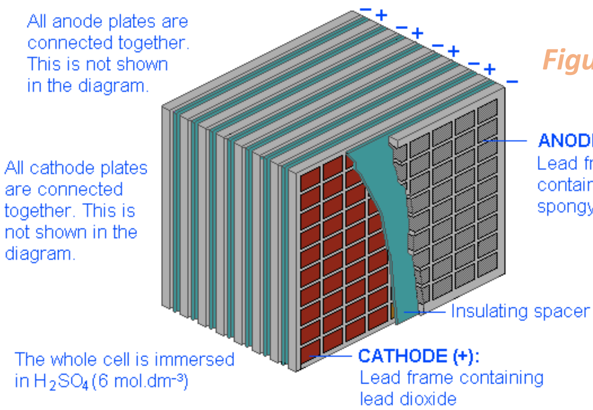
Figure 1:



Lead-Acid Battery:

A Lead-acid cell battery on the other hand is also another commonly used galvanic cell in society. A Lead-acid cell battery can generate electricity through the redox reaction thus can only occur if the positive terminal is connected with a negative terminal (completes the circuit).

Figure 2:



Silver- Oxide (Ag_2O) Button Cell:

In a Silver- Oxide Button Cell, zinc is the anode as it is more reactive than Silver Oxide (AgO2) thus is the cathode. An electrolyte solution of Potassium Hydroxide (KOH) enables the separation of zinc and silver oxide.

Voltage: 1.6 V

Anode (-): Zinc

Anode Half Equation:

$Zn_{(s)} + 2OH^{-1}{}_{(aq)} \rightarrow Zn(OH)_{2(s)} + 2e^{-}$

[zinc atoms are being oxidised to zinc ions]

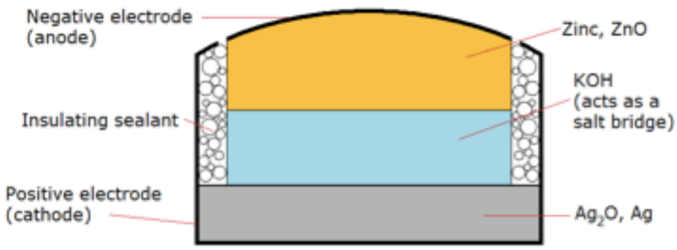
Cathode (+): Graphite (C), which is highly conductive, and Silver Oxide (Ag_2O) paste

Cathode Half Reaction:

$Ag_2O_{(s)} + H_2O_{(l)} + 2e^{-} \rightarrow 2Ag_{(s)} + 2OH^{-1}{}_{(aq)}$

[silver ions are reduced to silver atoms]

Figure 3:



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Evaluate and compare the the dry cell, lead-acid cell and silver- oxide button cell in terms of:

- ✓ *Chemistry*
- ✓ *Cost and practicality*
- ✓ *Impacts on society*
- ✓ *Environmental impact*

	Dry Cell Battery:	***Lead- Acid Cell:***	***Silver- Oxide Button Cell:***
Chemistry:	***Disadvantages:*** Lower voltage (1.5V) therefore less electricity is produced compared to a lead-acid cell and button cell (1.6V) Poor shelf life (1.5 years) Reaction between zinc electrodes and ammonium ions are relatively slow therefore can lead of battery deterioration	***Advantages:*** Higher voltage (2.2V) compared to a Dry Cell Battery and Button Cell ***Disadvantages:***	***Advantages:*** Higher voltage than Dry-Cell (1.5V) battery but less than that of a Lead-Acid Cell Long shelf-life Solid silver produced by the reduction reaction at the cathode improves the conductivity of the cell
Cost & Practicality	***Advantages:*** Much cheaper to purchase than a button cell ***Disadvantages:*** Non-rechargeable Non-reusable	***Advantages:*** Long life span Rechargeable Level of charge can easily be determined ***Disadvantages:*** Very large and heavy More expensive than a Dry Cell Battery and Button Cell Lead is a more reasonably expensive metal	***Advantages:*** Can be used in small devices as button cell is significantly small in size Long operating life (usually about 4-5 years) ***Disadvantages:*** More expensive than a dry cell battery although cheaper than a Lead- Acid Cell Non-rechargeable Cannot be used in low temperatures (underwater)
Impacts on Society:	***Advantages:*** Used in everyday appliances i.e. torches, clocks and battery-operated toys, remotes Most prevalent battery used in society	***Advantages:*** Ability to recharge makes the lead-acid cell suitable for automobiles Can have the ability to store solar energy if connected to solar panels	***Advantages:*** Due to its relative small size, it is extremely light weight and its stable voltage allows for devices to be i.e. medical devices to be developed Non-toxic if used in the body for medical purposes
Environmental Impact:	***Advantages:*** Causes minimal damage in environment as zinc casings cause no problem, manganese is readily oxidised to manganese (V) Oxide and ammonium salts and carbon are harmless ***Disadvantages:*** Contributes to landfills as this battery type is non-rechargeable and non-reusable	***Advantages:*** Ability to be recycled ***Disadvantages:*** Corrosive Sulfuric Acid (SO_4) can pollute the environment is battery is damaged Lead is toxic thus can cause anaemia and affect the brain if not properly disposed of	***Advantages:*** Non-toxic Often recycled due to the presence and value of Silver ***Disadvantages:*** KOH is caustic and can cause burns if button cell casing is damaged Older versions of the button cell contain mercury, a very unstable toxic liquid metal.

Natasha T.

5. Nuclear chemistry provides a range of materials

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

Isotopes: *same element with different numbers of neutrons present.*

For example, Carbon 12, and Carbon- 14. Hence, the higher the neutrons present, the more reactive the element.

Stable Isotopes: *element that doesn't emit any form of particles and remains unchanged*

Radioactive Isotopes: *unstable elements with different numbers of neutrons present that spontaneously emit radiation in the form of alpha, beta or gamma rays due to radioactive decay.*

There are three conditions under which radioactive decay occurs:

- Atomic number above 82
- Neutron : proton ratio > 1.5
- Atom lies outside the "zone of stability"

ZONE OF STABILITY:

Atomic Number	**Protons:Neutrons** (approx)
1-20	1:1
2-50	1:1.3
50-83	1:1.5
>83	Always unstable

Radioactive Decay: *an element emitting different types of particles in order to become stable*.

This can only depend on the elements 'zone of stability' section along the Periodic Table. There are currently three known types of radioactive decay that can be emitted from a radioactive isotope. These include:

Alpha Decay (α): *the release of two neutrons and and protons from a nucleus of a radioactive element.*

This type of alpha decay can be commonly referred to as a helium atom. The equation can be written as:

$$\square \text{ -------> } {}^{4}_{2}He + \square$$

For example, the disintegration of Uranium- 238 into Thorium, Radium- 226 disintegrating into Radon, Polonium- 209 disintegrating into Lead

$${}^{238}_{92}U \text{ ---------> } {}^{4}_{2}He + {}^{234}_{90}Th$$

$${}^{226}_{88}Ra \text{ -------> } {}^{4}_{2}He + {}^{222}_{86}Rn$$

$${}^{209}_{84}Po \text{ ------> } {}^{4}_{2}He + {}^{207}_{82}Pb$$

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***Beta Decay (β):** the relationship in which a neutron decomposes into a proton and electron or vice-versa*. This process allows for the atom to move closer to the optimal ratio of protons to neutrons. This is given in the equation:

n ------> p + e

For example, Colbalt- 60 is a commonly used radioisotope for cancer patients as it emits ***β*** particles.

$$^{60}_{27}Co \text{ ------> } ^{0}_{-1}e + ^{60}_{28}Ni$$

(gains an electron when ***β*** particles are emitted)

****The emission of β particles also emit gamma rays.***

It is the gamma rays that actually attack the cancer. *

***Gamma Rays:** always accompanied with either alpha or beta particles as they may cause mutations (biological damage) thus should never be emitted on their own.*

Comparison of dangers

	Alpha particles	Beta particles	Gamma rays
What are they?	Helium nucleus, $^{4}_{2}He$	Electron or positron $^{0}_{-1}e$ or $^{0}_{1}e$	High energy photons (electromagnetic radiation)
Mass	4 amu (Atomic mass units)	5×10^{-4} amu	0 rest mass
Electric charge	2+	1-	0
Penetrating ability	Extremely low	Low	Extremely high
Ionising ability	Extremely high	High	Very low
Can it be deflected?	Yes, with electric and magnetic fields.	Yes, with electric and magnetic fields.	No.
Speed	Relatively slow (5% c)	Very fast (up to 99% c)	c
Danger to humans	Low, because of its very low penetrating ability.	Low, because of its limited penetrating ability.	Very high, due to its extremely high penetrating ability (1m of lead, or many metres of concrete).

Type of particle	Alpha	Beta	Gamma
What is it?	Helium Nucleus	Electron	Pure energy
Charge	+2	-1	No charge
Penetrating Power	Low	Moderate	High
Ionising ability	High	Moderate	Low

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Describe how transuranic elements are produced

Transuranic Elements: *elements that are above atomic number 92.*

All these elements are artificially produced and are all radioactive. These elements are produced by bombarding the nuclei with atomic particles such as alpha, beta or gamma. There are three known methods used for the production of artificial radioactive elements. These include:

- Nuclear reactors
- High Speed Accelerators
- Alpha Bombardment of Nuclei

Describe recent discoveries of elements

Darmstadtium (Ds) has an atomic number of 110 and was produced by bombarding Lead- 208 with Nickel-64. This radioactive element is very unstable thus is able to decay within seconds; its half-life is around 11 seconds. Due to its relatively short half-life, it can only be used for research purposes.

$$^{208}_{82}Pb + ^{62}_{28}Ni \text{ -------> } ^{269}_{110}Ds + ^{1}_{0}n$$

Identify instruments and processes that can be used to detect radiation

Detecting Nuclear Radiation

Instruments to detect nuclear radiation are widely used for safety reasons and to ensure radioisotopes are working to their maximum efficiency.

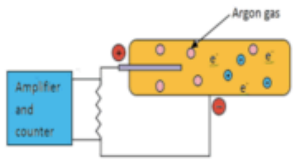
Photographic film

- Darkens in the presence of radioactivity
- Used today in the form of radiation badges as a safety measure: the amount of darkening of the film is a measure of the amount of radiation that the worker has received
- It detects all types of radiation but does not distinguish between the,

Cloud Chamber

- The chamber contains supersaturated vapours of water or alcohol. As radiation enters, vapours are disturbed and condense into droplets, leaving a trail characteristic of the type of radiation.
- Detects mainly alpha and beta radiation (and can distinguish between them)
  - Alpha leaves straight dense trail
  - Beta leaves zig-zag less dense trail
  - Gamma – very faint trail (hence it is not generally used to detect this type)

Geiger-Muller Counter



- How it works:
  - Radiation passes into the counter and particles hit gas molecules (usually argon)
  - Ionises them by knocking out an electron.
  - Electrons move to the positive electrode creating an electrical pulse.
  - Pulse is amplified and counted
  - Positive argon ions move to the negative electrode, completing the circuit.
- Best at detecting beta emission, but can detect others.

Scintillation Counter

- Uses substances that emit light when struck by radiation (eg. zinc sulfide)
- The flashes of light are electronically counted (by first amplifying in a photomultiplier) to measure the amount of radiation.

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Identify one use of a named radioisotope in the industry as well as in medicine:

Cobalt-60 – Industry

Cobalt-60– is used industrially for food irradiation. Food irradiation makes use of the gamma radiation emitted as Co-60 decays. This radiation is effective in destroying certain biological molecules and killing bacteria.

Advantages	Disadvantages
• The **gamma rays** emitted by Co-60 provide sufficient energy to destroy bacteria but not enough energy to make the food radioactive. • Co-60 also has an appropriately **long half life** (4-6 years) to minimise replacement but also short enough to allow for safe disposal of nuclear waste. • By destroying bacteria and moulds, food is made safer and fresher for longer (longer shelf life). This also reduces wastage of food.	• It does not necessarily kill all dangerous organisms • Some vitamin content is destroyed • May lead to the formation of harmful compounds in the food • Can lead to laxity of hygiene standards by food handlers due to over-reliance on irradiation disinfection

Technetium-99m – medicine

Technetium-99m is used in diagnostic medicine. Tc-99m can be combined with biological compounds to target specific organs in the human body which absorb those compounds. For example, if combined with a tin compound, Tc-99m binds to red blood cells. Radiation emitted by the isotope can then be imaged allowing the entire body's circulatory system to be mapped. Uses include diagnosis for:

- Brain tumours
- Blood circulation disorders
- Heart damage after a heart attack

Note: The 'm' in Tc-99m stands for 'metastable'. This means it decays by releasing gamma rays without alpha or beta radiation. In this way, Tc-99m decays into Tc-99.

Advantages	Disadvantages
• **Short half-life** – 6 hours. As it decays rapidly, there is minimal exposure and damage caused to the patient. • Has a **number of possible oxidation states** – this means it can be combined with a range of biomolecules. This allows for it to be transported to a number of locations in the body in order to study and diagnose different areas. e.g. the brain, kidneys, bone, liver and spleen • Emits **gamma rays** – readily detectable (140keV) • Gamma radiation emitted has relatively low energy	• The **short half-life** means that it is impractical to transport it directly from nuclear reactors. Thus, it must be created on site by the beta decay of Mo-99 (half-life 67 years) in Tc-99m generators. Many hospitals and medical centres would not be able to afford this equipment.

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General Assessment of Radioisotope Usage

Benefits from use	Problems with use

- Medical, Health & Safety benefits
  - Imaging
    (e.g. Technetium-99m for general imaging, Iodine-131 for the thyroid, Strontium-90 for bones etc)
  - Safer and longer-lasting foods (e.g. Cobalt-60)
  - Medical sterilisation (Cobalt-60)
  - Smoke alarms (e.g. Americum-241)
- Industry
  - Standardising production of materials – thickness gauges (strontium-90)
  - Leak detection tracing in heavy metal industries (e.g. Sodium-94)
	- Health & Safety problems
	  - **Nuclear reactors** (used for production) – can be dangerous if misoperated (e.g. meltdowns, nuclear proliferation)
	  - α,β and γ radiation can cause disruption to cellular processes due to the ionising ability of radiation. Radioactive elements that get incorporated into the body are particularly dangerous
	- Societal: **Expensive** to produce radioisotopes
	- Environmental: **Radioactive emissions** produced and disposed radioactive waste can cause damage to organisms if not used and stored safely (infection, cancer, tissue damage)

Assessment
The dangers can be managed by proper accounting and storage of nuclear assets, selecting radioisotopes with short half lives for medical uses, and carefully disposing of nuclear wastes. The benefits from improved medical diagnosis save lives. The value added to the economy from industry uses of radioisotopes is significant. Therefore, the use of radioisotopes in medicine and industry has a positive impact on society.