HSC Chemistry Notes - Production of Materials

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

1. construct word and balanced formulae equations of chemical reactions as they are encountered
Word Equation: **Hydrochloric Acid + Sodium Hydroxide → Sodium Chloride + Water**
Balanced Formula Equation: **$HCl + NaOH \rightarrow NaCl + H_2O$**

In any equation, the reactants will appear on the left hand side of the equation and the products on the right.

In numerous equations the state that the products/reactants are in are indicated as; solid(*s*), liquid(*l*), gas(*g*) or in an aqueous solution(*aq*).

2. identify the industrial source of ethylene from the cracking of some of the fractions from the refining of petroleum
Ethylene or Ethene (C_2H_4) is a hydrocarbon found in the naturally occurring substance, crude oil. Ethylene is formed from the process of fractional distillation in the fractional towers (for crude oil) but also through the process of **cracking** through the use of a catalyst (*catalytic cracking*) or heat (*thermal cracking*).

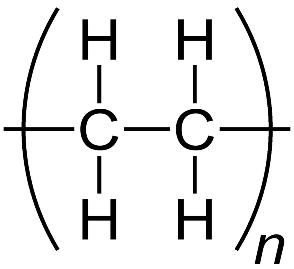
The process of cracking involves the breaking down of large chain hydrocarbons (which are undesired) into smaller "fractions" which form Ethylene. The cracking of ethane into ethylene through the use of steam is represented by:

$$C_2H_6 \rightarrow C_2H_4 + H_2$$

3. identify that ethylene, because of the high reactivity of its double bond, is readily transformed into many useful products
Ethylene in it's structure has one **double bond** between the two carbon atoms in the molecule. This double bond is very **easy to break** and form into a single bonded ethylene molecule - thus making ethylene a **highly reactive** substance. This means it can readily be turned into petrochemicals, including polymers, solvents and detergents (such as ethanol, polyethylene and polystyrene).

$C_2H_4 + H_2O \rightarrow C_2H_5OH$ (production of **ethanol**)
… + $C_2H_4 + C_2H_4 + C_2H_4$ + … (production of **polyethylene**)

4. identify that ethylene serves as a monomer from which polymers are formed
Monomer: Single molecules (such as ethylene) that when added form polymers.
Polymer: The addition of many monomers to form very long chains of monomers (which form new substances which specific qualities and uses for everyday life).



… + monomer + monomer + monomer + … → polymer

← Graphic representation of polyethylene where it can been seen that the chain can be repeated for n number of times

5. identify polyethylene as an addition polymer and explain the meaning of this term
Polyethylene is created by the addition of numerous numbers of single 'monomer' ethylene molecules which form a chain known as polyethylene. Polyethylene is an addition polymer because it requires the breaking of the double bonds in the ethylene monomers to form the single bonded chain. The addition of ethylene monomers → polyethylene polymer can be seen below:

… + $C_2H_4 + C_2H_4 + C_2H_4$ + … → **...$CH_2CH_2CH_2$...** (ethylene monomers → polyethylene)

The creation/production of a polymer requires the addition of a catalyst which begins the breaking of the double bonds. Specifically, in ethylene, in **catalyst Z is added to a group of ethylene monomers then Z will *break the double bond* in the first monomer and attach itself to it**, this makes the remaining empty bond extremely strong and will continue to form bonds with neighbouring monomers.
This addition reaction is different to the substitution reaction which ethane undergoes upon reaction.

6. outline the steps in the production of polyethylene as an example of a commercially and industrially important polymer

The process of making a polymer from monomers is known as polymerisation. To break the double bonds in ethylene, a catalyst is needed to be added to react with the double bond and join with other monomers. The production of polyethylene from start to finish, follows:

- **Fractional distillation** from petroleum
- **Thermal cracking** from ethane or catalytic cracking from larger hydrocarbons (such as $C_{30}H_{62}$) to form ethylene
- Ethylene then undergoes **addition polymerisation** with the ***aid of an initiator*** which forms radical free monomers and joins to other monomers to form a polymer

In the process of forming polyethylene, there are two types of polyethylene that are made:
– **High Density** polyethylene which is formed under normal pressure and **low heat**. High density polyethylene is quite **strong** and tightly packed with less space between monomer 'layers'. Used to make plastic bins, buckets and kitchen utensils.

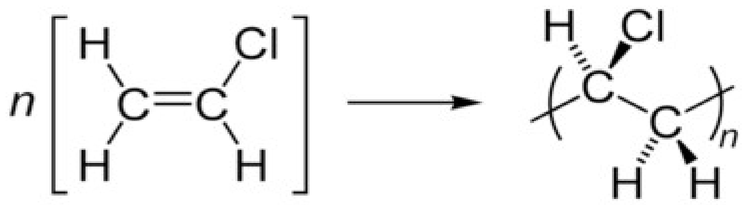
– **Low Density** polyethylene which is formed under high pressure and rather **high temperatures**. Low density polyethylene is **flexible** as there is a lot of free space between **branched** monomers (thus the dispersion forces are very weak). Used for food wrapping and milk cartons because it is waterproof.

Polyethylene is identifiable as an industrially and commercially important polymer because of it's vast and *prevalent use* in the production of *plastic bags* and *plastic-cling wrap*.

7. identify the following as commercially significant monomers: by both their systematic and common names

- vinyl chloride

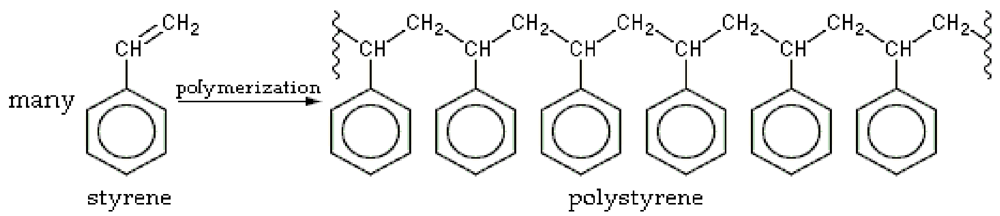
Vinyl Chloride (chloroethene) is the monomer used in the production of the polymer, polyvinyl chloride, **PVC**. Polyvinyl Chloride is an addition polymerisation as the Cl atoms are simply added in the reaction, rather than substituted, and is the only product of the reaction:



← Vinyl Chloride monomers on the left undergo addition polymerisation to form the polyvinyl chloride (PVC) - right.

- styrene

Styrene (phenylethene) is the monomer used to make **polystyrene**. Polystyrene is an addition polymerisation as it is the only product of the reaction. The C_6H_5 is also known as the benzene ring and may be represented as a hexagonal ring in many structural formulae:



← Left is the styrene monomer, which through polymerisation will form polystyrene.

Note: *The representation of CH or CH_2 is to the broken up into the normal diagrammatic format*

8. describe the use of the polymers made from the above monomers in terms of their properties

Polymer	Use	Properties
PVC (polyvinyl chloride)	**Drainage Pipes**	Rigid and strong nature between *powerful C-Cl polar intermolecular bonds.*
	Roof Sheeting	Strong and sturdy nature due to larger polar branching and will not let water through
Polystyrene	**CD Cases/Credit Cards**	Strong, rigid and resistance under heat + UV light. Transparency makes it useful.
	Foam Cups + Packaging	Upon expansion of polystyrene through the polymerisation process, the foam is formed, which is insulator of heat and cheap.

As a result of these properties and readily available uses, Polystyrene and PVC become an integral part of today's commercial and 'plastics' industries.

1. gather and present information from first-hand or secondary sources to write equations to represent all chemical reactions encountered in the HSC course

2. identify data, plan and perform a first-hand investigation to compare the re-activities of appropriate alkenes with the corresponding alkanes in bromine water

Alkanes and alkenes react differently and will display different properties when reacted with bromine or diluted bromine water. With this knowledge, it can be determined whether an alkene or its corresponding alkane is reacting with the bromine water.

The **alkane** will react with the diluted bromine water (BrOH) but **needs an extended period of time** for visible effects to occur. Under UV light or strong sunlight conditions over 24 hours, the alkane will eventually discolour the BrOH and become clear. The slow reaction is due to the single bond in the alkane.

The **alkene** on the other will **rapidly react** and there will be complete reaction with the Bromine water within 1 minute. The alkene reacts so rapidly due to the double bond between at least 2 carbon atoms (C=C).

Alkene/Cyclohexene - Addition Reaction

$$C_6H_{10} + Br_2 \rightarrow C_6H_{10}Br_2$$

The above reaction between cyclohexene and the bromine is an addition reaction, where the double C=C bond is broken and the bromine (Br) atoms attach themselves to the cyclohexene molecule. The fast discolouration of the bromine water <1 minute indicates that this is an alkene reaction.

This can only occur in the liquid state.

Alkane/Cyclohexane - Substitution Reaction

$$C_6H_{12} + Br_2 \rightarrow C_6H_{11}Br + HBr$$

The above reaction occurs between the alkane, cyclohexane and bromine. In this reaction over a long period of time the bromine water is **slowly discoloured** through the **aid of UV light**. During this process (as there is no double bond between the carbons) one of the Br atoms is substituted for a H atom - thus the remaining HBr remaining. The slow reaction indicates reaction with a single bond alkane.

Caution was taken when handling the bromine water because of its strong fumes which have the capacity to damage sensitive tissue around the nose and eyes. The experiment was conducted in the fume cupboard to minimise the risk of fumes.
The experiment could have been improved by measuring accurately the ratio of each hydrocarbon cyclohex-ane/ene and bromine water but care was taken to ensure that the mixture was not totally saturated by the Br_2.

3. analyse information from secondary sources such as computer simulations, molecular model kits or multimedia resources to model the polymerisation process
Using molecular modelling kits, it can be shown that ethylene monomers can undergo the polymerisation process with the aid of a catalyst (and create radical free chains) which will continue until two chains meet.

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

1. discuss the need for alternative sources of the compounds presently obtained from the petrochemical industry
Crude oil, as we already know, is obtained from boring into the **Earth's crust** and is composed of the fossilised remains of animal and plant matter which through photosynthesis and absorption has trapped the sun's energy. Because of this, **crude oil is a non-renewable resource**.

Today's modern **petrochemical industry** and common society has a **huge dependence on the hydrocarbons** which are extracted and refined from the crude oil. From each fraction, we obtain essential fuels, lubricants and hydrocarbons of which many are **used in production of polymers** and plastics. Of particular interest is the ethylene monomer which can be obtained.

Ethylene has its importance in the production of polyethylene. As the crude oil runs out of natural supply, so too does ethylene and scientists are pressured to think of alternative secondary source solutions to the issue. These issues and pressures may be relieved if further developments are made into how biomass (and in particular cellulose) can be used to efficiently **make alternative biopolymers which have a lesser impact on the environment** and are *biodegradable* but currently *expensive* to produce.

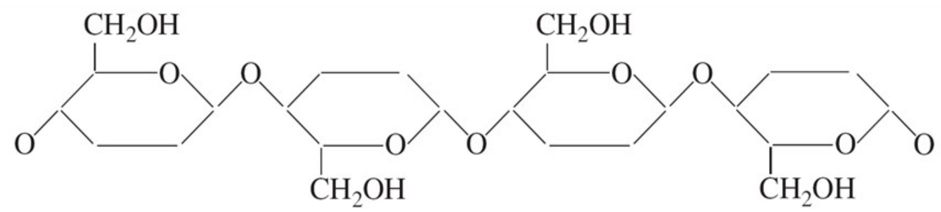
2. explain what is meant by a condensation polymer
A condensation polymer is the addition of monomers through the polymerisation process to form a large chained polymer with an **extra small molecule** – most commonly water (H_2O).

3. describe the reaction involved when a condensation polymer is formed
The reaction that takes place with the aid of an initiator catalyst is the addition of many monomers and the end result is the polymer and water.

... monomer + monomer + monomer ... → polymer + H_2O

4. describe the structure of cellulose and identify it as an example of a condensation polymer found as a major component of biomass
Cellulose is known as a condensation polymer as is forms from the glucose monomers and a small molecule, most commonly water. The equation is as follows:

... + glucose monomer + glucose monomer + ... → cellulose polymer + H_2O



The above is a depiction of the cellulose polymer. To achieve the straight chained arrangement of the polymer, the bonds must actually be in a '*zig-zag*' pattern.

In identifying monomers → polymers for condensation polymerisation we must be able to identify that there must be a **H_2O molecule left** in the reaction and by doing so, the monomers can link. In the glucose/cellulose case the *HOH is removed* from the respective ends of the glucose monomers and thus the free **C and O atoms will join to continue the polymer chain**.

5. identify that cellulose contains the basic carbon-chain structures needed to build petrochemicals and discuss its potential as a raw material

The **long chain carbon structure** of cellulose makes it a viable replacement for petroleum as the feedstock for plants. The conversion of cellulose into smaller chains such as ethylene and ethanol, although **currently possible through enzymes and initiators**, is **not economically efficient** for large scale production.

Cellulose is the major component of biomass and most is stored in waste material, thus its need and pressure on scientists to design economically effective ways to produce the requires petrochemicals from it.

1. 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

Biopol is a recently developed biopolymer consisting of two monomers known as PHB and PHV - this makes Biopol a co-polymer. Biopol is produced from the PHA enzyme, produced industrially by bacteria *Alcaligenes eutrophus*, which grow in tanks with a carbon based food source.

The properties of PHB include the **solubility in water**, permeable to oxygen, **resistant to UV light**, acids and bases; **biocompatable/biocompatible** and has a high tensile strength. With this, Biopol has a huge potential for *medical use*, but also the industrial uses. Biopol's usefulness in medicine extends from its properties, that it is biocompatable, which means the body will not reject it but rather accept as part of the human body - thus its potential for skin grafts or artificial organs.

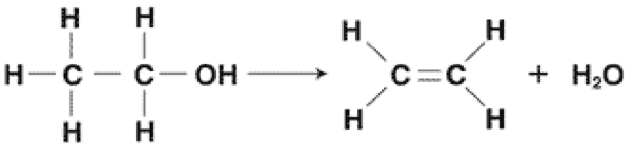
Biopol already has uses in carrier for slow release **insecticides** and **disposable containers** for shampoo

At present, **Biopol is more expensive than the regular polymers** in use today, and so it is only used when necessary or where it seems more affordable/efficient. It is seldom used because its quality is usually a **lower grade** than the original polymers.

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

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

The **dehydration** of ethylene means the removal of a water molecule from the original ethylene molecule with the aid of a dehydrating catalyst. This catalyst most commonly used is **concentrated sulphuric acid (H_2SO_4)**.



Ethanol Ethylene

$C_2H_5OH \rightarrow C_2H_4 + H_2O$

The dehydration process needs to occur at high temperatures. The concentrated sulphuric acid is needed because the double bond in ethylene is highly reactive and does not readily form - the **acid acts as a dehydrating agent** to remove the HOH from the ethanol molecule.

2. describe the addition of water to ethylene resulting in the production of ethanol and identify the need for a catalyst in this process and the catalyst used

The addition of a water molecule to ethylene is simply the opposite process above for the production of ethylene into ethanol. The use of **diluted sulphuric acid** is needed to act as a **hydrating agent** which aids to break the double bond in ethylene to form ethanol and attach the water molecule.

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$

The dilute sulphuric acid is only needed (compared to concentrated above) because the double bond is readily available to react. This saves money.

3. describe and account for the many uses of ethanol as a solvent for polar and non-polar substances
Because ethanol dissolves (in) both polar and non-polar substances, it is used as a **cleaning agent** or **solvent**

The ethanol molecule contains a **alkyl group** which contains the **CH_3** part of molecule which is **non-polar** (with electro-negativities of carbon and hydrogen being very similar). This alkyl group allows ethanol to dissolve and 'dissolve in' other non-polar substances due to **dispersion forces** which it can create. Ethanol also contains a **polar** section shared between the **OH hydroxyl group** of the molecule which because of **hydrogen bonding** can dissolve other polar substances. The CO part of the molecule is also very polar.

Because of its uses, **ethanol was a wide use in the solvent and cleaning industry in food dyes, perfumes and aftershaves, and medicinal uses for antiseptics**. It is able to dissolve a range of substance from amino acids, proteins and short chain hydrocarbons.

4. outline the use of ethanol as a fuel and explain why it can be called a renewable resource
Ethanol can be defined as a **renewable resource** because is can be produced as a waste product, naturally occurring from plants. Also, when ethanol is used as a fuel, carbon dioxide is given off as a product from the reaction. Although CO_2 is a detrimental greenhouse gas, the plants that initially produce the ethanol need the carbon dioxide for the photosynthesis process and eventually the creation of more ethanol.

The complete combustion of ethanol is shown as:

$$C_2H_5OH(g) \rightarrow CO_2(g) + H_2O(l) + \text{energy}$$

5. describe conditions under which fermentation of sugars is promoted
Sugar solutions will undergo the fermentation process with the presence of a catalyst, yeast. The yeast triggers the reaction. Fermentation is promoted in warm conditions with low levels of oxygen. Fermentation can **take several days**.

6. summarise the chemistry of the fermentation process
The fermentation process involves the addition of **yeast** to a sugar solution over several days. The **fermentation occurs around 30°C in anaerobic conditions**. The process gives of carbon dioxide as a product f the chemical reaction which occurs. The mixture that remains at the end of the fermentation process is a mixture of ethanol and water - how alcohol is made. **Yeast is defined as a natural enzyme** which causes the glucose in water to break down into ethanol molecules.

$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

7. define the molar heat of combustion of a compound and calculate the value for ethanol from first-hand data
The molar heat of combustion of a compound is the **amount of heat energy given off or gained per mole**, when it is burned. See blue dot point 6 for calculations. Using the formula:

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

where;
H = energy gained or given off *(J)*
m = mass of water or liquid being heater *(g)*
C = Specific heat capacity for water or liquid being heated *(water = 4.18J.C.g^{-1})*
T = change in temperatures *(°C)*

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

Advantages	Disadvantages
• Renewable resource (can be naturally made through fermentation and plants) • **Environmentally friendly.** The sugar cane from which ethanol can be produced absorbs some of the CO_2 given off - thus better than petroleum • Ethanol is totally **miscible** with water. Any major spillages into the rivers or oceans will not have an impact, but will simply dilute. • Will be easy to implement once the Earth's resource of crude oil (and thus petroleum) has run out.	• Large arable land is needed for the mass production of sugar cane to manufacture the ethanol • Ethanol is **expensive** to produce in comparison to current fuels/petroleum • **Waste disposal** from the fermentation process can be difficult to keep within environmental regulations • **Lower Energy Density** than current fuels. This means that per litre of ethanol, there will be less energy produced - this is probably the largest factor in ethanol still not becoming the main auto mobile fuel.

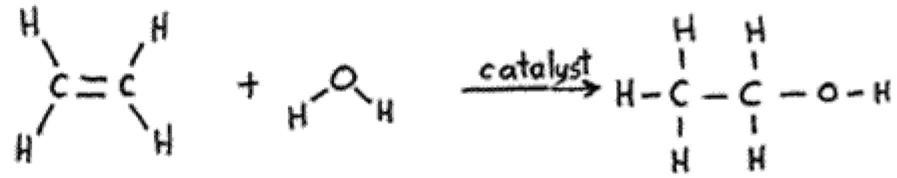
Currently ethanol is not a viable resource for an everyday fuel which will replace petroleum or diesel in motor vehicles on the roads. It is more currently suited for an additive in petrol.

9. identify the IUPAC nomenclature for straight-chained alkanols from C1 to C8

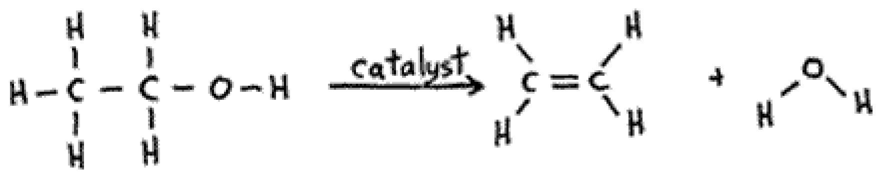
Carbon Chain	IUPAC Name	Structural Formula
C1	**Methanol**	CH_3OH
C2	**Ethanol**	C_2H_5OH
C3	**Propanol**	C_3H_7OH
C4	**Butanol**	C_4H_9OH
C5	**Pentanol**	$C_5H_{11}OH$
C6	**Hexanol**	$C_6H_{13}OH$
C7	**Heptanol**	$C_7H_{15}OH$
C8	**Octanol**	$C_8H_{17}OH$

1. process information from secondary sources such as molecular model kits, digital technologies or computer simulations to model:

– the addition of water to ethylene



– the dehydration of ethanol



The question may ask how the model kits were used to construct the models of the reactions and minor risks involved in using the model kits. **Risks** include: swallowing small springs, falling or tripping on model balls or eye damage from either spring or ball.

2. process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane

The industrial process of the production of ethanol from sugar can be summarised in the following:

- Sugar Cane Plant
- Leaves and Bagasse/Waste
- Cellulose (Crushing/Boiling with sulfuric acid)
- Glucose (Neutralisation)
- Fermentation
- Ethanol and CO_2 gas (8-12% ethanol)
- 96% **Ethanol** (distillation)

Cellulose → **Glucose** (through the breakdown from polymer into monomer units) → **Ethanol** (fermentation + distillation) → **Ethylene** (dehydration)

Firstly the **leaves are separated from the baggase**. The baggase is considered waste. The leaves are mostly cellulose. The **cellulose is then broken down** into the smaller **glucose** by **crushing** and boiling with sulfuric acid. Glucose is then **neutralised** and then **fermented with the addition of water and yeast** - acid is added to even pH to prevent bacterial growth. Ethanol is **fractionally distilled** from the fermentation mixture.

3. process information from secondary sources to summarise the use of ethanol as an alternative car fuel, evaluating the success of current usage

* Fill in with information and research from assignment due Term 5.

4. solve problems, plan and perform a first-hand investigation to carry out the fermentation of glucose and monitor mass changes

Apparatus:

The apparatus required a conical flask in which we will measure 100mL of water and mix with 10g of glucose for every 100mL of water that is filled into the conical flask. Pour into this glucose solution 1g of yeast for every 100mL of water (the yeast is the active enzyme in which the reaction will occur).

A test tube is to be filled with calcium hydroxide solution $Ca(OH)_2$, lime water into which a tube is placed into so that carbon dioxide gas can be trapped, also preventing the entrance of oxygen.
Place a rubber stopper into the top of the conical flask to which the other end of the tube is in.

Results and Calculations:

The results showed that there was a rapid decrease in mass over the day or two and then the process levelled out to a slow reaction (and mass loss became a very slow process).

Mass loss (therefore CO_2 gas): 7.68g
Molar Mass of CO_2: 12.01 + (16 x 2) = 44.01

Number of moles of CO_2 gas released: $\frac{7.68}{44.01} = 0.174505794\,mol$

- We are to assume that the air temperature is 25°C and that pressure is 100kPa. Therefore volume occupied by 1 mole of any gas = 24.79L

Volume of CO_2 (g) released: 1 mole releases 24.79L.

Therefore 0.174505794 mol releases (0.174505794 x 24.79)L = 4.325998... ≈ 4.36L

Using the balanced equation of glucose to ethanol: $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$ we can determine the volume of ethanol produced and thus the percentage of ethanol produced from the glucose solution.

Mole ratio of C_2H_5OH to CO_2 is 2:2. Molar mass of ethanol = 46.08, therefore mass of ethanol,

$$\frac{46.08}{44.01} \times 7.68 \approx 8.04\text{g}$$

Therefore percentage of ethanol produced is 8.04 ÷ 2 = 4.02%

Conclusion:
The results obtained cannot be deemed as the most reliable data as there is nothing particular to compare to. The results are accurate to produce some ethanol because of approximate 4% ethanol production which is about the same concentration of ethanol/alcohol in beers.

The water could have been evaporated thus the mass changes are not accurate. Some of the lime water had built up in the tube so a small ~0.1g mass increase may occur. The practical did produce ethanol and is therefore a suitable method for the production of ethanol through fermentation.

5. present information from secondary sources by writing a balanced equation for the fermentation of glucose to ethanol

Production of ethanol by fermentation:

$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

6. identify data sources, choose resources and perform a first-hand investigation to determine and compare heats of combustion of at least three liquid alkanols per gram and per mole

Aim: To determine the molar heat of combustion for some alkanols

Apparatus & Method: A known volume of water (200mL) is placed into a conical flask which is suspended above a spirit burner of an alkanol using a retort stand and clamps. The mass of the water and spirit burner will be weighed beforehand using sensitive scales to at least 0.1 degree of accuracy.

Once lighting the wick of the spirit burner and then the temperature of water has stop increasing, take the temperature of the water - the initial temperature will already have been recorded or known. Tabulate the data showing changes in temperature of water and the mass changes of the alkanols.

Results:

Alkanol	T_I (°C)	T_F (°C)	ΔT (°C)	M_I (g)	M_F (g)	ΔMass (g)
Methanol	**21**	**29**	**8**	**220.69**	**220.11**	0.58
Ethanol	**21**	**29**	**8**	**187.87**	**187.39**	0.48
Propanol	**21**	**29.5**	**8.5**	**224.58**	**224.17**	0.41

Calculations:

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

Methanol:

$$\Delta H = -200 \times 4.18 \times 8$$

$\Delta H = -6688J$ per 0.58g of methanol and therefore $\frac{-6688}{0.58} = -11531J$ per gram.

Thus, the heat of combustion per gram of methanol is 11 531J.
As 1 mole of methanol equals 32.032g (m = MM × n).

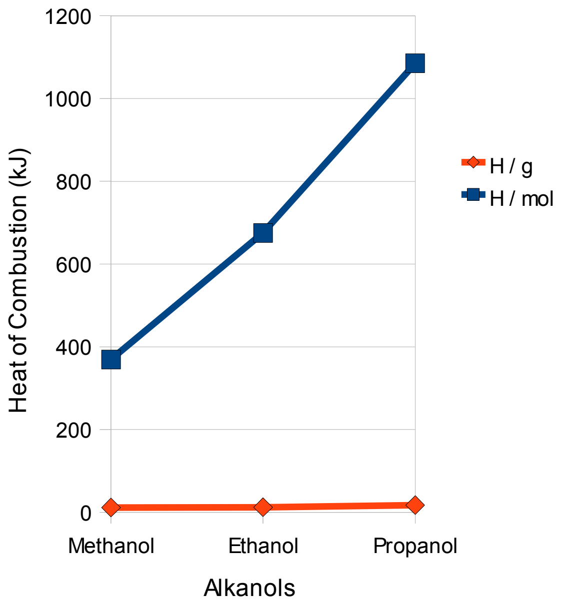
$$\frac{-6688}{0.58} = \frac{x}{32.032}$$

thus
$$x = -369\,362\,J$$
$$\Delta H = -396\,kJ\,mol^{-1}$$

and repeating this process for Ethanol and Propanol we will achieve the following results:

Alkanol	ΔH per gram (kJ)	ΔH per mol (kJ)
Methanol	11.53	369
Ethanol	12.2	675
Propanol	17.28	1085

Conclusion:



The graph shows an easy comparison between the heat of combustion of each alkanol per gram and per mole.

There are sources of error in this data which deem the results inaccurate and not valid. The spirit burner also heated the surroundings, not just the water in the container. There was evident black soot (un-burnt carbon) on the wick and bottom of the flask after heating.
Not only does this show incomplete combustion but it would have not allowed the values we achieved to reach the accepted values for the heats of combustion per alkanol.

Approximately half of the accepted value is what would be expected from the molar heat of combustion of each alkanol under school laboratory conditions and equipment.

The experiment did however lend itself to illustrate a pattern in the heat of combustion between each of the alkanols - that they increase with each higher C alkanol.

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

1. explain the displacement of metals from solution in terms of transfer of electrons
Metals will displace metal ions when the metal is higher on the standard potentials list (that is, it can be more readily oxidised).

For example, if we place a Zinc (Zn) metal into a Copper sulfate solution ($CuSO_4$), then the zinc will corrode and some of the copper will be deposited onto the zinc metal. As a result, the blue colour of the Copper sulfate solution fades to clear. This is a displacement reaction. The Zinc has displaced the Cu^{2+} ions since Zn is higher on the relative reactivity series. Thus as a result, the two substances are oxidised and reduced respectively, and two half equations can be written.

$$Zn \rightarrow Zn^{2+} + 2e^-$$
$$Cu^{2+} + 2e^- \rightarrow Cu$$

We can then add these two half reactions in which the electrons will cancel out to achieve the full reaction:

$$Cu^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Cu(s)$$

It is important to note that reduction and oxidation reactions must occur simultaneously in what are known as (galvanic) cells. In this cell, there is the transfer of electrons which results in the displacement of metal ions and metal solids. The metals which are placed in metallic solutions are known as the diodes.

2. identify the relationship between displacement of metal ions in solution by other metals to the relative activity of metals

Some standard potentials

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

The standard potentials sheet provided shows the relative activity of metals.

On the left are the metal ions displaced in solution, while on the right is the metal in its solid form.

Reactions going to the **right** are **reduction** reaction which is the gain of electrons.

Reactions which go to the **left** are **oxidation** reactions which is the loss of elections.

Metals higher on the activity series will displace metals which are lower than it. E.g. Potassium (K) will displace Nickel (Ni) because it has a lower voltage potential.

REDCAT - Reduction at the cathode
AN OX - Oxidation at the anode

The more reactive metal (the **higher up**) will become the **anode** where oxidation will take place.

3. account for changes in the oxidation state of species in terms of their loss or gain of electrons

Oxidation states are used to determine whether a substance has undergone oxidation or reduction. This process is used on only one element in an ionic substance or covalent substance in which we check the valency (charge) or that element on each side. The valency is checked by looking at the element which it is combined with.

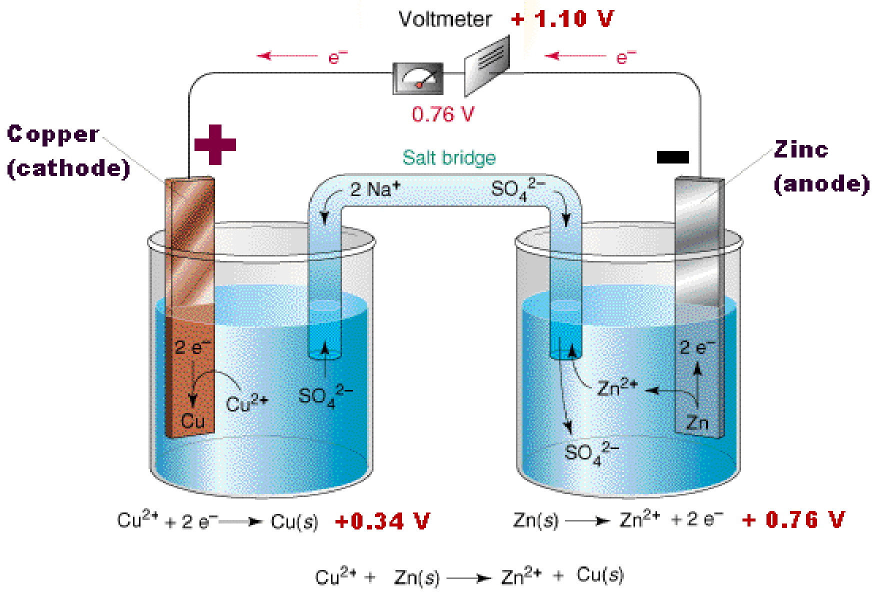
There are a set of groups which we require:

Group	Examples	oxidation State
Uncombined Elements	Na, H_2	**0**
Oxygen in Compounds	CO_2	**Valence of oxygen = -2**
Hydrogen in Compounds	NaH, H_2S	**Combined with metals -1** **Combined with non-metals +1**

The total valency of the compound equals the sum of the oxidation states of the atoms.

Oxidation involves an **increase** in oxidation state, from the uncombined element.
Reduction involves a **decrease** in oxidation state, from the uncombined element.

4. describe and explain galvanic cells in terms of oxidation/reduction reactions



- The **wire** that connects the two electrodes allows transfer of **electrons**.
- The **salt bridge** allows transfer of **ions**. (usually KNO_3)

To construct a reduction/oxidation reaction from the galvanic cell above, we need to **refer to the standard potentials** sheet. Look for the required two metals which are being used in the cell. The higher metal (Zn) will be oxidised and the lower metal (Cu) will be reduced. Since oxidation reactions go to the left, then the standard potential must be re-written in the other direction:

Half reactions
Ox: $Zn \rightarrow Zn^{2+} + 2e^-$
Red: $Cu^{2+} + 2e^- \rightarrow Cu$

From this we can formulate the full redox equation (in which always the electrons will cancel after adjusting the amount of metals or ions needed to make the electrons cancel).

Redox reaction
$\mathbf{Zn + Cu^{2+} \rightarrow Cu + Zn^{2+}}$

To find the voltage (potential difference) of the entire cell, we simply add the two half reactions as their red/ox forms, making sure that one is an oxidation reaction and the other a reduction. For **oxidation reactions we need to swap the polarity (sign)**.

$$Zn \rightarrow Zn^{2+} + 2e^- \qquad +0.76V$$
$$\underline{Cu^{2+} + 2e^- \rightarrow Cu \qquad +0.34V} = 1.1V$$

From this data we can conclude numerous details:
- Knowing that oxidation occurs at the anode, the Zinc electrode is anode. Therefore Copper is the cathode undergoing reduction
- Because we know that the Zinc anode is losing electrons we can say that the current is flowing from Zn to Cu.
- We would notice the **Zinc electrode become pale in colour** and may deteriorate a little, while the **Copper electrode builds up and may begin to shine**.

5. outline the construction of galvanic cells and trace the direction of electron flow
A galvanic cell is defined as an apparatus which has two metal electrodes (chunks of metal) in **solution**

of that metal (e.g. sulfate, nitrate etc.) in which a wire runs between the two containers and attaches to each of the metal pieces out of solution. A **'salt bridge' must be present** between the two separate cells in order for the entire cell to function and transfer electrons.

The salt bridge is a piece of filter paper soaked in a salt solution which prevents the two solutions from combining or mixing but allows for the transfer of electrons between cells. It essentially keeps an electrical neutrality.

The **electron flow can be determined by observing the half reactions** derived from a galvanic cells. Which ever electrode becomes the anode will obviously have oxidation occurring and therefore the loss of electrons. The other electrode becomes the cathode in which the electrons flow towards.
i.e. **anode** → **cathode** Is the electron flow in galvanic cells.

6. define the terms anode, cathode, electrode and electrolyte to describe galvanic cells

The **electrodes** are the two pieces of **metal (electrode)** partially placed in the solution. They are connected with a wire. The **electrolyte** is the **solution** in the beakers. The **anode** is the metal undergoing **oxidation**. The **cathode** is the metal undergoing **reduction**.

Anode: the electrode at which oxidation occurs
Cathode: the electrode at which reduction occurs
Electrode: a piece of metal semi-submerged in a solution of that metal
Electrolyte: the solution in which the electrodes are dipped - conduct electricity

1. perform a first-hand investigation to identify the conditions under which a galvanic cell is produced

2. 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

3. gather and present information on the structure and chemistry of a **dry cell** or lead-acid cell and evaluate it in comparison to one of the following:

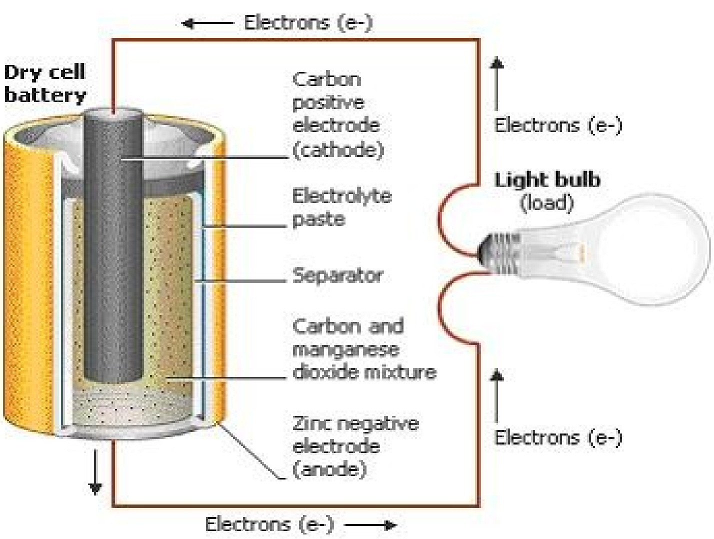
- button cell
- fuel cell
- vanadium redox cell
- **lithium cell**
- liquid junction photovoltaic device (Gratzel Cell)

in terms of: ***(Dry Cell)***

- chemistry

Oxidation Reaction: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
Reduction Reaction: $NH_4^+(aq) + MnO_2(s) + H_2O(l) + e^- \rightarrow Mn(OH)_3(s) + NH_3(aq)$

Redox Reaction: $Zn(s) + NH_4^+(aq) + MnO_2(s) + H_2O(l) \rightarrow Zn^{2+}(aq) + Mn(OH)_3(s) + NH_3(aq)$



The dry cell consists of a zinc anode and a manganese cathode, an **aqueous ammonium chloride (NH_4Cl) paste** beneath and then contains a mixture of **powdered carbon, manganese dioxide and ammonium chloride** (C, MnO_2, NH4Cl) surrounding a **carbon-graphite rod** (which is the positive cathode). As the cell is used **zinc ions are formed** and **ammonium ions are discharged**. Initially **1.5V**.

- cost and practicality

- very **cheap**
- **readily available**
- used in torches, TV remotes
- **short life**
- **cannot be recharged**

– impact on society

Because the dry battery is extremely **simple to use** and portable, they are found in many common devices it is often used in radios which are used to **transmit information** (and warning signals). Dry cells can also be used to power flash lights which humans utilise in emergency situations for a source of light (e.g. storms or power outages).

– environmental impacts

The common dry cell is robust, easy to store and use and **causes minimal damage** to the environment. The active **manganese(III) readily oxidises to a stable insoluble manganese(IV) oxide** and so does not impact on the environment. The small quantities of zinc are not an issue, while **ammonium and carbon are harmless**.

in terms of: ***(Lithium Iodine Cell)***

– chemistry

Cathode: Lithium (Li)
Anode: Iodine (I_2)
Electrolyte: Lithium Iodide

Oxidation Reaction: $Li(s) \rightarrow Li^{+}(aq) + e^{-}$
Reduction Reaction: $I_2(g) + e^{-} \rightarrow 2I^{-}(aq)$

There are numerous types of lithium cells, including basic lithium (single use) batteries, lithium-iodine cells and lithium-ion. Lithium is the ideal metal to make a negative electrode because it can **generate the highest voltage of any metal**, and having a **low molar mass it can produce more electrons per gram** than any other metal.

– cost and practicality

- used in mobile phones and laptops
- lithium-ion can be recharged, however **lithium iodine cells are single use**
- **long lasting**
- rather **light weight**
- produce much **more power/voltage than the dry cell** because of it's chemical properties
- **expensive**

– impact on society

The lithium battery and lithium ion cells have allowed people to use their **high power demanding electronics** and lithium cells see use in **medical applications since it does not produce any gas** and is a slow self-discharge. The batteries are often used for portable **entertainment**; when used in torches, they can provide hours of life which could save lives in emergency situations.

– environmental impacts

Lithium reacts with air and water, so must be tightly sealed and when the batteries are punctured, they can cause serious **damage to waterways and soil quality** - affecting animal life.

4. solve problems and analyse information to calculate the potential E^0 requirement of named electrochemical processes using tables of standard potentials and half-equations

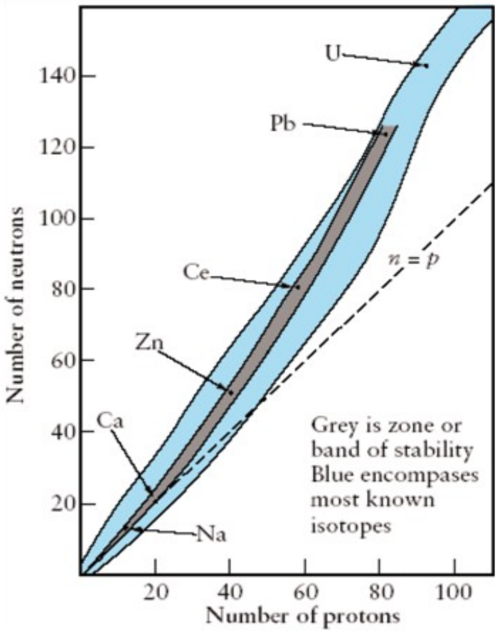
This requires the use of the list of standard potentials.

i. Identify which half reactions are needed noting which is higher on the list
ii. Decide which of the two is the reduction and which is oxidation reaction
iii. Change the oxidation reaction accordingly
iv. Create an overall equation, eliminating electrons
v. Add the redox E^0 potential values, ensuring that the oxidation value's sign has been changed.

It should be noted that experimental data will rarely ever be equal to the given data on data sheet due to environmental changes in conditions and equipment. The standard potentials are conducted in 25°C and at 100kPa, with 1 mol/L solution - any alteration in these values will result in changed data. Also, the voltmeter used to measure the potential difference between the two half cells acts also as a resistor, thus consuming a portion of the generated voltage.

5. Nuclear chemistry provides a range of materials

1. distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable



Radioactive isotopes are isotopes of a particular element which emit either **alpha** (helium nucleus $^4He_2$)/**beta** (electron $^0e_{-1}$) **particles** or **gamma radiation**. An isotope is a form of an element, thus have the same amount of protons and elections but changed mass number - therefore changed amount of neutrons. The conditions under which the nucleus of an isotope becomes radioactive is when **size of the nucleus or ratio of protons to neutrons is too high**.

2. describe how transuranic elements are produced

Transuranic elements are those on the periodic table which come **after Uranium** (92), thus those with a proton count of 93 or greater. All transuranic elements are **not found in nature** because they are manufactured in the laboratory, in nuclear reactors. Transuranic elements are formed by **firing protons into the nucleus**, thus changing the proton count and type of element. All transuranic elements are **radioactive**.

3. describe how commercial radioisotopes are produced

Commercially, radioisotopes are produced by the **bombardment of other nuclei with neutrons or high speed positively charged particles** (such as helium). The very small positively charged particles are **produced in linear accelerators** and **cyclotrons**.
Both the linear accelerators and cyclotrons operate on magnetic fields and attraction between particles to pull the positively charged particles at extremely high speeds and then impact into a nucleus - changing the charge and type of element.

4. identify instruments and processes that can be used to detect radiation

- ***Photographic Film:*** a darkening in the photographic film was used as an indication of the amount of radiation that is present or a person has received.
- ***Cloud Chamber:*** is an instrument containing a supersaturated vaporous mixture of water and alcohol. When the radiation passes through the vapour, it ionises some of the air which act as nuclei in which drops of liquid form on them - this way, the radiation is apparent in a visual way.
- ***Geiger-Müller Counter/Tube:*** a tube like instrument which **radiation** (particularly best with beta particles) **passes through a thin film to enter a tube filled with argon. The radiation particles ionise the argon atoms**, generating electrical impulses which are measured in a counter or amplified via sound.

5. identify one use of a named isotope:

– in industry

Common domestic **fire alarms** contain a small amount of **alpha particles - americium-241**

– in medicine

Technetium-99m is commonly used as a **tracer for diagnosis** in patients, to show up cancerous growths

6. describe the way in which the above named industrial and medical radioisotopes are used and explain their use in terms of their chemical properties

Americium-241 is used in smoke alarms to warn people of when fires are nearby because of it's radioactive nature and nature to decay into alpha particles. The *radioactive decay is*:

$$^{241}Am_{95} \rightarrow {}^{237}Np_{93} + {}^4He_2$$

In which, the alpha particles ionise air and are collected by an electrode and the resulting current is measured. When smoke is present, the small solid particles block the contact between the ionised air particles and the electrode, disrupting the current and resulting in the alarm.

Technetium-99m is used as a tracker for cell growths and blood flow abnormalities in the field of medicine. Tc-99m is injected directly into the person's blood stream and is observed by the gamma particles it emits as it decays in the patients body. The *radioactive decay is* shown as:

$$^{99m}Tc_{43} \rightarrow {}^{99m}Tc_{43} + \gamma$$

Tc-99m is used as a medical tracker in the bloodstream:

- **short half-life**: approx. **6 hours**
- can **easily be excreted** and causes no side effects
- **emits low-energy gamma radiation**
- **easily attaches to biological carriers** and will show blood flow abnormalities

1. process information from secondary sources to describe recent discoveries of elements

No extremely recent discoveries of new elements have been found. However, this said, elements 107, 108 and 109 were discovered in the 1980s and 118 in 1999. The most recent discoveries were made in nuclear reactors where protons (or positively charged particles) were fired at extreme speeds into the nucleus of heavy atoms which change the structure and type of atom - each more radioactive than the last.

2. use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine

Benefits: *Industry*

- **Ability to make monitoring equipment** that is **more sensitive**, accurate and reliable than other materials, with the use of radioisotopes
- Better **sterilisation** of machines and tools in the industrial workforce
- **Examine machinery and buildings** which were previously not possible without radioisotopes

Benefits: *Medicine*

- Radioisotopes have opened up a wide **range of non-invasive diagnostic procedures** for patients, which would have been impossible without radioisotopes
- Introduction of **radiation therapy for treating many forms of cancer**

Problems: *Industry + Medicine*

The main threat and problem for the use of radioisotopes in industry and medicine arises from the fact that they are **damaging to humans** (and other life forms).

- **Tissue Damage** - which is **immediate** and can show up as **skin burns or nausea**, if the radiation is mild, or can result in **death** if the radiation exposure is high
- **Cancer** - (particularly leukaemia and lung cancer)which is a **prolonged** symptom and does not show up until approximately 20 years after the exposure.
- **Genetic Damage** - leading to deformities in offspring

To avoid the problems and risks associated with the exposure to these radioisotopes used in the fields of industry and medicine, people must observe and strictly abide by safety practices and materials.