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**2018** HIGHER SCHOOL CERTIFICATE  
COURSE MATERIALS

# HSC Chemistry

## Production Of Materials

### Term 4 – Week 2

Name .....

Class day and time .....

Teacher name .....

# Term 4 – Week 2 – Theory

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

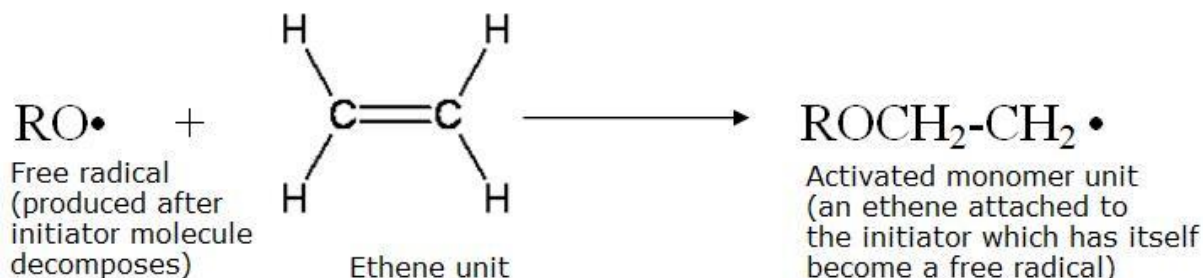
Polyethylene is industrially produced by two methods, one which produces branched chains, and the other produces linear chains.

## Gas phase process

In the gas phase process, extremely high pressure and temperature (around 1000 to 3000 atmospheres at 300°C) are used. The steps of this process are as follows:

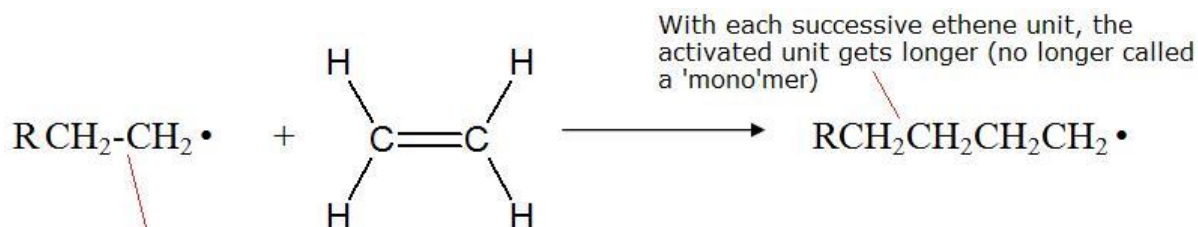
### 1. Initiation

A tiny amount of **initiator molecules** containing a peroxide group (-O-O- group) is introduced into the ethene chamber. The initiator molecules rapidly decompose under the extreme conditions of the reaction chamber, forming **free radicals** (molecules containing unbonded electrons). The free radicals attack the double bond in the ethene units, causing them to become free radicals themselves. At this stage, an ethene unit which has been attached by a free radical initiator is called an **activated monomer**.



### 2. Propagation

Activated monomers start finding more ethene units, attacking their double bond and joining with them using the activated monomer's unbonded electron.



Activated monomer unit continues to grow, attaching to more and more unactivated ethene units using its free electron

### 3. Termination

When the free radical from step 2 (pretty long by now) meets with another free radical like itself, their spare electrons join, forming a stable bond. This stabilises both parts as a single long polymer molecule.



When 2 activated units come in contact, the growth is terminated, as the long activated chains combine, forming a polymer molecule.



The result of this process is polyethylene chains with extensive branching, which prevents close packing of the polymer chains. As a result, the product is low density, and non-crystalline in structure. This is called low-density polyethylene, or **LDPE** for short.

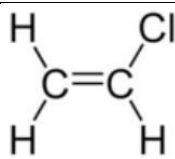
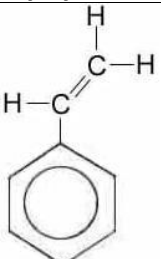
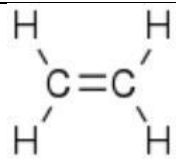
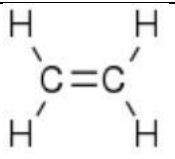
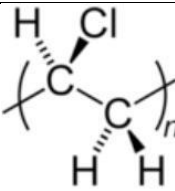
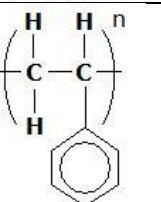
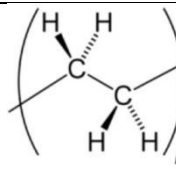
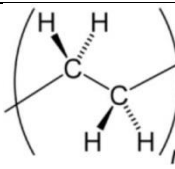
### Ziegler-Natta process

In the ZN process, only relatively low temperatures and pressures are required (60°C at a few atmospheres). Karl Ziegler discovered that by passing ethene through an alkane solution mixed with titanium(III) chloride and trialkylaluminium compounds, ethene would polymerise into linear chains with little branching. With this process, ethene units are bubbled through the alkane / catalyst mixture until the desired amount is obtained, then the dissolved polymer molecules are removed from the solution via distillation.

The linear chains are able to pack tightly together, forming high-density polyethylene, or **HDPE** for short.

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

The physical properties of polymers vary greatly according to the monomers used. Below is a summary of some properties of commonly encountered polymers in your HSC course.

	PVC	Polystyrene	LDPE	HDPE
Structure of monomer				
Structure of polymer				

Polymer	Physical properties	Uses
PVC	<ul style="list-style-type: none"> <li>Rigid, strong, lightweight</li> <li>Resists weathering effect (rain, sun etc) relatively well.</li> <li>Fire resistant</li> <li>Excellent electrical insulator</li> <li>Over time, UV from sunlight breaks PVC bonds down, making it brittle</li> </ul>	<ul style="list-style-type: none"> <li>Flexible tubing (e.g. electrical wire insulation, garden hoses etc). PVC can be made flexible by adding plasticisers.</li> <li>Water pipes (because it is very chemically stable)</li> <li>Oil bottles (because it is insoluble to most hydrocarbon solvents)</li> <li>Toys (low cost plastic)</li> </ul>
Polystyrene	<ul style="list-style-type: none"> <li>Very rigid (due to a high degree of chain stiffening)</li> <li>Chemically stable</li> <li>Electrical insulator</li> <li>Can be made transparent</li> </ul>	<ul style="list-style-type: none"> <li>Used in tool handles, due to good strength and insulation</li> <li>In polystyrene cups. When filled with air bubbles, polystyrene is an excellent thermal insulator</li> <li>General insulation material around the house (for the same reason above)</li> </ul>
LDPE	<ul style="list-style-type: none"> <li>Soft and flexible</li> <li>Resists water and is relatively chemically stable</li> <li>Translucent / transparent</li> <li>Electrical insulator</li> <li>Very cheap and easily manufactured</li> </ul>	<ul style="list-style-type: none"> <li>Cling-wrap, drink bottles and food containers, due to its flexibility, light weight and transparency</li> <li>Wire insulation (due to it being an electrical insulator, and flexibility)</li> </ul>
HDPE	<ul style="list-style-type: none"> <li>Stiff and hard</li> <li>High tensile strength</li> <li>Chemically stable</li> <li>Translucent / transparent</li> <li>Electrical insulator</li> <li>Very cheap and easily manufactured</li> </ul>	<ul style="list-style-type: none"> <li>Wheelie bins, due to its toughness and rigidity</li> <li>Car interior parts (dashboard, headunit cover etc) due to its chemical stability (resists sunlight and heat)</li> </ul>

### Reasons for some properties of polymers

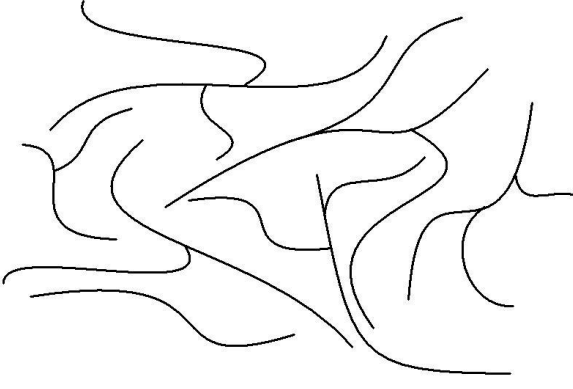
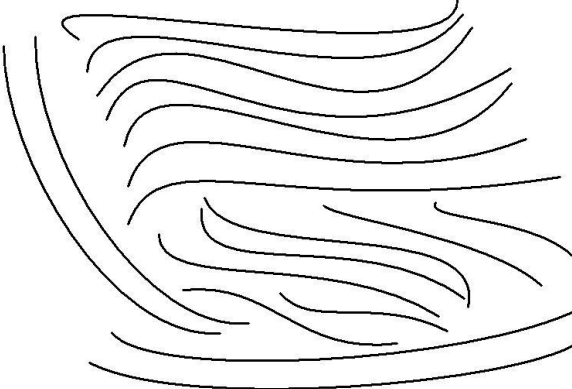
**Chain length:** the longer the chain lengths of polymer molecules, the harder and more rigid they tend to be. This is due to stronger dispersion forces holding the long molecules together.

**Chain branching:** the more branching there is within chains, the less tightly packed chains are within a polymer. This results in lighter weight, greater flexibility and softness.

**Chain stiffening:** by replacing a hydrogen atom in the monomer with a bigger group (e.g. a phenyl group for styrene), this makes polymer units interlock more easily, preventing them from slipping past each other. This results in a significant increase in **hardness, tensile strength and rigidity**.

**Use of plasticisers:**

Some polymers can have their flexibility increased by plasticiser additives. PVC is a common polymer where plasticisers are often added to increase flexibility.

<b>Structure of LDPE vs HDPE</b>	
<p>Extensive branching of polymer chains prevent LDPE chains from packing tightly together, resulting in a low-density, light-weight, flexible and opaque polymer.</p>	<p>Absence of branching allows linear branches to pack tightly together in an amorphous way, with crystalline regions. These regions give HDPE high density, higher strength, less flexibility, and a degree of transparency.</p>
	

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

This dot-point is included throughout the study of this course, since we write all chemical equations for all reactions as they are encountered. Therefore a separate study of this dot-point is unnecessary. Below is a list of common reactions studied in this course. It is a good idea before exams to go through this list and make sure you understand well each and every type of chemical reaction that is relevant to your exam.

#### List of common reactions in entire course

- **Synthesis reactions:  $A + B \rightarrow AB$** 
  - E.g.  $2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$  (burning of magnesium in air)
  - E.g.  $\text{H}_{2(g)} + \text{O}_{2(g)} \rightarrow \text{H}_2\text{O}_{(g)}$  (burning hydrogen gas in air)
  - E.g.  $2\text{Fe}_{(s)} + 3\text{O}_{2(g)} \rightarrow 2\text{Fe}_2\text{O}_{3(s)}$  (rusting of iron)
- **Decomposition reactions:  $AB \rightarrow A + B$** 
  - E.g.  $2\text{H}_2\text{O}_{(l)} \rightarrow 2\text{H}_{2(g)} + \text{O}_{2(g)}$  (electrolysis of water)
  - E.g.  $\text{AgCl}_{(s)} \rightarrow 2\text{Ag}_{(s)} + \text{Cl}_{2(g)}$  (decomposition of silver chloride, used in photographic paper)
  - $\text{CaCO}_{3(s)} \rightarrow \text{CaO}_{(s)} + \text{CO}_{2(g)}$  (heating calcium carbonate evacuates carbon dioxide gas)
- **Combustion reactions: Fuel + Oxygen  $\rightarrow$  Water + Carbon dioxide**
  - E.g.  $\text{C}_2\text{H}_5\text{OH}_{(l)} + 3\text{O}_{2(g)} \rightarrow 2\text{CO}_{2(g)} + 3\text{H}_2\text{O}_{(g)}$  (combustion of ethanol)
  - E.g.  $2\text{C}_8\text{H}_{18(g)} + 25\text{O}_{2(g)} \rightarrow 16\text{CO}_{2(g)} + 18\text{H}_2\text{O}_{(g)}$  (combustion of petrol, as octane)
- **Neutralisation reactions: Acid + Base  $\rightarrow$  Water + Salt**
  - E.g.  $\text{HCl} + \text{NaOH} \rightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}_{(l)}$
  - E.g.  $\text{H}_2\text{SO}_4 + 2\text{NH}_3_{(aq)} \rightarrow (\text{NH}_4)_2\text{SO}_4_{(aq)}$  (ammonia + sulfuric acid  $\rightarrow$  ammonium sulfate)
  - E.g.  $2\text{H}_2\text{O}_{(l)} \rightleftharpoons \text{H}_3\text{O}^+_{(aq)} + \text{OH}^-_{(aq)}$  (self-ionisation and neutralisation of water)
- **Metal / acid reactions: Metal + Acid  $\rightarrow$  Hydrogen gas + Salt**
  - E.g.  $\text{Mg}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{MgCl}_{2(aq)} + \text{H}_{2(g)}$
  - E.g.  $\text{Zn}_{(s)} + \text{H}_2\text{SO}_{4(aq)} \rightarrow \text{ZnSO}_{4(aq)} + \text{H}_{2(g)}$
- **Precipitation reactions: Salt + Salt  $\rightarrow$  Precipitate + Salt**
  - E.g.  $\text{AgNO}_3_{(aq)} + \text{NaCl}_{(aq)} \rightarrow \text{NaNO}_3_{(aq)} + \text{AgCl}_{(s)}$
  - $\text{Ba}(\text{NO}_3)_2_{(aq)} + \text{Na}_2\text{CO}_3_{(aq)} \rightarrow \text{BaCO}_3_{(s)} + 2\text{NaNO}_3_{(aq)}$
- **Acid + Carbonate reactions: Salt + Carbon dioxide + Water**
  - E.g.  $\text{CaCO}_3_{(s)} + \text{H}_2\text{SO}_{4(aq)} \rightarrow \text{CaSO}_4_{(s)} + \text{H}_2\text{O}_{(l)} + \text{CO}_2_{(g)}$
  - E.g.  $\text{CO}_3^{2-}_{(aq)} + 2\text{H}^+_{(aq)} \rightarrow \text{CO}_2_{(g)} + \text{H}_2\text{O}_{(l)}$  (net reaction for all of this type)
- **Buffer / reversible reactions:**
  - E.g.  $2\text{NaHCO}_3_{(aq)} \rightleftharpoons \text{Na}_2\text{CO}_3_{(aq)} + 2\text{H}^+_{(aq)}$  (sodium hydrogen carbonate acting as buffer)
  - E.g.  $\text{CH}_3\text{COOH}_{(aq)} \rightleftharpoons \text{CH}_3\text{COO}^-_{(aq)} + \text{H}^+_{(aq)}$  (example of an acidic buffer)
  - E.g.  $\text{NH}_3_{(aq)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{NH}_4^+_{(aq)} + \text{OH}^-_{(aq)}$  (example of an alkaline buffer)

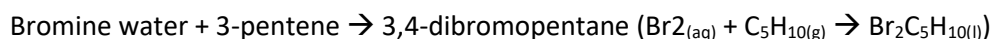
Some specific reactions you will encounter in later topics:

- **Haber process:**  $3\text{H}_{2(g)} + \text{N}_{2(g)} \rightleftharpoons 2\text{NH}_{3(g)}$  (used to make fertiliser, explosives, and as an input for other chemical processes)
- **Solvay process:**  $2\text{NaCl} + \text{CaCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CaCl}_2(\text{aq})$  (used to produce soda ash, useful as a buffer, to soften water, making soaps, making glass and as input for other chemical processes)
- **Identify data, plan and perform a first-hand investigation to compare the reactivities of appropriate alkenes with the corresponding alkanes in bromine water**

Alkenes undergo an **addition reaction** when applied to bromine water. This is a spontaneous reaction, and is facilitated by the opening of its double bond, allowing individual bromine atoms to attach onto the new bonds. The general reaction for this type of test is:

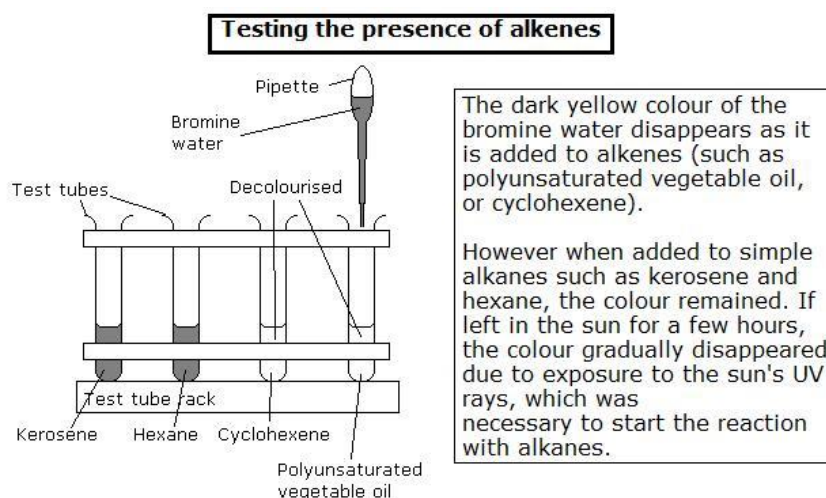


For example:



This occurs because the double bond is attacked by the bromine water. The resultant reaction is simply the addition of bromine to the alkene to form a bromoalkane.

In exams, students can recall that cyclohexene and polyunsaturated vegetable oil decolourised bromine water's yellow colour when it was added. Alkanes, with an absence of the double bond, were unable to react with the bromine water. (In order for any reaction to occur, UV light must be applied to allow for a substitution reaction with alkanes) The fact that alkenes spontaneously undergo an addition reaction while alkanes, with the same reactant (bromine water) requires the help of UV indicates that alkenes have a much higher reactivity than similar alkanes.





- Analyse information from secondary sources such as computer simulations, molecular model kits or multimedia resources to model the polymerisation process

Model kits can be used to demonstrate the polymerisation process. Polymerisation occurs as either of the two main processes: addition and condensation.

In addition polymerisation, monomer units possessing a double bond open this bond, and attach themselves onto adjacent units. We have already studied the process of this with ethene and ethene-based monomers. Using model kits, this can be demonstrated by opening up the double bond and attaching it with the newly formed holes of adjacent monomer units.

In condensation polymerisation, monomer units relinquish functional groups to accommodate the bonding sites needed to attach themselves with adjacent units. Condensation polymerisation requires functional groups which can detach and reform, releasing a small molecule per bond. Usually, condensation polymerisation involves monomer units leaving a hydrogen and a hydroxy group on either side, producing a water molecule per connection between two units. (For example, if  $n$  monomer units join, then  $n-1$   $H_2O$  molecules form) A prime example of this is the formation of polysaccharides.

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

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

#### **Why we need an alternative**

We currently derive ethene, petrol and other important fuels and chemicals from crude oil. As we know, **crude oil is not a renewable resource**, and it will eventually run out. Since the entire plastics industry relies on ethene as a primary feedstock, and our power generation, fuels for cars, trucks and planes are all products derived from crude oil, we need to find alternative sources of these chemicals before crude oil runs out, or gets too expensive.

We may argue that in the short run, the petrochemical industry (i.e. industry which includes plastics, but all other chemical manufacture derived from ethene and similar primary units) won't be affected much, since the bulk of crude oil is being sold as fuels for vehicles. This is true to an extent, since as crude oil runs out, the hike in prices will affect fuel and energy prices much more than feedstock prices for the petrochemical industry, since it uses only a small portion of the total crude oil output. However in the long run, as crude oil almost completely runs out, even feedstock prices will increase significantly, threatening the entire petrochemical industry.

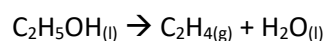
**Alternative sources**

Biomass is a promising potential alternative, as it contains all the elements (carbon, hydrogen, oxygen) needed to make the chemicals used in the petrochemical industry. Biomass is the waste material from all organic matter. Basically, dead plant material is used as it is abundant from agriculture processes. For example, sugar cane is a good source of biomass, since after the sugar is extracted from cane, the crushed stalks can be used to produce ethanol.

The main advantage is its renewability and the cost-effectiveness of recycling dead plant and organic matter into chemical feedstock. The problem with using biomass is chemically converting biomass into more useful compounds such as ethanol – it is a slow and expensive process.

At the moment, biomass can be successfully converted into ethanol using bacterial fermentation. Plant material is fermented with special bacteria (yeast) which feeds on the dead plant material and produces ethanol as a waste product. The mixture is separated using fractional distillation, which removes the ethanol from the bacteria / biomass / water mixture, which is a waste product of fermentation.

Ethanol can then be dehydrated into ethene using concentrated sulfuric acid as the catalyst:



Advantages of biomass	Disadvantages of biomass
<ul style="list-style-type: none"> <li>• <b>Environmentally friendlier</b> (arguably), since we are using plant material instead of fossil fuels to produce ethene</li> <li>• <b>Recycles</b> otherwise useless dead plant material which is a waste product of agricultural processes</li> <li>• <b>Pure product:</b> if biomass produced fuels, the products would be very pure, unlike fossil fuels which contain sulfur and other impurities which contribute to greenhouse gases once combusted</li> <li>• <b>Renewable:</b> when fossil fuels eventually runs out, we can rely on biomass indefinitely in theory, since we can always grow more plant material (using sunlight for photosynthesis), and the entire process is carbon neutral (meaning there's no net contribution to greenhouse gases)</li> </ul>	<ul style="list-style-type: none"> <li>• End product of ethene is <b>more expensive</b> using this method than using traditional thermal cracking / Ziegler-Natta methods</li> <li>• <b>More steps</b> between biomass and ethene, since fermentation (slow process), distillation and dehydration is required</li> <li>• <b>Fermentation produces waste</b>, so the plant material is not 100% recycled</li> <li>• <b>Arguably not environmentally friendlier</b> since the extra energy used in fermentation, distillation, production of sulfuric acid used to dehydrate ethanol, and the dehydration process itself might contribute even more greenhouse gases than there would have been with the conventional methods</li> <li>• <b>Economically unsound</b> since governments like giving subsidies to promote using biomass, even though it is currently too expensive and hence economically inefficient (students of economics should understand this well)</li> </ul>

# Term 4 – Week 2 – Homework

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

1. Outline the steps in the production of polyethylene using the gas phase process. [6 marks]

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2. Polymer chain length can be controlled by controlling the amount of initiator molecules injected into the reaction chamber. The more initiator molecules added, the shorter the average chain length, and vice versa. Explain why this is the case. [3 marks]

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

1. Complete this table. [3 marks]

Monomer name (common)	Monomer name (systematic)	Structure of monomer
Ethylene		
Vinyl chloride		
Styrene		

2. Attaching a large substituent group onto a monomer hardens the resultant polymer. Give 2 examples of common polymers that use this principle and explain why this is the case. [3 marks]

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

1. Complete the following table for synthesis reactions: [4 marks]

Reactants	Likely product
Non-metal oxide + water	
Metal oxide + water	
Non-metal oxide + metal oxide	
Ammonia + acid	
Non-metal oxide + base	
Most metals + oxygen	
Most metals + halogens	

2. Complete the word equation for each of the following synthesis reactions: [1 mark each]

a. Sulfur trioxide + water →

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b. Calcium oxide + water →

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

1. Account for the difference in reactivity observed between alkanes and alkenes in a first hand investigation you performed. **[3 marks]**

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- **Analyse information from secondary sources such as computer simulations, molecular model kits or multimedia resources to model the polymerisation process**

1. Evaluate the technical accuracy of using molecular model kits to model the polymerisation process, in particular the representation of the double bond 'opening up'. **[3 marks]**

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

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

1. Assess the importance of extraction of materials from biomass to reduce our dependence on fossil fuels. **[5 marks]**

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**End of homework**

