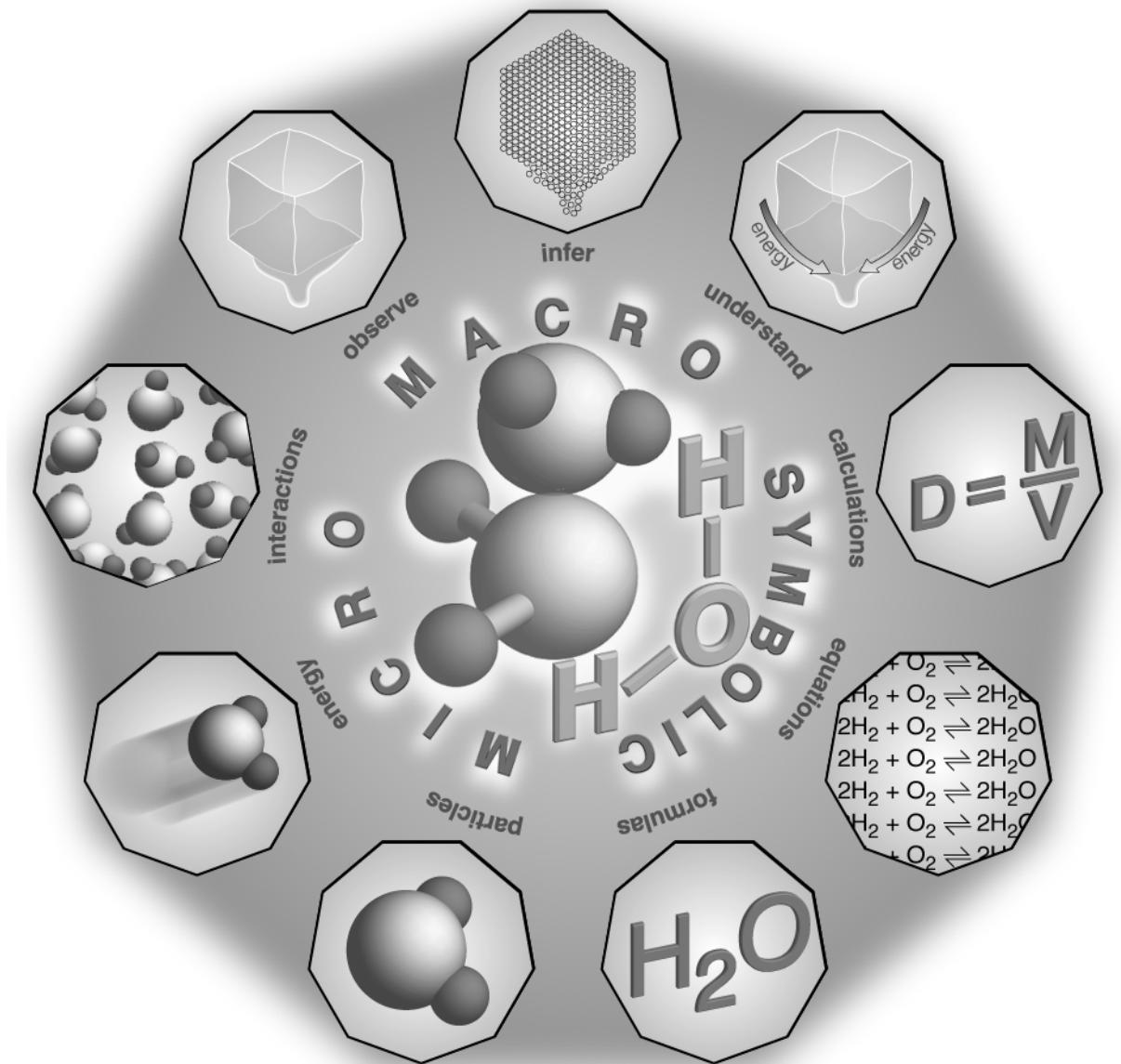




# The identification and production of materials



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infer  
understand



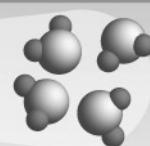
**SYMBOLIC**

$H_2O$  formulas  
equations  
calculations



**MICRO**

particles  
energy  
interactions



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**MACRO**observe  
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equations  
calculations**MICRO**particles  
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## Module overview

The extracts below are from the *Chemistry Stage 6 Syllabus* © Board of Studies NSW, originally issued 1999. The most up-to-date version is to be found at [http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

'Humans have always exploited their natural environment for all their needs including food, clothing and shelter. As the cultural development of humans continued, they looked for a greater variety of materials to cater for their needs.'

In the Preliminary module *Metals* you studied how important metals were in the development of human cultures. For a society to progress to a bronze age or iron age based culture access was needed to suitable minerals and energy to extract the metals.

'The twentieth century saw an explosion in both the use of traditional materials and in the research for development of a wider range of materials to satisfy the specialist needs of space travel and the information technologies. Added to this was a reduction in availability of the traditional resources to supply the increasing world population.'

In the twentieth century materials based upon non-metals such as carbon and semi-metals such as silicon have revolutionised transportation and communication. Increasing affluence and the importance placed upon material possessions and mobility have increased incentives to develop alternative materials and energy sources.

'Chemists and chemical engineers continue to play a pivotal role in the search for new sources of traditional materials such as those from the petrochemical industry. As the fossil organic reserves dwindle, new sources of the organic chemicals presently used have to be found. In addition, chemists are continually searching for compounds to be used in the design and production of new materials to replace those that have been deemed no longer satisfactory for needs.'

Chemical knowledge, understanding and skills have underpinned the development of silicon chips, optical fibres, solar cells, plastics, ceramics, new alloys and more efficient use of energy sources.

## Outcomes

The main course outcomes to which this *Identification and production of materials* module contributes are:

A student:

- H4 assesses the impacts of applications of chemistry on society and the environment
- H5 identifies possible future directions of chemical research
- H6 explains reactions between elements and compounds in terms of atomic structures and periodicity
- H7 describes the chemical basis of energy transformations in chemical reactions
- H8 assesses the range of factors which influence the type and rate of chemical reactions
- H9 describes and predicts reactions involving carbon compounds
- H10 analyses stoichiometric relationships
- H11 justifies the appropriateness of a particular investigation plan
- H12 evaluates ways in which accuracy and reliability could be improved in investigations
- H13 uses terminology and reporting styles appropriately and successfully to communicate information and understanding
- H14 assesses the validity of conclusions from gathered data and information
- H15 explains why an investigation is best undertaken individually or by a team
- H16 demonstrates and justifies positive values about and attitude towards both the living and non-living components of the environment, ethical behaviour and a desire for critical evaluation of the consequences of the applications of science.

*Extracts from Chemistry Stage 6 Syllabus* (Board of Studies NSW, originally issued 1999. The most up-to-date version can be found on the Board's website at [http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

# Indicative time

This module is designed to take a minimum of thirty hours. There are a number of practical activities. Organising materials and equipment for carrying out all these activities could take additional time but in doing so you will better understand the type of work chemists do.

# Resources

Materials and equipment you need to carry out activities are listed below. Access to a computer and the world wide web are important for the study of modern chemistry. An important skill to develop in chemistry is planning ahead and thinking things through before carrying out the action. Make sure the resources you need are available when you start an activity. For details see the activity in the appropriate part.

## For Part 1 you will require:

- an alkane eg. cyclohexane if you have access to a laboratory
- an alkene eg. cyclohexene if you have access to a laboratory
- bromine water in a dropper bottle, eye protection (glasses or goggles) and access to a laboratory OR iodine tincture/iodine paint (purchased from a pharmacy) and a dropper bottle
- ten test tubes with stoppers
- food oils such as safflower, olive, peanut, etc.
- baby oil (or light liquid paraffin oil)
- tomato juice
- drinking straws or wooden skewers
- coloured pencils
- 3 transparent plastic bags and ties to seal the bags
- 8 transparent glass containers (eg. beakers/test tubes/petri dishes)
- 1 ripe and 1 green banana OR 1 ripe and 1 unripe apple
- an area where you can leave the 3 plastic bags and contents undisturbed for a few days (away from pets and young children)
- molecular model kit OR Lego® style blocks  
OR jelly lollies (such as cut jelly snakes) and toothpicks
- ethanol or methylated spirits
- balloon

- skewer at least 30 cm long
- some petroleum jelly/soft paraffin/vaseline.

**For Part 2 you will require:**

- a stick of celery with a leafy top
- access to clean water
- some transparent adhesive tape and a piece of newspaper
- hand lens or magnifying glass
- tincture of iodine solution and a dropper bottle
- three glass or plastic containers
- filter paper
- access to earth (topsoil) and plant material such as grass clippings or leaves
- a paint roller tray OR a funnel with some cotton wool for a plug
- liquid volume measuring device to measure 100 mL for a tray or 10 mL for a funnel
- cellulase (from some biological suppliers) and Clinistix™ strips (from a pharmacy)
- at least 1 m of metal wire (bare or plastic covered)
- means of cutting the metal wire eg. pliers
- plasticine or Blu-tack®

**For Part 3 you will require:**

- molecular model kit OR Maltesers® and toothpicks and a red marker pen OR coloured jelly jubes/marshmallows and toothpicks
- methylated spirits
- household substances eg. some of the following: biro ink, boot polish, candle wax, grease, oil, aspirin tablets, salt, sugar, gelatine or jelly crystals, vinegar, soap, glycerol
- a balance capable of weighing to at least the nearest gram
- a gas tight container with a tube passing to a smaller container
- 25 g sucrose (table sugar)
- 1 g table salt
- 7 g dried yeast (found in the bread making or flour section of a supermarket - usually in 7 g, 12 g or 28 g packets)
- limewater

- alcohol burner
- alkanols such as methanol, ethanol (or methylated spirits), propanol
- a means of measuring the mass of burner to at least 0.01 g OR  
a means of measuring the volume of alkanol used to 0.2 mL and a data source of alkanol densities
- 500 mL conical flask or empty aluminium drink can
- a thermometer measuring to at least 0.5 of a Celsius degree
- a box of matches
- a means of supporting the conical flask or empty aluminium drink can about 5 cm above the top of the burner flame

**For Part 4 you will require:**

- iron nail (if rusty, clean surface with iron wool)
- solution of copper(II) ions eg. copper(II) sulfate solution or a solution of copper(II) acetate prepared by dissolving copper carbonate in vinegar; copper that has been exposed to the atmosphere (but not near salt water) for a long time can be covered with green carbonate
- small transparent container to hold the nail partly in and partly out of the solution
- finely divided zinc Zn(s); this can be obtained by shaking out powder from the bottom of a plastic bag that contained galvanised nails or by running a metal file down the side of a galvanised nail many times
- a dilute iodine solution I<sub>2</sub>(aq); prepared by adding one drop of iodine tincture to every two millilitres of water
- a small test tube to hold the iodine solution
- a variety of metals eg. steel paper clip, brass drawing pin, zinc galvanised nail, copper wire, silver plated cutlery, nickel plated jewellery.
- an electrolyte solution eg. a citrus fruit juice solution such as in a lemon which has been rolled and massaged by hand to enable the citric acid solution to move freely; cut the fruit in half  
OR a solution of acid such as vinegar (5%w/w acetic acid solution) or a salt solution (make about 5%w/w salt) in a container
- to detect the current produced you will need a multimeter able to measure to at least 0.2 volts DC
- two small liquid containers in the range 50 - 300 mL.

**For Part 5 you will require:**

- Internet access to complete Exercise 5.2.

# Icons

The following icons are used within this module. The meaning of each icon is written beside it.



The hand icon means there is an activity for you to do.  
It may be an experiment or you may make something.



You need to use a computer for this activity.



Discuss ideas with someone else. You could speak with family or friends or anyone else who is available. Perhaps you could telephone someone?



There is a safety issue that you need to consider.



There are suggested answers for the following questions at the end of the part.



There is an exercise at the end of the part for you to complete.



You need to go outside or away from your desk for this activity.

# Additional resources

- Morton, B. (1999.) *Ethylene senior chemistry*. Orica Limited.
- Anderson, A. (1998.) *Polyethylene senior chemistry*. Orica Limited.
- T P Lyons et al (Editors). (1995.) *The alcohol textbook*. Nottingham University Press.
- *The nuclear source*. ANSTO. (1992.)

# Glossary

The following words, listed here with their meanings, are found in the learning material in this module. They appear bolded the first time they occur in the learning material.

<b>ABS</b>	mixture of polyacrylonitrile, polybutadiene and polystyrene
<b>addition polymerisation</b>	polymer formation by adding together of monomer molecules containing C=C
<b>agrochemical</b>	chemical used in agriculture such as fertiliser, pesticide, herbicide
<b>alcohol</b>	organic molecular substance with OH group
<b>alkane</b>	$C_nH_{2n+2}$
<b>alkanoic acid</b>	$C_nH_{2n+1}COOH$
<b>alkanol</b>	$C_nH_{2n+1}OH$
<b>alkene</b>	$C_nH_{2n}$ or hydrocarbon containing C=C
<b>alkyne</b>	$C_nH_{2n-2}$ or hydrocarbon containing carbon to carbon triple bond
<b>amide</b>	molecule containing NHCO; the linkage between monomers in polyamides such as nylon
<b>amino acid</b>	$H_2N-RCH-COOH$ where the R group varies
<b>amorphous</b>	'without structure'; non-crystalline
<b>anhydrous</b>	without water
<b>anode</b>	electrode at which oxidation occurs mnemonic: AN OX
<b>bioconversion</b>	conversion of one chemical to another by a living thing
<b>biodiesel</b>	diesel fuel from living things
<b>bioethanol</b>	ethanol from cellulose in biomass
<b>biogas</b>	combustible gas, usually methane, from living things
<b>biomass</b>	organic matter produced by photosynthesis; mostly cellulose
<b>biopolymer</b>	naturally occurring polymer generated using renewable resources like micro-organisms or plants

button cell	button shaped electrochemical cell
catalyst	substance which speeds up a chemical reaction and remains unchanged at the end of the reaction
catalytic	involving a catalyst
catalytic cracking	cracking large hydrocarbon molecules to small hydrocarbon molecules with hot catalyst
cathode	electrode at which reduction occurs mnemonic: RED CAT ( <u>reduction</u> at the <u>cathode</u> )
cellulase	enzyme or group of enzymes that change cellulose to glucose
cellulose	polymer of $\beta$ -glucose
chain reaction	a sequence of self-sustaining reactions; important in polymerisation and nuclear fission
chemotherapy	treatment using chemicals
clinstix™	glucose test stick
condensation polymer	polymer formed by monomer molecules condensing out a small molecule
copolymer	polymer made from more than one monomer
cracking	breaking a large molecule into smaller molecules
crystallinity	proportion of polymer that is in crystal (regularly arranged) form
cyanide	CN group in organic compound or CN <sup>-</sup> in inorganic compound
cyclotron	compact accelerator that sends charged particles in a spiral path
decay	change to something simpler; radioactive decay occurs spontaneously producing a nucleus with fewer nucleons or a nucleus with less energy
delocalised electrons	electrons that move between atoms in a molecule or structure
dehydration	loss of water

denatured	deprived of its nature; ethanol, is made unpalatable for drinking by the addition of poisonous and bitter substances
dry cell	cell where electrolyte is paste or liquid absorbed in a porous medium
electrode	metal or graphite which transfers electrons in or out of an electrolyte
electrolysis	chemical reaction caused by electrical energy
electrolyte	liquid substance or solution through which ions can move
enhanced greenhouse effect	increase over the Earth's natural greenhouse effect as a result of human activity releasing extra gases eg. CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, CFCs
enzyme	biological catalyst
extrapolate	estimate a quantity by extending beyond the range of measured data
feedstock	raw materials for production
fermentation	controlled chemical changed catalysed by enzymes from organisms such as yeast
fission products	products of fission of a nucleus to smaller parts
flammable	easily set on fire
fossil fuel	fuel formed from the remains of plants or animals which lived millions of years ago
free radical	atom or molecule with a lone (unpaired) electron; very reactive
fuel	substance that undergoes a change releasing useful energy
galvanic cell	electrochemical cell capable of releasing electrical energy from chemical energy
genetic engineering; genetic modification; genetic manipulation	alteration of the genes in chromosomes of cells to attempt to change the capabilities of offspring
Gratzel cell	liquid junction photovoltaic device
half equation	equation showing oxidation or reduction
half-life	time required for radioactivity level to be halved
heat of combustion	heat change when a substance is combusted

HDPE	high density polyethene
hydration	addition of water
intermediate	in between; a chemical species formed between reactant(s) and product(s)
internal combustion engine	engine that combusts fuel in a chamber to release moving energy
ionising radiation	electromagnetic (UV, X-rays) or alpha/beta/gamma radiation capable of ionising atoms to positive ions and electrons
isotopes	atoms of the same element; they have the same atomic no. but different mass numbers
LDPE	low density polyethene
lead-acid cell	electrochemical cell consisting of a lead plate and a lead oxide plate in concentrated sulfuric acid
liquid junction photovoltaic device	cell changing light energy absorbed by a liquid junction between anode and cathode to electrical energy
lithium cell	galvanic cell containing lithium and having high energy output per kg eg. Li-FeS <sub>2</sub> 1.5 V non-rechargeable or Li-MnO <sub>2</sub> rechargeable
lyophilic	fat loving; non-polar substance
metabolic engineering	transfer of genes for a metabolic pathway from one organism to another
metabolic pathway	pathway used by an organism to carry out a chemical change; catalysed by enzyme(s)
methanogen	'methane former'; bacteria that make methane
mnemonic	assisting the memory
molecular model kit	kit consisting of plastic pieces that can be joined together to represent the atoms and bonds in a molecule
monomer	compound with small molecules able to join together to form long chain polymer molecule
monounsaturated	molecule with one unsaturated group C=C
naphtha	fraction of petroleum distillation not in demand; can be changed to fractions in demand such as petrol or used as feedstock for petrochemical processes
nitrile group	-CN group in a carbon compound

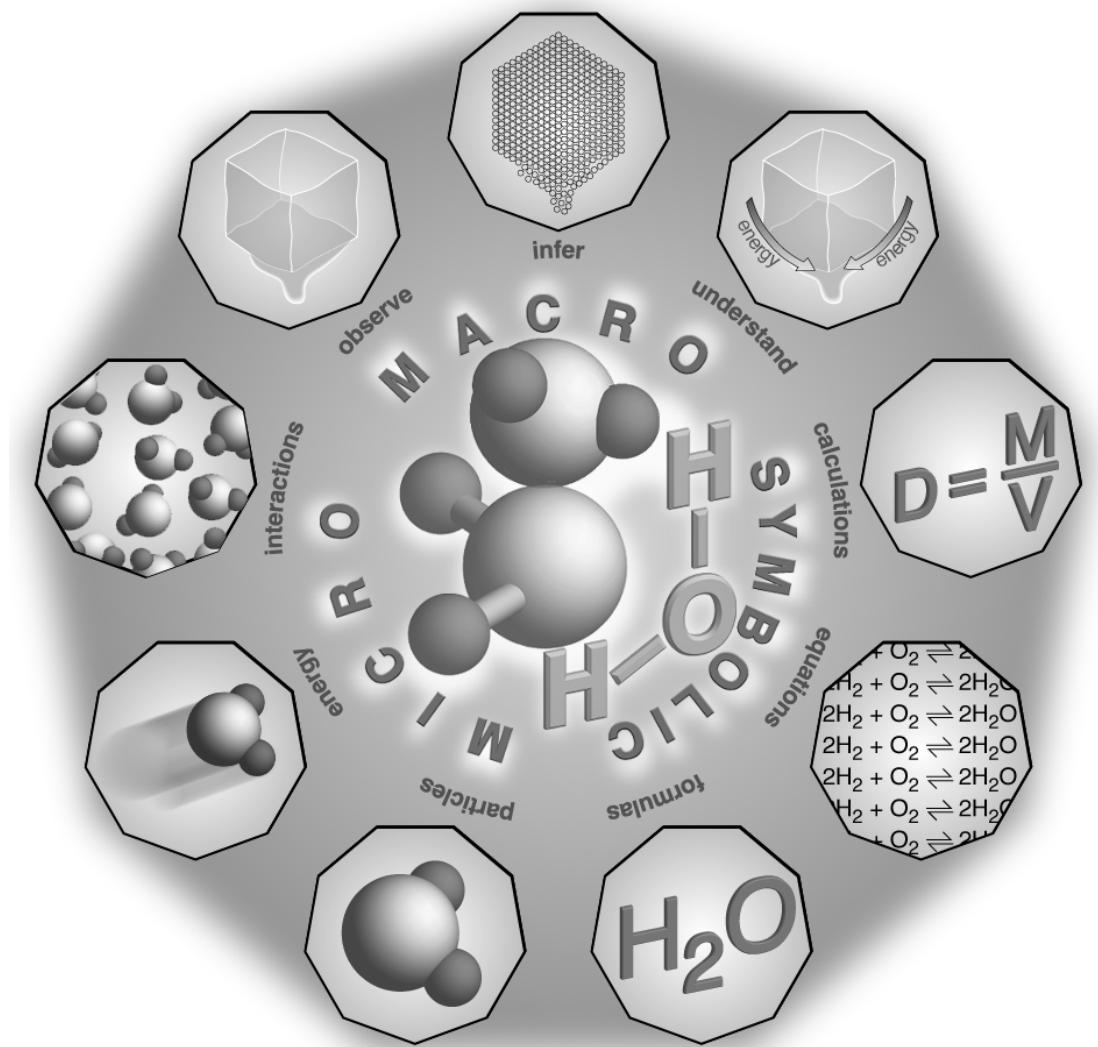
non-degradable	unable to be decomposed naturally by decay bacteria or fungi
non-ionising radiation	low energy radioactivity that has enough energy to excite electrons to higher energy levels but insufficient energy to ionise atoms
non-renewable	resource that is available in fixed amount and could be used up completely eg. petroleum
nuclear fission	division of a nucleus into two unequal masses releasing neutrons, gamma rays and massive amounts of energy
nuclear reactor	equipment for releasing nuclear energy slowly in a usable form
nucleon	particle in a nucleus; proton or neutron
organometallic	compound containing an organic part and a metal
oxidant	oxidising agent; chemical species that causes oxidation (loss of electrons)
oxidation state = oxidation number	number that increases on oxidation and decreases on reduction
particle accelerator	device for accelerating charged particles
PE	Polyethene = polyethylene = polythene
peptide linkage	NHCO in proteins between amino acids
PET	Polyethylene terephthalate plastic used to make recyclable soft drink bottles; positron-emission tomography technique for imaging the brain using radioisotopes made in a cyclotron
petranol	mixture of petrol and alcohol
petrochemical	chemical made from compounds in petroleum
photovoltaic	light energy to electrical energy eg. as in silicon solar or liquid junction Gratzel cell
plasticiser	chemical the molecules of which fit between polymer chains increasing flexibility
poly(ethene)	polymer of ethene
polymer	long chain molecule formed by joining monomer molecules
Polyunsaturated	molecule with more than one C=C group
potential	potential difference or voltage measured in V

PP	polypropylene, polymer of propene <chem>CH3CH=CH2</chem>
PPVC	plasticiser added PVC that is more flexible
pretreatment	treatment of material before processing
PS	polystyrene
PVC	polyvinylchloride
radioactive isotope	radioisotope
radioisotope	radioactive isotope
radionuclide	radioactive nuclide = radioisotope
reaction mechanism	how reactants change in producing products
redox	abbreviation of reduction-oxidation
reductant	reducing agent; chemical species that causes reduction (gain of electrons )
reduction	gain of electrons by a chemical species
renewable	resource that can be used then reformed from products by input of solar energy
SAN	mixture of polystyrene and polyacrylonitrile
saturated	carbon compound saturated with hydrogen containing C–C bonds and no double or triple bonds
steam cracking	cracking by mixing with steam and passing through hot coils
surface reaction	reaction occurring on the surface of a solid
thermoplastic	polymer material that can be melted by heat (thermo) and shaped (plastic)
tincture	aqueous alcohol solution
tracers	radioisotopes used to signal passage of an atom through a system
transuranic	element with an atomic number above 92, beyond uranium
UPVC	unplasticised PVC; rigid PVC
V	PVC abbreviation for recyclable material
zeolites	aluminium silicates; different types are used as catalysts, molecular sieves and separators



# The identification and production of materials

## Part 1: Fossil fuel polymers



<b>Common names of monomer</b>	<b>Systematic name of monomer</b>	<b>Polymer uses</b>	<b>Recyclable plastic symbol</b>
ethylene	ethene	bags, water pipes, gas pipes, buckets, bottles, garbage bins	 HDPE  LDPE
vinyl chloride, chloroethylene	chloroethene	garden hoses, shoe soles, conduit, waste water pipes, credit cards, floor tiles	 V or PVC
styrene, vinyl benzene, phenyl ethene	ethenylbenzene	plastic cutlery, brittle toys, CD cases, bike helmet padding	 PS
acrylonitrile, vinyl cyanide, propenenitrile	propenenitrile	acrylic fibres, synthetic rubbers, carpets, making carbon fibre	 OTHERS

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understand



**SYMBOLIC**

$H_2O$  formulas  
equations  
calculations



**MICRO**



particles  
energy  
interactions

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**MACRO**observe  
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calculations**MICRO**particles  
energy  
interactions

# Introduction

Fossil fuels provided the energy that has fuelled a marked increase in the world's population over the last two hundred years. In the last century fossil fuels have become increasingly important in providing raw materials such as ethene to make useful materials like the addition polymers poly(ethene), poly(vinylchloride), poly(acrylonitrile) and poly(styrene).

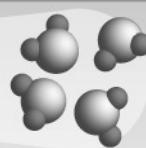
In Part 1 you will be given opportunities to learn to:

- identify the industrial source of ethene from the cracking of some of the fractions from the refining of petroleum
- explain that catalytic cracking is an example of an industrial process that involves surface reactions with inorganic catalysts
- explain the relationship between the properties of alkanes and alkenes and their non-polar nature and weak dispersion forces between molecules
- identify that ethene, because of the high reactivity of its double bond is readily transformed into many useful products
- identify that ethene serves as a monomer from which polymers are made
- identify poly(ethene) as an addition polymer and explain the meaning of this term
- outline the steps in the production of poly(ethene) as an example of a commercially and industrially important polymer
- identify the following as commercially significant monomers:
  - vinyl chloride
  - acrylonitrile
  - styreneby both their systematic and common names
- account for the uses of the polymers made from the above monomers in terms of their properties.

In Part 1 you will be given opportunities to:

- identify data, plan and perform a first-hand investigation to compare the reactivities of appropriate alkenes with the corresponding alkanes in bromine water and iodine in solution
- gather and present information from first-hand or secondary sources to write equations to represent all chemical reactions encountered
- analyse information from secondary sources such as computer simulations, molecular model kits and multimedia resources to model the polymerisation process and use available evidence to relate the arrangement of covalent bonds in polymers to the loose coiling and intertwining of polymer strands.

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understand**SYMBOLIC** $H_2O$  formulas  
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# Reactivities of alkenes and alkanes

Three activities are listed below comparing reactions of alkenes and alkanes or studying reactions of compounds containing the carbon to carbon double bonds, C=C, found in alkenes. The first and third activities that involve bromine water should only be carried out in laboratory conditions. The second and third activity involving iodine solution can be safely carried out at home.



Special care is needed if using bromine water. It is a corrosive solution, a skin irritant and releases irritant vapour. Use a fume cupboard whenever possible, otherwise use small quantities in a well ventilated area.

Bromine water can be prepared by opening or carefully breaking a glass ampoule of 2 mL of liquid bromine at the bottom of a container of 400 mL of water in a fume cupboard. Dissolution of all the bromine prepares a 0.1 M solution. The 400 mL should be divided into two lots and stored in well sealed containers. Bromine water loses bromine to the air and changes concentration whenever the container lid is removed. One lot of bromine water should be used first. Comparison of the intensity of its colour with the second sealed lot will give an approximate idea of any decrease in concentration.

When not in use the bromine solution must be kept in a well sealed container, preferably within a larger sealed container, in a refrigerator (not a freezer). The 0.1 M solution should be diluted to about 0.01 M for use by students. A small dropper bottle provides convenient access. Students must wear eye protection (glasses or goggles) when using bromine solution.

Iodine solution is less hazardous and can be prepared from iodine tincture (2.5% iodine w/v, approximately 0.1 M) or iodine paint (5% iodine w/v, approximately 0.2 M) which can be purchased at pharmacies (\$3-5 for 50 mL). The purchased solutions contain iodine dissolved in aqueous alcohol. Before use the solutions must be diluted to about 0.1% iodine w/v solution. One drop of iodine tincture to each millilitre of water or one drop of iodine paint to every 2 mL of water will produce about 0.1% iodine w/v solution. Store solutions in a sealed container in a refrigerator.



**Activity 1: Reactivity of cyclohexane and cyclohexene with bromine water.** This activity requires access to a supervised laboratory.



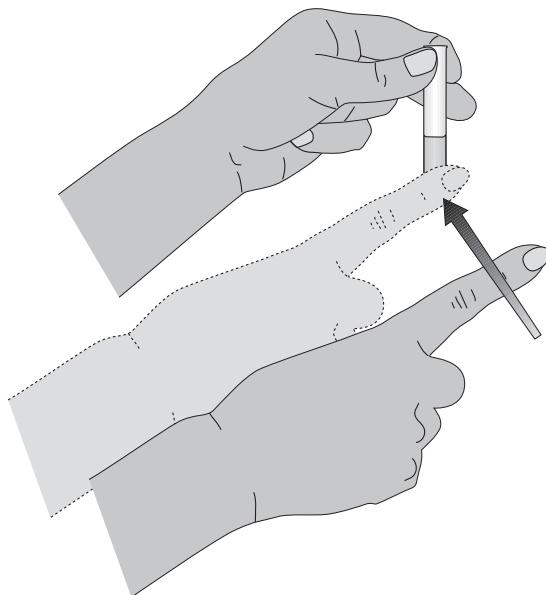
Cyclohexane and cyclohexene are highly **flammable** and release moderately toxic vapour. Wear eye protection especially when using bromine water.

**What you will need:**

- two glass test tubes or small beakers
- cyclohexane
- cyclohexene
- 0.01 M bromine water in a dropper bottle.

**What you will do:**

- 1 Add about 1 mL (about twenty drops) of cyclohexane to one container and about 1 mL of cyclohexene to the other container. Fill your lungs with air then gently wave your hand over the top of a container towards your nose. Take a short sniff of air containing the vapour into your nose then breathe much more air from your lungs out through your nose. Repeat for the other container. Note the odour difference.
- 2 Add an equal volume of bromine water to each of the liquids then shake each container to the same extent.



How to hold a test tube and shake its contents

- 3 Leave the containers to settle, then observe.

- 4 Use your observations and data in the table below to record observations and conclusions.

Properties	Cyclohexane	Cyclohexene
odour		
density (g cm <sup>-3</sup> )	0.77	0.81
colour before addition of bromine water		
colour after shaking with bromine water		
colour of bromine water before addition		
colour of water layer after shaking		

If you think about your observations you will probably conclude that the alkane did not react whereas the alkene did react with the bromine.  
Alkene removes bromine from its water solution.



- 1 Which observation(s) can be interpreted as showing that bromine has reacted with the alkene?

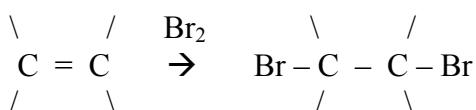
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- 2 What happens to the colour of bromine water when the bromine reacts?

---

Check your answers.

The reactive C=C in alkenes can react with bromine:



The compound formed is a 1,2-dibromoalkane. Cyclohexene forms 1,2-dibromocyclohexane. Because two molecules (bromine and cyclohexene) add to give a single molecule (1,2-dibromocyclohexane) the reaction is called an addition reaction. Note that the double bond has changed to a single bond as two of the electrons in the double bond were needed to form covalent bonds with the two bromine atoms added.



## Activity 2: Reactivity of iodine water with food oils

### What you will need:

- approximately 0.1% iodine water (made by adding a drop of iodine tincture to each millilitre of water used) in a dropper bottle
- test tubes with stoppers
- at least two different food oils
- baby oil (or light liquid paraffin oil).

### Background information

Food oils such as safflower, olive, peanut, etc. have varying amounts of unsaturation. If each hydrocarbon chain is **saturated** with hydrogen, that is only has C – C bonds, then the oil is called a saturated oil. If an oil molecule has one C = C the oil is **monounsaturated**. When there is more than one C = C per molecule the oil is called **polyunsaturated**. A balanced diet should include all three types of oils.

You can determine which oils are most unsaturated by comparing the amount of iodine that reacts when the oils are shaken with iodine water.

Many food oils are coloured yellow, the same colour as dilute iodine water. To make change easier to see you will shake the iodine water with baby oil. When the non-polar iodine molecules transfer from the polar water layer to the non-polar baby oil layer the iodine appears a violet colour.

When shaken together vigorously oil and water will tend to form a white emulsion. An emulsion is a suspension of small droplets of one liquid in another liquid. An emulsion is white because the surface of the small droplets reflect light. If you wait five minutes the emulsion should separate into two layers. This enables you to see any colours in the more dense, polar, water layer and the less dense, non-polar, oil layer.

To test a food oil for unsaturation:

- 1 Add some iodine water to the test tube.
- 2 Add about half the iodine water volume of baby oil, stopper the test tube and shake vigorously up and down for ten seconds. The yellow to violet colour change is due to a physical change as non-polar iodine moves from water to non-polar oil.
- 3 Add food oil, stopper the test tube and shake vigorously up and down for ten seconds. If the violet colour disappears the iodine has reacted with unsaturated groups in that food oil.

The loss of violet colour is due to a chemical change as iodine disappears reacting chemically with  $-C=C-$  to form  $-C-C-$



In the space below plan a first-hand investigation to compare the amount of saturation in at least two different food oils. Perform your investigation and write a report that includes aim, method, results and a conclusion. Remember to use labelled diagrams and tables where relevant.



### Activity 3 Tomato juice rainbow using bromine water or iodine water

#### What you will need:

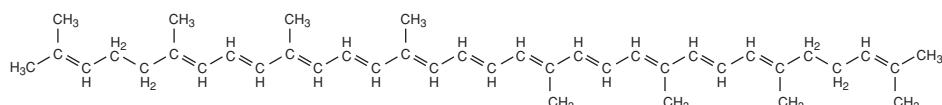
- tomato juice (normally contains about 20 mg of lycopene per mL)
- about ten transparent containers (test tubes or beakers)
- bromine water or iodine water in dropper bottles
- drinking straws—NOT to be used for drinking—or wooden skewers to stir the tomato juice with the bromine water or iodine water
- coloured pencils.



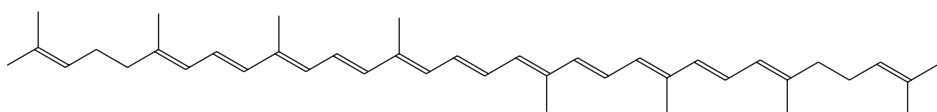
Don't forget your eye protection whenever using bromine water. The results with bromine water are usually more colourful than with iodine water.

### Background information:

Tomato juice, watermelon and pink grapefruit contain a red coloured plant chemical (phytochemical) called lycopene. Lycopene is a hydrocarbon  $C_{40}H_{56}$  with the following structure:



or more simply drawn as:



Lycopene is an antioxidant, able to neutralise harmful reactive substances in the body called **free radicals**. There is evidence that a diet high in lycopene reduces the incidence of heart attacks and certain cancers such as prostate cancer. Cooking tomatoes provide more lycopene because the heat breaks down tomato cell walls freeing the lycopene.

The alternating double and single bonds in lycopene provide **delocalised** electrons that can move freely from carbon atom to carbon atom. Most carbon compounds are colourless but a compound such as lycopene with lots of delocalised electrons in a long chain can absorb parts of visible light. The colour of a compound is the colour of the light that is not absorbed, that is the colour that is reflected or transmitted to your eye.

Lycopene crystals are a tomato red colour. Tomato juice containing lycopene is red.



Which colour of visible light is not absorbed by lycopene?

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### What you will do:

- 1 Place about 5 mL of tomato juice in the ten test tubes (or small beakers).
- 2 Add varying amounts of bromine water or iodine water to each container. Experiment with different amounts to try and produce a range of colours.

It is possible, but difficult, to produce the range of visible spectrum colours red (unreacted tomato juice), orange, yellow, green and blue.

- 3 Draw what you see using the coloured pencils. Provide informative labels to show the amounts of tomato juice and bromine or iodine water used.



Explain what you have observed in terms of possible reactions of lycopene with bromine or iodine and changes in the structure of lycopene.

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Check your answer.

## Ethene, leaves, apples and bananas

Towards the end of the 1800s it was noticed that trees near street lamps in a German city lost their leaves unexpectedly. Investigations showed that ethene in leaking gas used to fuel the street lamps was responsible. Ethene was also found to be given off by ripening fruit and acted as a plant hormone. Today ethene at about 10 ppm concentration is used to ripen and colour bananas, pears, mangoes, tomatoes and citrus, to induce flowering in pineapple plants and to improve the growth and appearance of bean sprouts.



### Investigating ethene

#### You will need:

- 3 transparent plastic bags and ties to seal the bags
- 8 transparent glass containers (eg. beakers/test tubes/petri dishes)
- 12 mL of diluted (about 0.01M) bromine water and eye protection (glasses or goggles) and/or

12 mL diluted iodine solution made by adding 12 drops of 2.5% w/v iodine tincture to 12 mL of water

[If you do not have access to diluted bromine or iodine you could try a very dilute solution of potassium permanganate KMnO<sub>4</sub> solution which is a light purple colour. KMnO<sub>4</sub> crystals can be purchased at pharmacies as Condy's crystals]

- 1 ripe banana and 1 green banana OR 1 ripe apple and 1 unripe apple
- an area where you can leave the 3 plastic bags and contents undisturbed for a few days (away from pets and young children).

### What you will do:

- 1 Into each of three bags as well as the area where the bags are to be kept place:
    - 3 mL diluted bromine water in an open container and/or
    - 3 mL diluted iodine solution in an open container.
  - 2 To a bag labelled R add a ripe banana or apple.
  - 3 To a bag labelled G add a green banana or unripe apple.
  - 4 No banana or apple goes into the bag labelled N.
  - 5 Seal each bag with a tie then place the three bags in the same area. Make sure the bags are not exposed to direct sunlight or heat. The bags should contain about the same amount of air each.
  - 6 Observe the three transparent bags over the next three days and note any changes in their contents.
- 1 Why was diluted bromine or iodine solution placed in the area near where the plastic bags were kept?



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- 2 Why was no banana or apple placed in one of the bags?

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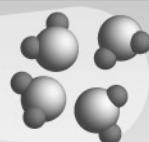
- 3 Can you come to some conclusions from your observations?

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Check your answers.

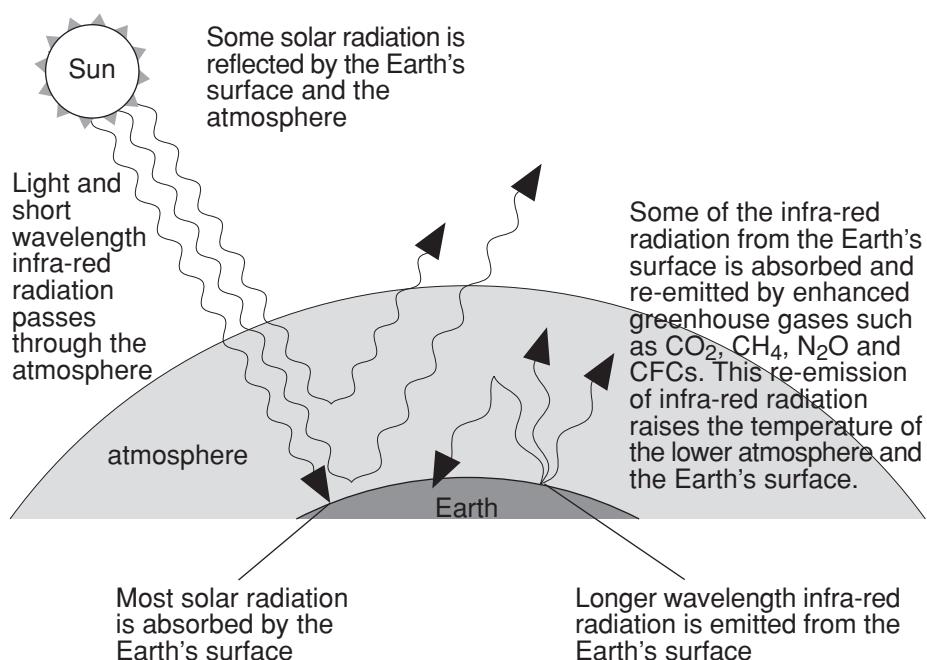
**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Fuel or raw material

Some projections of current rates of use of Australian fossil fuels based upon known reserves indicate the availability of:

- coal supplies for about 1000 years
- natural gas supplies for about 100 years
- petroleum supplies for about 10 years.

There are ways of converting the more plentiful solid coal to liquid fuels such as compressed natural gas and petrol but at costs to the environment. The conversion methods can produce considerable waste and do not overcome the **enhanced greenhouse effect**. Burning the carbon that has been trapped for millions of years in any fossil fuel increases carbon dioxide levels in the global atmosphere. Carbon dioxide is not considered a pollutant locally but is globally. Higher concentrations of carbon dioxide trap more heat within the atmosphere and are believed to raise temperatures globally.



Fossil fuels to date have mostly been used as fuels – burnt in air as a source of heat energy. Because supplies are limited and carbon compounds are so important in making synthetic rubbers, synthetic textile fibres, plastics, paints, detergents, pharmaceuticals, cosmetics, herbicides, pesticides, agricultural chemicals and so on, the use of fossil fuels as fuels—burnt and lost for ever—is increasingly questioned.

A wiser use that would benefit many more humans for many more generations would be to use fossil ‘fuels’ as raw materials only. This requires alternative methods of making energy available such as the biomass to ethanol and electrochemical and nuclear methods. You will cover these in Parts 2 to 5 of this module.

Petroleum is regarded as the most valuable of fossil fuels because of its greater diversity of compounds compared with natural gas or coal.

**Petrochemicals** are chemicals made from compounds in petroleum. However the main use for over 90% of petroleum hydrocarbons consumed worldwide is still as fuel.



Consider the C1 to C8 alkanes. Complete the first and second columns of the table. Do you remember the general formula for alkanes?  $C_nH_{2n+2}$

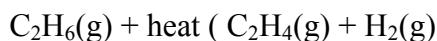
Alkane	Formula	Use
methane	$CH_4$	natural gas
ethane	$C_2H_6$	petrochemical
propane		liquefied petroleum gas (LPG)
	$C_4H_{10}$	liquefied petroleum gas (LPG)
pentane		petrol used in cold climates
	$C_6H_{14}$	petrol used in cold climates
heptane		petrol
octane		petrol

Which one of the C1 to C8 alkanes is too valuable to use as a fuel?

Ethane is too valuable to use as a fuel as it can easily be changed into ethene, the petrochemical used in greatest amount for making plastics.

# Ethene production

Ethane gas can be converted to ethene gas by **cracking**—breaking larger molecules (eg. ethane) into smaller molecules (ethene and hydrogen).



Cracking is endothermic because a molecule has to be broken apart into smaller molecules.

The hydrogen by-product can be used for other reactions such as changing polyunsaturated liquid food oils into partly saturated solid fats (such as margarine).

There are two main sources of ethene:

- as a by-product of the **catalytic cracking** of low value petroleum fractions to high value petrol
- as the main product in **steam cracking** of ethane or low value petroleum fractions.

## Catalytic cracking

Catalytic cracking is an example of an industrial process that involves surface reactions with inorganic catalysts. The solid inorganic catalyst for cracking to produce ethene is usually a synthetic **zeolite** (aluminium silicate) with a large surface area. The zeolite catalyses the breakdown of larger hydrocarbon molecules to smaller hydrocarbon molecules including some ethene.

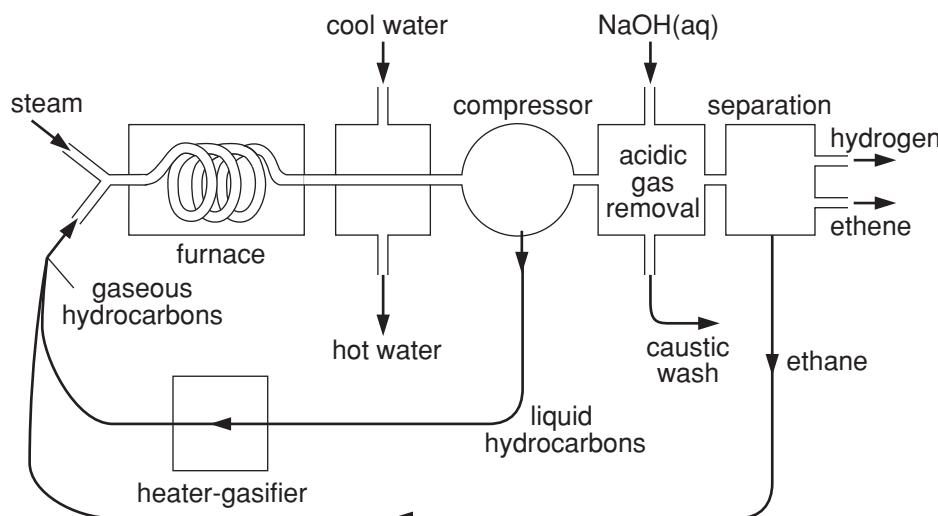
Small lumps of the solid catalyst are circulated between a reactor and a regenerator. Because these lumps move like the molecules in a fluid the solid catalyst is said to be fluidised.

In the reactor the lumps of catalyst become coated with carbon and other unwanted deposits. These lumps flow out of the reactor to a higher temperature regenerator where air reacts with the solid deposits to form gases which escape. The cleaned lumps of catalyst are circulated back to the reactor.

## Steam cracking

An efficient way of producing ethene is by steam cracking. Ethane from natural gas or vaporised gas oil (a higher boiling fraction of petroleum distillation containing C10 to C30 hydrocarbons) is mixed with half its weight of steam.

The mixture enters furnace coils where it is heated to about 850°C at low pressure for less than a second to produce ethene. Any carbon produced that could reduce the efficiency of the process reacts with the steam to form two gaseous products which can be used as fuels.



The process of steam cracking.



In steam cracking carbon and steam react to form a very poisonous carbon oxide gas and the lightest (lowest density) gas known. Write an equation in symbols for this reaction.

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Check your answer.



Complete Exercise 1.1: *Petroleum fractions cracked to ethene.*

## Ethene production in Australia

The main centres for ethene production in Australia are at Orica (formerly ICI), Botany, Sydney and Kencor, Altona, Melbourne. Over 80% of the ethene produced is used to make polyethene for processors and manufacturers based in these two large population centres.

Both of these production facilities are close to petroleum refineries. Sydney's petroleum comes mostly from Australian and middle eastern oilfields while Melbourne's petroleum is extracted from Bass Strait oilfields.

Ethene production at Orica in Sydney since 1957 has involved four different processes. The processes have changed with availability of more economic raw materials (**feedstock**) and improved technology:

- 1957-1966 Dehydration of ethanol with sulfuric acid acting both as a catalyst and a dehydrating agent.



- 1966-1983 Catalytic cracking of **naphtha** (C5 to C10 hydrocarbons).



large molecule free radicals each with +  
an unpaired electron •



The small molecules could be recycled for further cracking to ethene.



Outline the catalytic cracking of  $\text{C}_6\text{H}_{14}$  to produce ethene.

Check your answer.

- 1983-1996 Steam cracking of LPG (C3 and C4 hydrocarbons).
- 1996-2000 Steam cracking of ethane pipelined from the Cooper Basin in South Australia.

Ethene production at Kemcor in Melbourne since 1970 has involved steam cracking of ethane from the Bass Strait gas fields and gas oil fractions (C10 -C30 hydrocarbons) from Altona petroleum refinery.

Alkanes and alkenes are non-polar molecules and so have weak dispersion forces between the molecules. Ethane and ethene are small hydrocarbon molecules so their dispersion forces are extremely weak. This makes it very difficult and expensive to compress these gases to liquid, a more compact form in which to transport chemicals.

The Altona cracking units are connected to surrounding manufacturers which use the ethene produced to make polymers.

By having a petroleum refinery, natural gas ethane extraction, cracking and polymerisation units close together in a petrochemical complex gaseous ethane and ethene are easily moved between the units through gas pipelines. Expensive compression to change non-polar gas to compact liquid is not required.

Ethene, because of the high reactivity of its double bond, reacts to form many useful products such as poly(ethene). Other chemicals which contain reactive double bonds are:

- styrene which reacts to form poly(styrene)
- vinyl chloride which forms poly(vinyl chloride)
- acrylonitrile which forms poly(acrylonitrile).

Note: Just as ethene is commonly called ethylene, polyethene is commonly called polyethylene or abbreviated to polythene.

- 1 Suggest two reasons why most producers of ethene use steam cracking rather than catalytic cracking.



- 2 At Orica, each 1000 t of ethane produces about 780 t of ethene.
- a) Using the mole concept and molecular masses calculate the amount of hydrogen you would expect produced with each 780 t of ethene.

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- b) Most reactions involving carbon compounds do not give all of the desired products. As well as ethene and hydrogen what mass of other substances would you expect produced from each 1000 t of ethane?

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Check your answers.

Complete Exercise 1.2: *Products from ethene.*



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Monomers and polymers

**Monomers** are small molecules able to join together to form long chain molecules called **polymers**. When the small monomer molecules add together to form the polymer and no other product the reaction is called **addition polymerisation**. If the polymer name is written as poly(ethene) then ethene is the monomer and polyethene is the polymer.

## Addition polymerisation

When an alkene monomer polymerises the double bonds change to single bonds. Two of the electrons originally in each double bond are used to link the carbon atoms together into long thin linear chains.



$n$  units of monomer  $\rightarrow$  polymer made of  $n$  monomer units

Polyethene is used for plastic bags, clingwrap and black water pipes.



### What you will need:

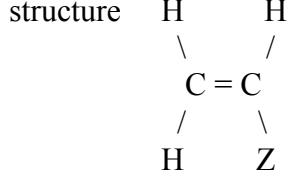
- molecular model kit or
- jelly lollies (such as cut jelly snakes) and toothpicks or
- Lego® style blocks.

### What you do:

- 1 Make up at least four models of ethene  $C_2H_4$
- 2 Join the models together to make part of a polyethene molecule  $(C_2H_4)_n$ . Notice that the reactive double bonds are changed to more stable single bonds as the molecules join up.

# Polymers

Monomers that undergo addition polymerisation usually have the structure



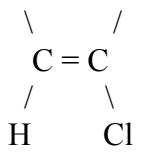
where Z can vary in different substances



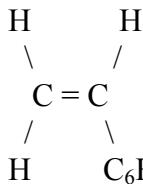
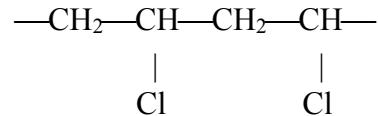
What does Z represent in ethene? \_\_\_\_\_

Check your answer.

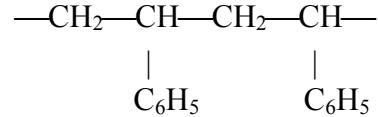
Examples: H H



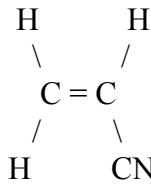
vinyl chloride  $\rightarrow$  polyvinylchloride PVC



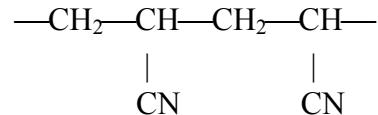
styrene  $\rightarrow$  polystyrene



$\text{C}_6\text{H}_5$  represents a ring of six carbons and five hydrogens



acrylonitrile  $\rightarrow$  polyacrylonitrile



Acrylonitrile can be called vinyl cyanide as the organic nitrile group CN is also called the cyanide group.

These monomers are commercially significant as they are used in large quantities to produce polymers.

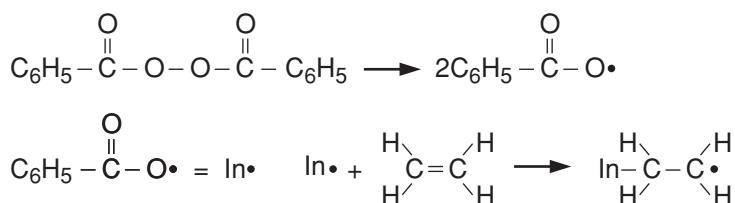
# Production of polyethene

Varying production conditions and catalysts can produce different polyethene molecules. Polyethene molecules of different sizes and different amounts of branching will have different properties and therefore different uses. The two main types of polyethene produced are:

- relatively soft low density polyethene (LDPE) composed of tangled chains with molecular masses of less than 100 000
- harder high density polyethene (HDPE) composed of aligned chains with molecular masses above 100 000.

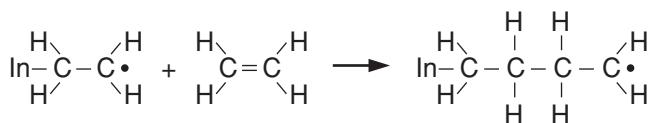
Low density polyethene LDPE is made by subjecting ethene to high pressures. The reaction is initiated by a peroxide containing a O–O bond which breaks easily on heating producing two free radicals. When a free radical joins onto an ethene molecule the ethene free radical produced becomes reactive.

## Initiation



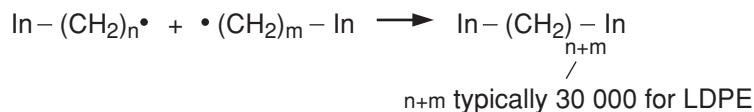
Growth occurs by an ethene free radical adding on other ethene molecules. The growth stage is called propagation.

## Propagation

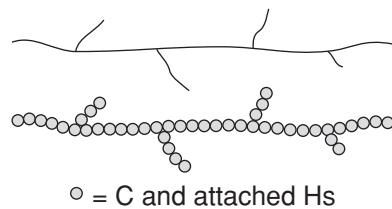


The chain of ethenes grows until this free radical ethene chain combines with another free radical ethene chain to form a complete polyethene molecule. Combination of free radicals is called termination.

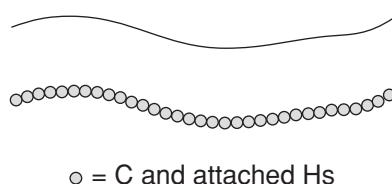
## Termination



The high pressure conditions with many molecule collisions produces short branches along the length of the LDPE chain.



High density polyethene HDPE is made at low pressures. Catalysts used consist of transition metals and **organometallic** compounds. These catalysts enable a more ordered orientation of reacting ethenes producing very long unbranched molecules.



Industry and chemists usually refer to monomers by their common names but these names cannot always be used to predict the formula. A systematic name enables a person familiar with systematic nomenclature to predict the formula. Recycling code symbols appear on many objects made of polyethene, PVC and polystyrene.

Common names of monomer	Systematic name of monomer	Polymer uses	Recyclable plastic symbol
ethylene	ethene	bags, water pipes, gas pipes, buckets, bottles, garbage bins	2 HDPE 4 LDPE
vinyl chloride, chloroethylene	chloroethene	garden hoses, shoe soles, conduit, waste water pipes, credit cards, floor tiles	3 V or PVC
styrene, vinyl benzene, phenyl ethene	ethenylbenzene	plastic cutlery, brittle toys, CD cases, bike helmet padding	6 PS
acrylonitrile, vinyl cyanide, propenenitrile	propenenitrile	acrylic fibres, synthetic rubbers, carpets, making carbon fibre	7 OTHERS

The monomers may be gases or liquids but addition polymers are all solids because they are larger molecules with significant dispersion forces.

The bonding within the molecules are strong covalent bonds but the long thin molecules are held together by weaker dispersion forces. When heated the weaker dispersion forces are overcome and the molecules can flow into new shapes.

These addition polymers are called **thermoplastics** because they are easily melted and shaped.

## Investigating LDPE and HDPE

In 2000 nearly 10 kg of polyethene (**PE**) was produced per person on Earth. The weight of polyethene produced each year is greater than the weight of all other plastics. In most countries the weight of (cheap) polyethene used is greater than the combined weight of all other plastics used in that country.



### Distinguishing between LDPE and HDPE

#### What you will need:

- LDPE eg. plastic food bag, anything with recycling code 4
- HDPE eg. plastic milk container, anything with recycling code 2
- Some fruit juice/milk containers have a HDPE body and a LDPE lid
- a 2/3 water and 1/3 ethanol (or methylated spirits) liquid mixture with a density of approximately  $0.94 \text{ g cm}^{-3}$ .

Push the plastic below the liquid surface wiping off any attached air bubbles.



- 1 Why does LDPE float while HDPE sinks? Answer this question at the micro level (that is, in terms of particles) and at the macro level (that is, in terms of a property of the material).

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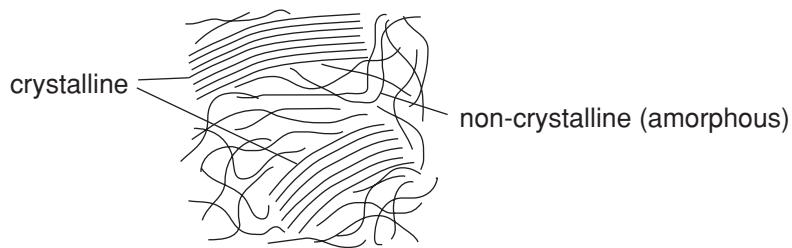
- 2 Predict which type of chain would pack together most closely and form crystals (regular arrangements) most easily.

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- 3 Would this closer packing produce LDPE or HDPE?
- 
- 4 Which structure would produce a softer, more flexible plastic for wrapping around and containing food?
- 
- 5 Which structure would produce a harder, rigid plastic suitable for buckets and plastic rulers?
- 
- 6 Using simple diagrams to represent micro level structures of polyethene explain why LDPE floats while HDPE sinks in the mixture of water and ethanol.
- 
- 
- 
- 
- 7 List objects in your home that are made from LDPE and objects that are made from HDPE.
- 
- 
- 
- 
- 
- 
- 

8 The amount of polymer in crystal form determines its **crystallinity**.

Most polymers are a mixture of crystalline regions where the molecules are aligned and non-crystalline (**amorphous**) regions where the molecules are tangled.



Crystalline region	Non-crystalline region
opaque	transparent
higher MP	lower MP
rigid	flexible
low permeability to gases	permeable to gases

Which form of PE has the greatest crystallinity – LDPE or HDPE?

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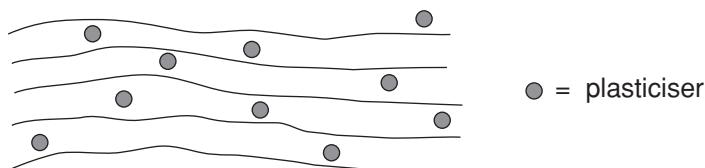
Check your answers.

You should now be able to explain the different properties of LDPE and HDPE using models of how the molecules are arranged.

## Properties and polymer structures

The properties of a polymer are determined by the polymer structure and size of the polymer molecules. The greater rigidity of polyvinylchloride (PVC), polystyrene (PS) and polyacrylonitrile (PAN) compared with polyethene (PE) are partly due to the bulkier Cl, C<sub>6</sub>H<sub>5</sub> and CN groups compared with H in the polymer structure. Larger molecular size as well as greater crystallinity produce less flexibility, greater hardness and higher MP in HDPE compared with LDPE. These different structures can be used to explain why HDPE plastic bags are crinkly while LDPE plastic bags are softer and tear more easily.

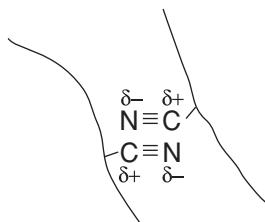
Polyvinyl chloride is often marked UPVC or PPVC depending on whether the PVC is unplasticised or plasticised. **Plasticisers** are molecules which fit between polymer chains and reduce dispersion forces. The addition of plasticisers makes PPVC much more flexible than UPVC.



PVC is water resistant. It is used for raincoats, shower curtains and waste water pipes. PVC is also flame resistant – when PVC is heated it releases chlorine atoms which inhibit combustion reactions.

In polystyrene the bulky C<sub>6</sub>H<sub>5</sub> groups both increase dispersion forces and inhibit large crystal formation. The low crystallinity makes polystyrene transparent and suitable for clear plastic drinking glasses and CD (compact disk) cases. If polystyrene absorbs liquid pentane and is heated to 36°C the pentane boils and changes to gas. This expands the polystyrene forming a white material of very low density. The expanded polystyrene formed is also a good heat insulator and used for hot drink cups as well as packaging material and shock absorber inside bike helmets.

Polyacrylonitrile is found mixed with other polymers in acrylic fibres, synthetic rubbers and synthetic furs. PVC is added to polyacrylonitrile in acrylics to improve dyeing. SAN is a mixture of polystyrene and polyacrylonitrile used in latex paints, syringes and plastic plates. ABS is a mixture of polyacrylonitrile, polybutadiene and polystyrene used for strong and lightweight bumper bars. Polyacrylonitrile added to these and other polymers makes the materials much stronger. The nitrile (cyanide) group –CN is very polar. The strong attraction between opposite charges on adjoining nitrile groups holds polymer chains tightly together producing strong materials.



## Investigating bonds between polymer molecules

The covalent bonds within a polymer molecule are strong and difficult to break. Dispersion forces between long thin polymer molecules are weaker and can be more easily broken and reform.

### What you will need:

- a balloon made of a polymer – rubber
- a skewer at least 30 cm long
- some petroleum jelly/soft paraffin/Vaseline®.

### What you will do:

- 1 Blow up a balloon with about half the normal amount of air and tie the end in a knot.
- 2 Coat the skewer with some petroleum jelly/soft paraffin/Vaseline.

- 3 Push the sharp end of the skewer into the balloon where it narrows towards the knot. Keep pushing steadily until the sharp end reaches the small round region at the top of the balloon where it is least stretched.
- 4 Push the sharp end of the skewer through this least stretched part of the rubber. Keep pushing until a few cm of the sharp end is sticking out the end of the balloon.
- 5 Think about what has happened to the long thin polymer molecules of the balloon as the skewer is pushed through.

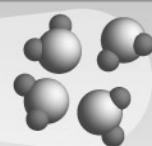
### Discussion

The balloon should not burst (but may slowly leak air). The pushed skewer overcomes dispersion forces between rubber polymer molecules as it is pushed through. The petroleum jelly/soft paraffin/Vaseline provides a seal between the skewer and balloon.

If the skewer is removed the balloon will go down because the rubber cannot form dispersion forces strong enough to stop leakage of air.

Complete Exercise 1.3: *Fossil fuel products*.



**MACRO**observe  
infer  
understand**SYMBOLIC**
 $H_2O$  formulas  
equations  
calculations
**MICRO**particles  
energy  
interactions

# Suggested answers

## Activity 1

Properties	Cyclohexane	Cyclohexene
odour	mild	strong
density ( $\text{g cm}^{-3}$ )	0.77	0.81
colour before addition of bromine water	colourless	colourless
colour after shaking with bromine water	colourless	colourless
colour of bromine water before addition	yellow	yellow
colour of water layer after shaking	yellow	colourless

- 1 The change in colour of bromine water from yellow to colourless when shaken with cyclohexene. The cyclohexane did not affect the colour of the bromine water.
- 2 Bromine water changes from yellow to colourless as the yellow bromine reacts.

## Reactivity of iodine water with food oils

**Aim:**

To compare the amount of saturation in olive oil and peanut oil by reaction with iodine water.

**Method:**

- 1 Add an equal amount of iodine water to the two test tubes.
- 2 Add about half the iodine water volume of baby oil, stopper the test tubes and shake vigorously up and down for ten seconds.
- 3 Add two drops each of olive oil and peanut oil to the separate test tubes; stopper and shake in the same way then compare colours.
- 4 If no colour change add a further two drops of oil to each test tube and repeat shaking.

**Result:**

The test tube containing olive oil was the first to lose its violet colour.

**Conclusion:**

Olive oil contains more unsaturated hydrocarbons than peanut oil.

**Activity 3: Tomato juice**

Red light is not absorbed by lycopene.

Bromine or iodine atoms can add to any carbons joined by double bonds changing the bonds between the carbons to single bonds. The removal of double bonds and their delocalised electrons (used to attach the bromine/iodine atoms) affects the parts of visible light that are absorbed. As more bromine/iodine atoms add to a lycopene molecule the colours absorbed, and therefore the colour reflected by a solid or transmitted by a solution, changes.

**Ethene, leaves, apples and bananas**

- 1 Dilute solutions of bromine/iodine were kept as a control – to see the rate at which other substances in the air react with bromine/iodine or the rate at which bromine/iodine escape from the solution into air.
- 2 No fruit was placed in one of the bags as a control eg. to see if chemicals released by the plastic bag affected the bromine/iodine solution.
- 3 Results will depend on the stage of ripeness of fruit, temperature, and so on. As the banana/apple ripen ethene may be released and react with the bromine/iodine decolourising the solution.

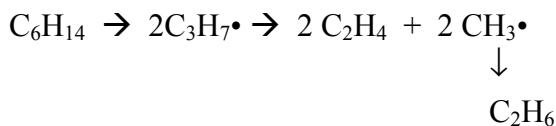
## Fuel or raw material?

Alkane	Formula	Use
methane	CH <sub>4</sub>	natural gas
ethane	C <sub>2</sub> H <sub>6</sub>	petrochemical
propane	C <sub>3</sub> H <sub>8</sub>	liquefied petroleum gas (LPG)
<i>butane</i>	C <sub>4</sub> H <sub>10</sub>	liquefied petroleum gas (LPG)
pentane	C <sub>5</sub> H <sub>12</sub>	petrol used in cold climates
<i>hexane</i>	C <sub>6</sub> H <sub>14</sub>	petrol used in cold climates
heptane	C <sub>7</sub> H <sub>16</sub>	petrol
octane	C <sub>8</sub> H <sub>18</sub>	petrol

## Steam cracking



## Ethene production in Australia



1 No catalyst or catalyst cleaning is required.

Steam reacts with and removes carbon deposits on inside of coils.

Ethene is the main product of steam cracking but only a by-product of catalytic cracking.

2 a)

$$\begin{array}{ccc} C_2H_6 & \rightarrow & C_2H_4 + H_2 \\ \text{molecular mass} & 30 & 28 \quad 2 \\ \text{mass formed} & 780 \text{ t} & ? \\ & & ? = (2/28) \times 780 \\ & & = 56 \text{ t} \end{array}$$

b) Applying conservation of mass  $1000 - 780 - 56 = 164 \text{ t}$   
 164 t of other substances besides the desired product C<sub>2</sub>H<sub>4</sub> and by-product H<sub>2</sub> could be produced.

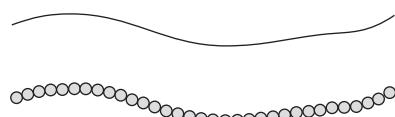
# Polymers

Z = H in ethene.

## Investigating LDPE and HDPE

- 1 Branched LDPE polymer chains are kept further apart. The lower density of LDPE enables it to float on the alcohol-water mixture.

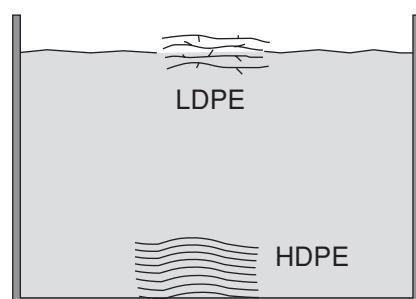
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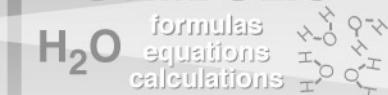
○ = C and attached Hs

- 3 Closer packing produces HDPE.
- 4 LDPE branched molecules cannot get close enough to attract and so can slip over one another and flex more easily.
- 5 HDPE unbranched molecules can get closer, bond more strongly through dispersion forces and form more compact crystals.

6



- 7 LDPE: garbage bags and bins, shampoo bottles, flexible black irrigation pipes, black agricultural sheets.  
HDPE: crinkly shopping bags, freezer bags, milk bottles and crates, buckets, rigid agricultural pipes.
- 8 HDPE has the greatest crystallinity.

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# Exercises – Part 1

Exercises 1.1 to 1.3

Name: \_\_\_\_\_

## Exercise 1.1: Petroleum fractions cracked to ethene

Complete the table below by naming the petroleum fractions.

Petroleum fraction	Hydro-carbons	Density g cm <sup>-3</sup>	BP range °C	Typical ethene yield %	Typical propene yield %	Typical methane yield %
	C3 – C4	–	–42 to 0	40	15	25
	C5 – C10	0.66	35 to 150	35	14	20
	C10–C30	0.82	185 to 335	27	13	12

Use the information in the table to complete the statements about the products of cracking.

- 1 The larger the cracked molecules the \_\_\_\_\_ the yield of both the smaller by-product \_\_\_\_\_ and the larger by-product \_\_\_\_\_.
- 2 The by-product \_\_\_\_\_ could be used as a fuel while the by-product \_\_\_\_\_ could be used to make polypropylene plastic.

## Exercise 1.2: Products from ethene

Ethene C<sub>2</sub>H<sub>4</sub> is very reactive and can be used to make a wide range of carbon compounds. Complete this table by completing the systematic names of:

Compound			Use
Common name	Systematic name	Structural formula	
ethylene oxide	1,2 epoxyethane	(CH <sub>2</sub> ) <sub>2</sub> O	steriliser
acetic acid		CH <sub>3</sub> COOH	preserving food
ethylene dichloride		ClCH <sub>2</sub> CH <sub>2</sub> Cl	fumigant
ethyl chloride	chloroethane	CH <sub>3</sub> CH <sub>2</sub> Cl	refrigerant
ethyl bromide		CH <sub>3</sub> CH <sub>2</sub> Br	refrigerant
ethyl alcohol		CH <sub>3</sub> CH <sub>2</sub> OH	disinfectant

Compounds are made from ethene by a variety of addition reactions such as:

- oxidation – addition of oxygen
- halogenation – addition of halogen
- hydrohalogenation – addition of hydrogen halide
- hydration – addition of water.

Use the common names in the table to complete these statements:

\_\_\_\_\_ and \_\_\_\_\_ are made by oxidation of ethene.

\_\_\_\_\_ is made by halogenation of ethene.

\_\_\_\_\_ is made by hydration of ethene.

\_\_\_\_\_ and \_\_\_\_\_ are made by hydrohalogenation of ethene.

### Exercise 1.3: Fossil fuel products

The table below shows, by mass, the top 40 chemicals produced in the USA in 1995.

- Use your chemical knowledge to decide which seven of these 40 chemicals are monomers produced for addition polymerisation.
- Tick the 24 chemicals, other than sodium carbonate, urea and carbon dioxide, which contain carbon and are fossil fuel products.
- Put HC in the number column for each hydrocarbon.

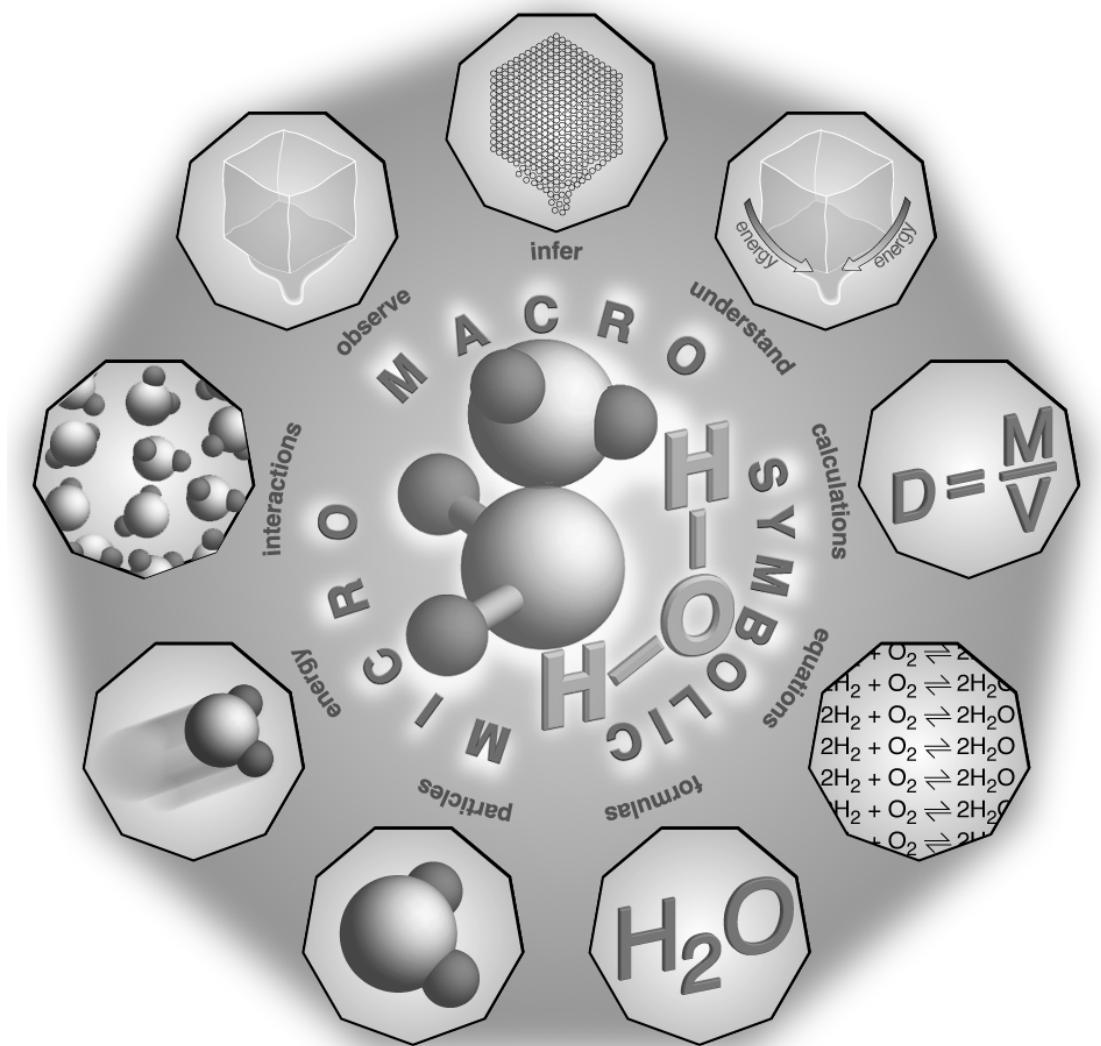
1	sulfuric acid $43 \times 10^6$ tonnes	21	methanol $5.1 \times 10^6$ tonnes
2	nitrogen	22	carbon dioxide
3	oxygen	23	xylene $C_8H_{10}$
4	ethylene	24	formaldehyde HCHO
5	lime	25	dimethyl terephthalate $C_{10}H_{10}O_4$
6	ammonia	26	ethylene oxide
7	phosphoric acid	27	hydrochloric acid
8	sodium hydroxide	28	toluene $C_7H_8$
9	propylene	29	p-xylene $C_8H_{10}$
10	chlorine $11 \times 10^6$ tonnes	30	cumene $C_9H_{12}$ $2.6 \times 10^6$ tonnes
11	sodium carbonate	31	ammonium sulfate
12	methyl tert-butylether $C_5H_{12}O$	32	ethylene glycol
13	ethylene dichloride	33	acetic acid
14	nitric acid	34	phenol $C_6H_5OH$
15	urea $(NH_2)_2CO$	35	propylene oxide
16	ammonium nitrate	36	1,3-butadiene
17	benzene $C_6H_6$	37	carbon black
18	vinyl chloride	38	isobutylene
19	ethylbenzene $C_8H_{11}$	39	potash
20	styrene $5.2 \times 10^6$ tonnes	40	acrylonitrile $1.5 \times 10^6$ tonnes





# The identification and production of materials

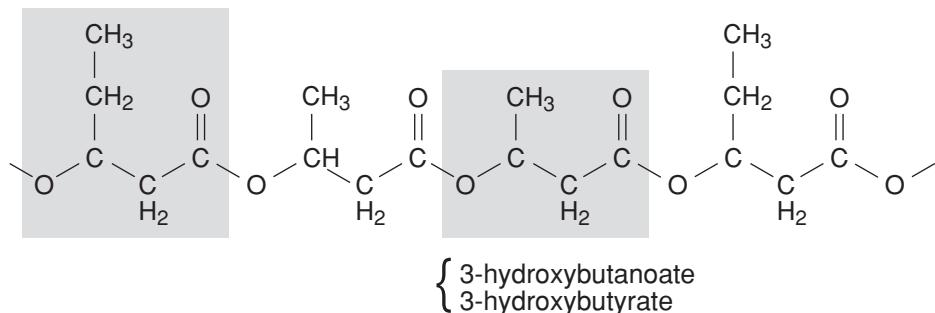
## Part 2: Biomass to biopolymers



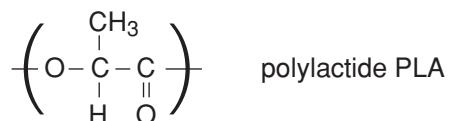
# Biopolymers

Biopol - a mixture of PHB and PHV

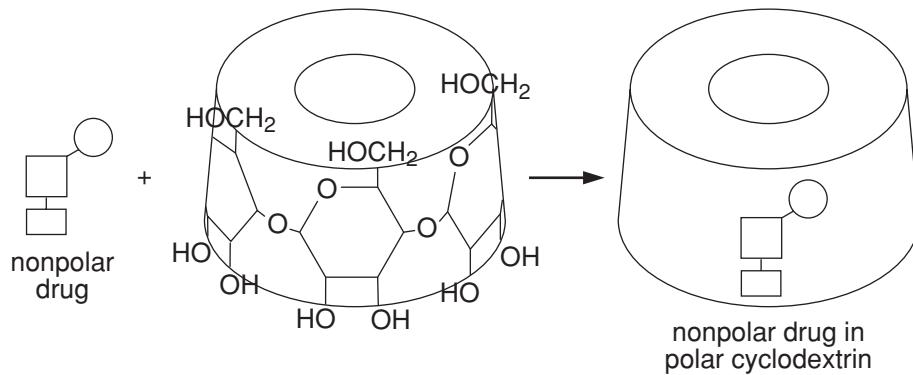
{ 3-hydroxyvalerate  
3-hydroxypentanoate



PLA - polylactide



Cyclodextrin



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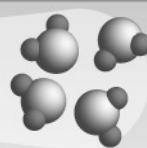
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# Introduction

The limitations of using non-renewable resources such as fossils fuels for both energy and raw materials have alerted society to the importance of reducing dependence on fossil fuels. Recently there has been increased support of scientific research into the use of renewable resources such as biomass.

**Biomass** is any organic matter produced by photosynthetic conversion of light energy to chemical energy. Provided the matter involved is recycled, biomass could be a source of raw materials and energy for as long as the sun supplies Earth with solar energy.

In Part 2 you will be given opportunities to learn to:

- discuss the need for alternative sources of the compounds presently obtained from the petrochemical industry
- explain what is meant by a condensation polymer and describe the reaction involved when a condensation polymer is formed
- describe the structure of cellulose and identify it as an example of a condensation polymer found as a major component of biomass
- identify that cellulose contains the basic carbon-chain structures needed to build petrochemicals and discuss its potential as a raw material
- assess current developments in the use of biopolymers and describe a process currently used industrially to produce polymers

In Part 2 you will be given opportunities to:

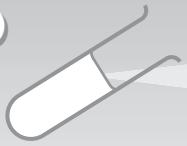
- solve problems and perform a first-hand investigation to identify cellulose and analyse information to examine the effect of decay bacteria on cellulose
- process data from secondary sources to analyse the efficiency of conversion of plant material to ethanol

- use available evidence to gather, process and present data from secondary sources and analyse progress in the 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.

*Extracts from Chemistry Stage 6 Syllabus* (Board of Studies NSW, originally issued 1999. The most up-to-date version is to be found at [http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

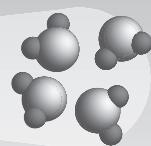
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# Cellulose



In this activity you will be investigating cellulose.

### What you will need:

- a fresh stick of celery with a leafy top
- access to clean water
- some transparent adhesive tape and a piece of newspaper
- hand lens or magnifying glass
- tincture of iodine solution and a dropper bottle
- a glass or plastic container
- a filter paper.

### Method and results:

- 1 Break off or cut off the top half of the celery stick.
- 2 Place the top half with a leafy top in a glass or plastic container containing a few millilitres of tincture of iodine solution; you may need to have the leaves at the top of the celery stick lean against something so the beaker/container does not fall over.
- 3 Wash the bottom half of the celery stick with clean water and then start chewing it. Do all parts of the celery stick taste and chew the same or do you notice differences?

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Draw the chewed end of the celery stick

In some parts of the world chewed ends of sticks are used as toothbrushes. How clean do your teeth feel now? \_\_\_\_\_

- 4 Take a strip of adhesive tape and place the sticky surface onto a piece of newspaper. Pull the adhesive tape off the newspaper. Can you see cellulose fibres attached to the adhesive tape? A hand lens or magnifying glass could be useful here. Draw what you can see and include information to show the estimated size of the fibres.
- 5 Tear the edge off a filter paper. Draw what you can see at the torn edge and include information to show the size of any fibres.
- 6 Place a drop of tincture of iodine on an unprinted part of the newspaper and on part of the filter paper. Describe what happens.

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- 7 Place the edge of the newspaper and the edge of the filter paper in some water. Observe what happens, as water moves to, through and beyond the iodine spots.

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- 8 Lift the end of the celery stick out of the tincture of iodine solution, wash it with water, then draw what you can see. Once again include information on size in your diagram.

### **Discussion:**

You only need the same word five times to complete this discussion of your activity.

You have just been investigating:

- the \_\_\_\_\_ tubes in a stem that carry liquid from roots to leaves
- the \_\_\_\_\_ rich parts of celery that are hard to eat but do a good job of cleaning your teeth
- the fibres of \_\_\_\_\_ that make up a newspaper
- the fibres of \_\_\_\_\_ that make up a filter paper and trap insoluble residue during filtration
- the fibres of \_\_\_\_\_, which although insoluble in water, are able to attract water molecules and draw them upwards by capillary action.

The answer is the chemical that is formed by polymerisation of approximately half of the glucose produced in photosynthesis.

$5 \times 10^{11}$  tonnes of the plant material produced on land each year by photosynthetic fixation of CO<sub>2</sub> comprises this chemical – cellulose.

A cellulose molecule C<sub>x</sub>(H<sub>2</sub>O)<sub>y</sub> contains between 500 and 14 000 glucose C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> units and is flat and rigid – ideal as a construction material for the cell walls of plants and bacteria.

## **Identifying cellulose**

Identifying cellulose chemically is difficult, especially in the presence of starch. Iodine solution turns both pure starch and cellulose that has been treated with concentrated sulfuric acid dark blue.

Most dry plant material is up to 50% cellulose and up to 5% starch.

Testing plant material for cellulose by adding concentrated sulfuric acid then iodine solution is not a satisfactory test.



Explain why testing plant material for cellulose with concentrated sulfuric acid and iodine solution is not a satisfactory test.

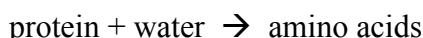
Check your answer.

Earlier you should have chewed and swallowed some celery stick.

By mass your body would have obtained about:

- 95% water
- 2% carbohydrates such as starch and sugars
- 2% cellulose
- 1% protein.

Enzymes for digestion in your mouth, stomach and intestines are able to catalyse the reaction of water with the polymer molecules of starch and protein:



The small water soluble glucose and amino acid molecules produced can be absorbed into the blood stream and provide nourishment to your body.

Cellulose fibres cannot be digested by enzymes in the human digestive system. They pass to the outside as fibre, undigested material, in the faeces. Even though this fibre is undigested it is considered to be an important part of the human diet that keeps intestinal muscles well-exercised. The condition of muscles on the inside of your body in your heart and digestive system are more important to your health than any muscle displayed on the outside of your body.

Certain bacteria and fungi, not found in humans, are able to produce enzymes called **cellulases** that can break down the water insoluble cellulose polymer. These bacteria are important in enabling grass eating animals to live on grass while the fungi are important in decomposing wood. If you pick up a piece of wood that has had fungi digesting its cellulose the wood feels very light.

Remember that carbohydrate names often end in -ose while enzyme names usually end in -ase. Cellulose is a carbohydrate while cellulase is an enzyme that acts on cellulose.



Using an example explain why correct spelling of chemical names is so important in chemistry.

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Check your answer.

## Decay of plant material



**Activity 1:** In this activity you will be measuring decay using iodine solution.

Starch is found in most plant material and is one of the first compounds to be decayed by bacteria. If plant material is mixed with earth and starts to decay the extent of decay can be measured by the amount of soluble starch in run-off. This method could be used to monitor the decay of buried plant material on a hillside where rapid decay could cause slippage.

As you learnt in Part 1, soluble starch reacts with iodine producing a dark blue complex. When run-off does not react with yellow iodine water to produce this blue colour the decay of starch by bacteria must be complete. The intensity of blue colour obtained is a rough indicator of the amount of soluble starch in the run-off.

### What you will need:

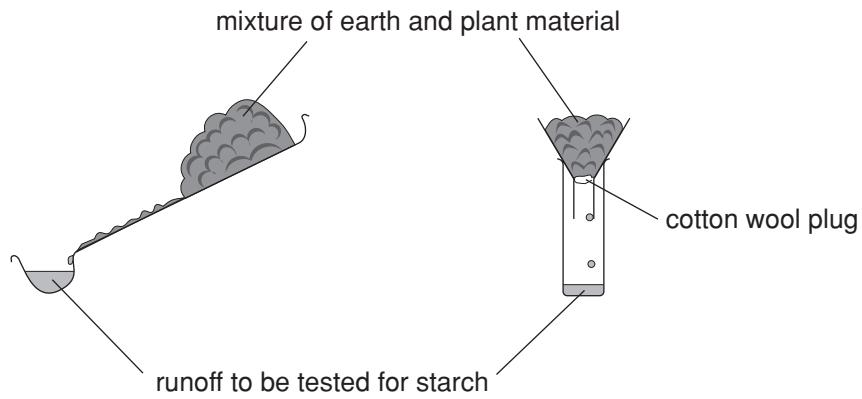
- well-mixed mound of approximately 50% earth and 50% plant material; make sure some of the earth is from a place where plants decompose such as leaf litter, under rotting wood or from a compost heap
- a tray – an old paint roller tray would be best – or a funnel with a cotton wool plug to hold the mixture above a container
- liquid volume measuring device able to hold up to 100 mL water for the tray or 10 mL water for the funnel
- tincture of iodine solution diluted to one tenth normal concentration in a dropper bottle
- small glass or plastic container or test tube for collecting and testing run-off.

### Method:

- 1 Pile the mixture of approximately 50% earth and 50% plant material onto the tray. Tilt the tray slightly so that any water poured onto the pile will run through the pile and out to the end. A paint roller tray is best as run-off will collect in the end where a paint roller goes.

OR

Fill a funnel within a centimetre of its top with a mixture of approximately 50% earth and 50% plant material. Place a container or test tube underneath the funnel outlet.



- 2 Once a day pour water over the mound or into the top of the funnel. Collect run-off that collects in the tray or container and test for the presence of starch using the iodine test.

Try to control the conditions by:

- pouring the water in the same way each day
- allowing the same amount of time (eg. an hour) before collecting runoff and testing the same amount of run-off with the same amount of iodine solution.

A tray may require 100 mL of water a day while a funnel may require only 10 mL of water a day to obtain sufficient run-off to test.

- 3 Record the results for at least a week and perhaps two weeks if there is no change in the test result.

## Results

Design a table to record and compare your results

## **Conclusions:**

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**Activity 2:** In this activity you will be measuring decay using cellulase and Clinistix™.

Although there is no specific chemical test for cellulose the amount of cellulose decay can be measured using cellulase, then testing for the glucose produced.

Cellulase can be purchased from some biological suppliers. One form of cellulose is as granules based on cellulase concentrate from *Trichoderma reesei* organisms. This is used as a viscosity reducing enzyme in mixtures bought by bakers for products such as pancakes, waffles and donuts. The cellulase breaks cellulose down to glucose.

Glucose can be detected using Clinistix™ which are available from pharmacies for testing glucose in urine. The presence of glucose in urine is an indicator of diabetes. The Clinistix™ colour changes according to the concentration of glucose in a solution (this colour change depends on reactions involving enzymes called glucose oxidase and peroxidase). Glucose test tape cannot be used because it is paper cellulose based. The cellulase will react with the cellulose of the paper and give misleading results.

### **What you will need**

- filter paper (practically pure cellulose)
- cellulase
- Clinistix™ strips [\$10-15 per 100 strips from a pharmacy]
- three glass or plastic containers.

### **Method**

- 1 Add dry cellulase to water to produce a slurry.
- 2 Tear a filter paper up into small pieces to increase its surface area. Set up two containers with equal amounts of filter paper.
- 3 Read the remaining steps 4 and 5 then design a table to compare and record results.

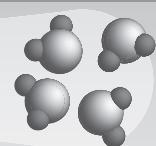
- 4 Add the cellulase slurry to the filter paper in one container. Add water to both containers so the paper is covered with the same amount of liquid. The container without the cellulase is the control. Place the containers in a warm location. Cellulase acts best at a temperature of about 50°C.
- 5 Every five minutes test each container for the presence of glucose by dipping the sensitive end of a Clinistix™ strip in to the liquid. Read the instructions carefully as you need to record the colour exactly 10 seconds after the strip is immersed in the liquid. A new strip must be used each time you test a solution.
- 6 After 30 minutes finish testing. Look carefully at the liquid in the two containers. Can you see small cellulose fibres floating in the liquid. Is there any difference between the cellulose fibres in the cellulase container and the control container?

## Results

## Conclusions



If you would like to see scanning electron microscope images of the changes that occur on filter paper digested by cellulase producing bacteria go to [www.lmpc.edu.au/science](http://www.lmpc.edu.au/science) for a link.

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## Biomass to energy conversion

The amount of energy captured by biosynthetic conversion of light energy to chemical energy is probably ‘an order of magnitude’ greater than the amount of energy used by the world’s human population.

[Do you remember that order of magnitude refers to powers of 10?  $10^2$  is one order of magnitude greater than  $10^1$  while  $10^4$  is three orders of magnitude greater than  $10^1$ . ‘an order of magnitude’ greater means about 10 times larger.]

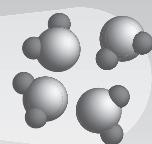
In other words there is about ten times as much energy stored in plants than is required for the activities requiring energy of over six billion human beings. Only about 5% of a typical crop plant is harvested as food. If the energy stored in the remaining, largely unused 95% of crop plants could be converted to energy this would reduce human dependence on fossil fuel energy resources significantly.

The energy stored in carbon compounds in biomass could be released by:

- burning dry plants or plant products instead of fossil fuels in electric power stations eg. waste wood from forestry, straw and grain husks from cereal grains, crushed cane after cane sugar extraction
- converting cellulose to methane using anaerobic bacteria eg. animal waste from intensive animal farming such as pigs and chickens, cattle dung from meat or dairy production; the methane can be burnt as an impure gaseous fuel.
- converting starches and sugars in cereals or sugar cane to ethanol by fermentation; the ethanol needs to be separated from an ethanol rich water fermentation mix before use in internal combustion engines

All of these methods have been tried in Australia but many of them are uneconomic when fossil fuels are so readily available and cheap. The gathering of dry plants or plant products requires input of fossil fuel to operate machinery and transport, waste cellulose digesters require construction of collection channels from intensive animal farms and considerable energy is required to separate ethanol from fermentation mixes by distillation.

As non-renewable fossil fuels become more difficult to obtain and more expensive, greater use may be made of renewable biomass as an energy source. Countries trying to reduce dependence on imports of fossil fuels, such as in the United States and Brazil, are often prepared to subsidise biomass to energy conversion.

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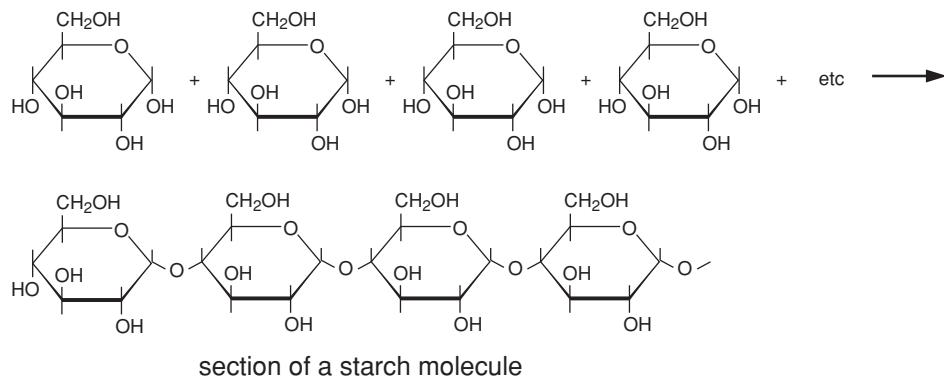
# Condensation polymers

Condensation polymers are formed by monomer molecules reacting together and eliminating (condensing out) small molecules such as water.

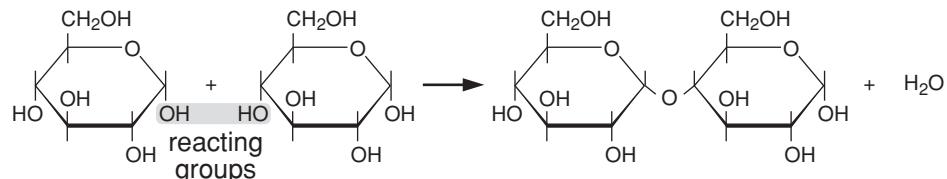
Plants use the glucose produced by photosynthesis to form the condensation polymers starch and cellulose.



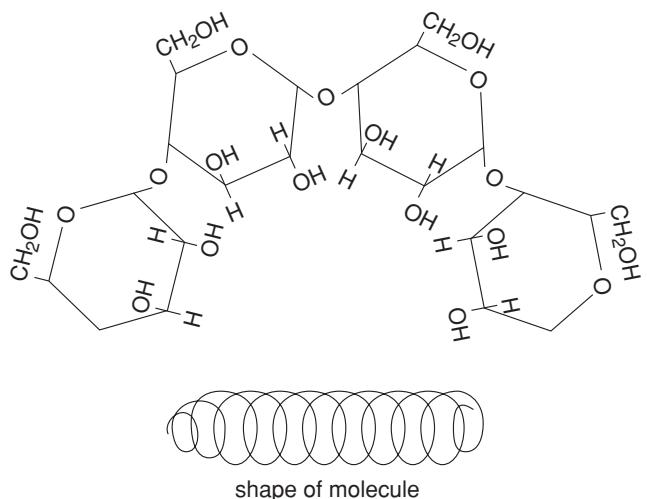
monomer  $\rightarrow$  polymer + water



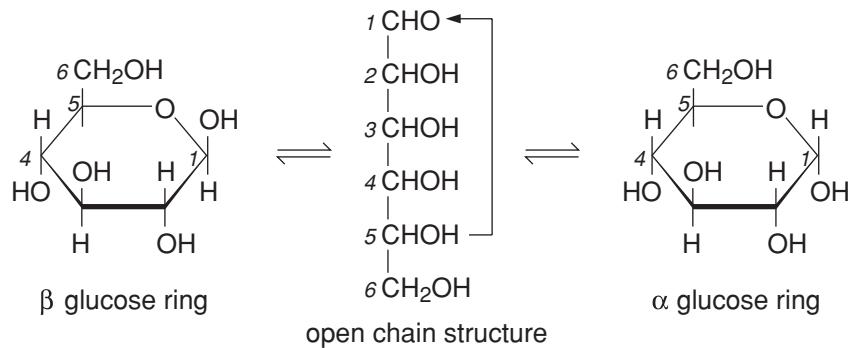
Two hydroxy groups on adjoining glucose molecules react condensing out a water molecule.



In the water soluble amylose form of starch the  $\text{CH}_2\text{OH}$  groups of the glucose units are on the same side and a spiral structure forms. Every six glucose units there is one turn of the spiral. A large number of hydroxy groups  $\text{OH}$  are available on the inside and outside of the spiral to bond with water molecules and so the starch is water soluble.

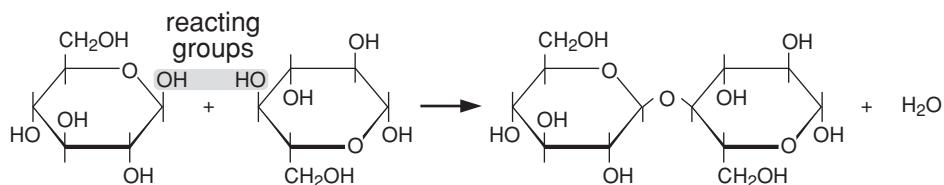


A glucose molecule can exist as an open chain structure or in two closed ring structures known as  $\alpha$ -glucose (alpha glucose) and  $\beta$ -glucose (beta glucose). In a glucose solution all three structures are present and there is rapid conversion between the three structures.

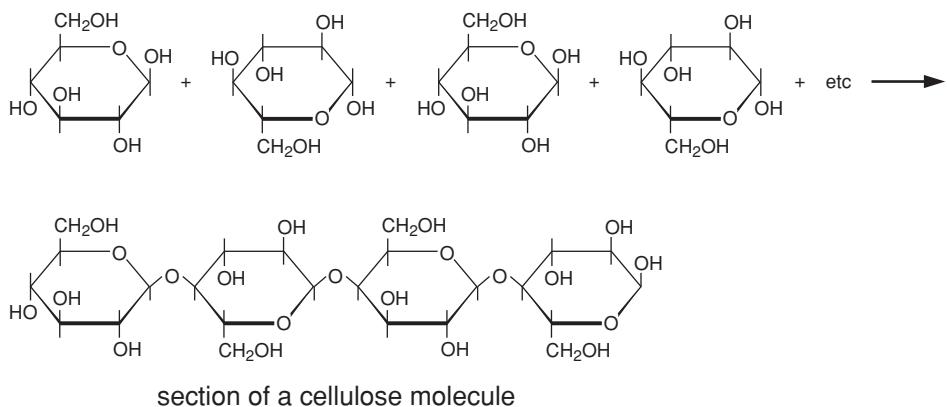


Number carbons 2 and 3 in the ring diagrams.

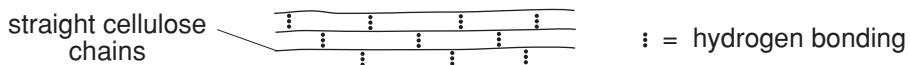
Starch is formed from  $\alpha$ -glucose (alpha glucose) but cellulose forms from  $\beta$ -glucose.  $\beta$ -glucose (beta glucose) differs from  $\alpha$ -glucose in the arrangement of the hydroxy group around carbon number 1. For two  $\beta$ -glucose molecules to join one molecule needs to be upside down relative to the other molecule.



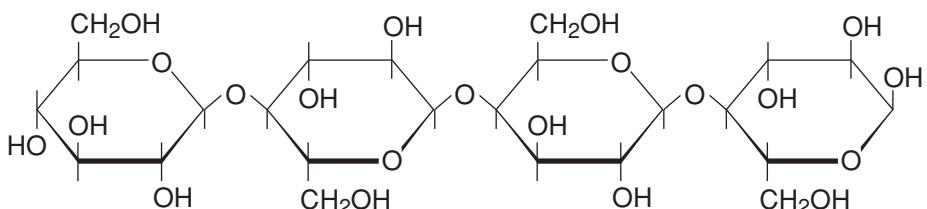
Cellulose is a flat, straight and rigid molecule because the bulky  $CH_2OH$  groups are on alternate sides of adjoining glucose units.



Many of the hydroxy groups are available to hydrogen bond cellulose molecules together side by side.



This forms long strong cellulose fibres that make wood such a strong building material. The reduced availability of hydroxy groups for bonding with water and the joining of cellulose molecules together to form very large aggregations of molecules in fibres makes cellulose insoluble in water. The high degree of hydrogen bonding between chains of cellulose also makes it much more resistant to chemical attack. The hydrogen bonding between the cellulose chains makes the polymer rigid. This reduces the flexing of the chains required in the hydrolysis that breaks the glucose units apart.



-  a) In what ways is the structure of cellulose similar to hydrocarbons from petroleum?

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- b) In what ways is the structure of cellulose different from hydrocarbons?

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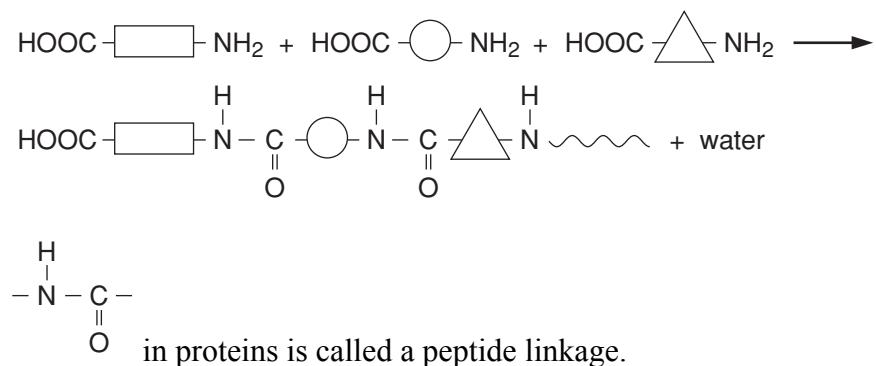
- c) Which of the hydrocarbons you studied in Part 1 of this module is most like cellulose?
- 

Check your answers.

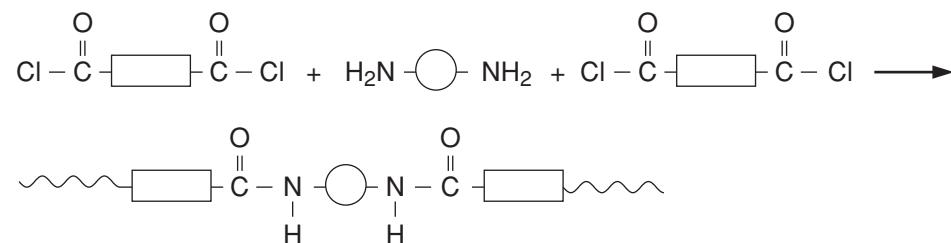
Proteins are also condensation polymers:

amino acids → protein + water

Each amino acid has an amino group –NH<sub>2</sub> and an acid group –COOH. Up to 23 different amino acids can be found in a protein. Ten of the 23 are called essential amino acids because they must be part of an animal's diet (eaten as the amino acid or as part of proteins) for proper growth. The other 13 amino acids can be synthesized by the animal from other chemicals in its diet.



Synthetic condensation polymers such as nylon and kevlar also have the same NHCO linkage. The linkage is called an amide linkage and the polymers are called polyamides  
formation of a polyamide (in this case a nylon)



When this nylon condensation polymer is formed the by-product is not water. What is the by-product?

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Check your answer.



Complete Exercise 2.1: *Making polymers*.

## Starch and cellulose molecules



### What you will need:

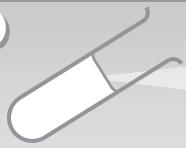
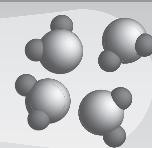
- metal wire (bare or plastic covered) – at least 1 m length
- means of cutting the metal wire eg. pliers
- plasticine or Blu-tack®.

### What you will do:

- 1 Cut the metal wire in half and then in half again. Wind a quarter length around a pencil/ballpoint pen then slide the pencil/ballpoint pen out. Repeat this procedure to make another spiral. Are these spirals modelling starch or cellulose? \_\_\_\_\_
- 2 Cut the remaining metal wire into 10 cm lengths. Place the lengths side by side then join the lengths together at different points using plasticine or Blu-tack®. Would this model or the previous model be best as reinforcing in a structure? \_\_\_\_\_
- 3 Design a simple test of the structural strength of these two different models. Describe your test:
- 4 The colour of iodine depends very much on its surroundings. Concentrated iodine water is brown, dilute iodine water is yellow and iodine in saturated oils such as baby oil is violet. When iodine enters the spiral of a starch molecule interactions between the electrons of iodine and the starch produce a dark blue colour. If cellulose is treated with concentrated sulfuric acid and then iodine solution a dark blue colour is produced. What structural change do you think the concentrated sulfuric acid could produce in the cellulose molecules?



Complete Exercise 2.2: *Ironing, cellulose and water*.

**MACRO**observe  
infer  
understand**SYMBOLIC**
 $H_2O$  formulas  
equations  
calculations
**MICRO**particles  
energy  
interactions

## Biomass to raw material conversion

Dried plant material typically consists of 60% cellulose, 20% lignin, 10% protein, 5% sugars and starches and 5% miscellaneous chemicals including fats, oils and waxes.

Bacteria and fungi quickly decompose the protein, sugars and starches.

Some bacteria secrete cellulases which react water with the high molecular weight cellulose molecules to produce glucose.

Fermenting **anaerobic** bacteria then change the glucose to the C4 to C1 **alkanoic acids** and carbon dioxide and hydrogen gases.

Molecular formula	Systematic name	Alternative names
RCOOH	alkanoic acid	~~~~~ic acid/alkanoate
HCOOH	methanoic acid	formic acid/formate
CH <sub>3</sub> COOH	ethanoic acid	acetic acid/acetate
CH <sub>3</sub> CH <sub>2</sub> COOH	propanoic acid	propionic acid/propionate
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOH	butanoic acid	butyric acid/butyrate

Anaerobic **methanogen** bacteria react the carbon dioxide and hydrogen gases to form methane and water:



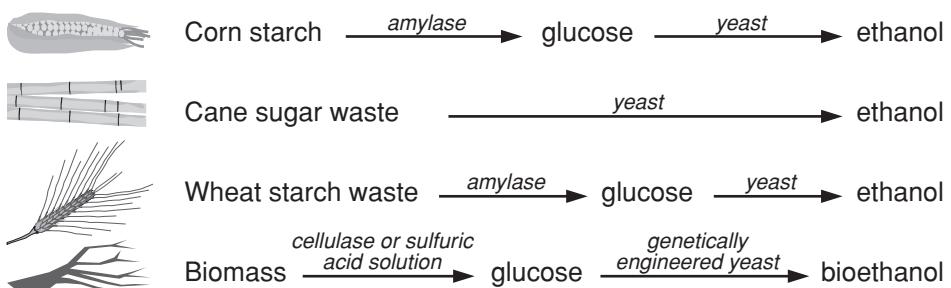
- 1 Is this reaction exothermic or endothermic? \_\_\_\_\_
- 2 The energy released by this reaction is used by the methanogen bacteria as their main energy source. Methane gas is sometimes called marsh gas as bubbles of methane are released at the surface of marshes.  
Where in the marsh do you think the methanogen bacteria are found?  
\_\_\_\_\_

- 3 Use the information provided above to draw a flow chart showing how the carbohydrate cellulose can be changed to the hydrocarbon methane and to alkanoic acids. Use a blank sheet of your own for the drawing.

Check your answer.

## Converting plant material to ethanol

There are a number of methods of converting plant materials to ethanol:



**Bioethanol** is ethanol produced from cellulose in biomass, rather than starch or sugar in biomass. Bioethanol is the same chemical as ethanol,  $\text{C}_2\text{H}_5\text{OH}$ . Bioethanol is simply ethanol that has been obtained, with greater difficulty, from the more plentiful resource cellulose.

The ethanol produced is a valuable raw material for producing other chemicals. For example dehydration of ethanol  $\text{C}_2\text{H}_5\text{OH} \rightarrow \text{C}_2\text{H}_4 + \text{H}_2\text{O}$  produces ethene. Ethene can be polymerised or used to make other polymer monomers. Thus renewable biomass is converted to ethene which normally comes from non-renewable petroleum.



Use this information to complete the following sentences:

- 1 **Amylase** is an enzyme which hydrolyses the polymer starch to form the monomer \_\_\_\_\_.
- 2 Cellulase is an enzyme which hydrolyses the polymer \_\_\_\_\_ to form sugar monomers.
- 3 The names of \_\_\_\_\_ usually end in the letters 'ase'
- 4 The names of carbohydrates such as glucose, sucrose, amylose and cellulose usually end in the letters '\_\_\_\_\_.'
- 5 Enzymes from yeast are used to convert glucose to \_\_\_\_\_.
- 6 The method which is used for waste wood uses the enzyme \_\_\_\_\_ or \_\_\_\_\_ acid.

- 7 One of these four methods shown in the diagram is based on recent developments in technology. Name the method which is a recent development and justify your answer.

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- 8 Use a search engine such as <http://www.google.com> or <http://www.northernlight.com> to find out which of the above processes is carried out by the following:

- a) The Manildra Group at Nowra, NSW, Australia.

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- b) CSR at Sarina, Queensland, Australia.

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- 9 Disposal of solid waste (garbage) is a major problem for cities throughout the world. One of the four methods of converting plant material to ethanol has been suggested as being appropriate for solid waste disposal sites near cities. The ethanol produced could be used as a fuel for city motor vehicles as ethanol is 35% oxygen by mass. This oxygen enhances the burning of petrol resulting in more efficient burning and reduced exhaust emissions.

- Predict which of the four methods is a possible future direction of chemical research on solid waste disposal by cities
- Justify your prediction.
- Identify the two most suitable starting materials for this process present in solid waste that is a mixture of plastic, paper, metal, glass and food scraps.

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Check your answers.

## Efficiency of conversion of plant material

In the year 2000 production methods for converting carbohydrates to ethanol cost 50–60 Australian cents per litre of ethanol produced. At present there is no government subsidy in Australia for ethanol used by cars. To be economically competitive with petrol the production of ethanol needs to be made more efficient so that production costs decrease to 30–35 Australian cents per litre. A car using petranol, a mixture of 85% petrol and 15% ethanol, produces less pollutants than a car using 100% petrol.

In the USA where a higher proportion of petroleum has to be imported than in Australia (USA has 3% of world's oil reserves while consuming 25% of the world's oil), government subsidies lower the price of ethanol. Brazil has reduced its dependence on large imports of petroleum by using its vast land resources and sugar cane production to produce ethanol.

Efficiency of conversion of plant carbohydrate to ethanol

Plant material	% converted to ethanol
sugar beet	86
sugar cane	66
potato starch	59
cassava starch	50
maize (corn) starch	25



Analyse (draw out and relate implications) the previous page of information and your general knowledge to explain why Brazil uses sugar cane (66% converted to ethanol) rather than sugar beet (86% converted to ethanol) for ethanol production.

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Check your answer.

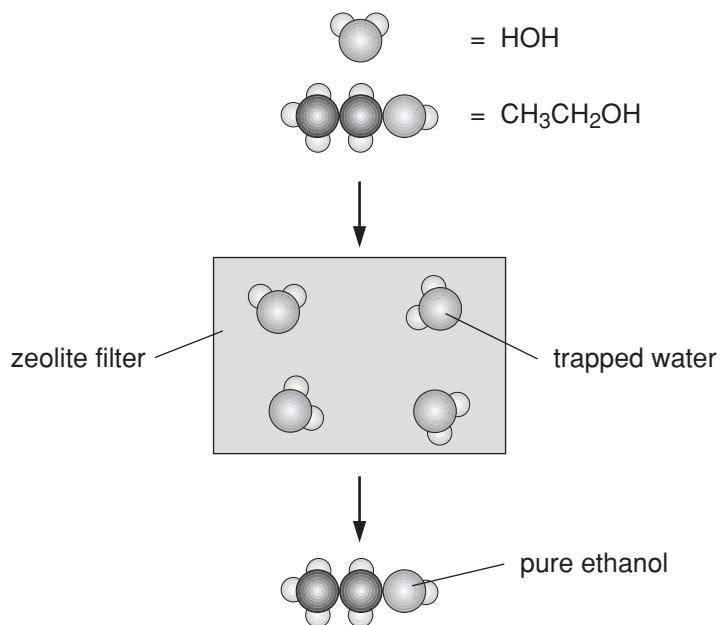
Research is trying to improve the efficiency in all three stages: **pretreatment, bioconversion** and product recovery.

- 1 Pretreatment of raw materials, eg. by shredding, steam pressure, acid hydrolysis, makes the carbohydrates more readily available to microbes

- 2 Bioconversion is fermentation of carbohydrate by bacteria or yeast to change biomass to product
- 3 Product recovery is separation of the ethanol from the fermentation mixture.

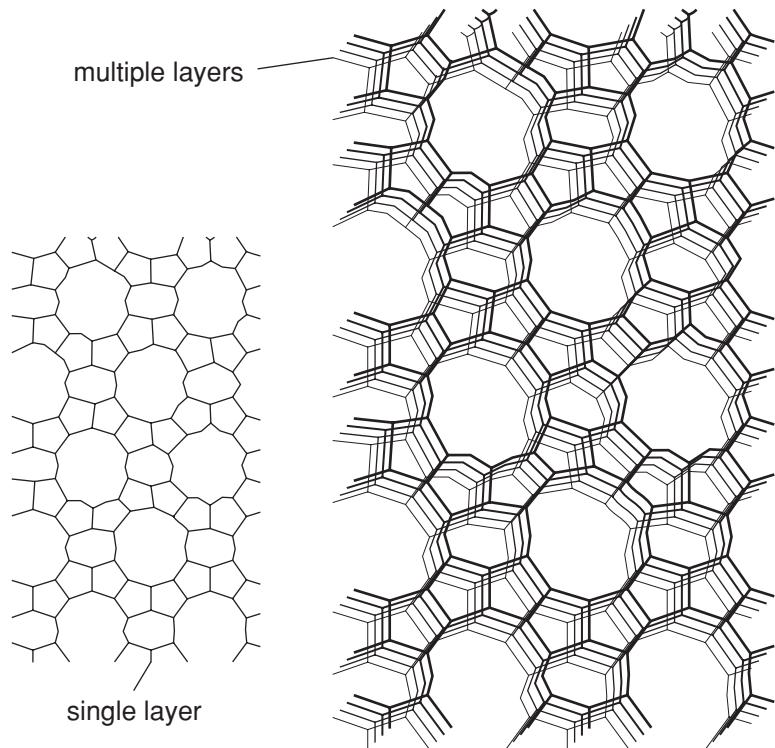
Here are some examples of current research directions:

- The biomass is a porous solid material so research is focussed on ways of improving movement of water and acid from solution into the solid and movement of sugars out of solid into the solution.
- Major advances have been made by genetic modification of a bacterium called *Zymomonas mobilis*. This bacterium has a shorter fermentation time (three or four times faster than yeast) and produces more ethanol per kg of plant material than yeast. At present cellulase enzymes cost about 20 Australian cents per litre of ethanol produced.
- Distillation of ethanol from the fermentation mixture can require half the energy released when the ethanol is used as a fuel. Distillation is being replaced by low energy methods such as using solid zeolite minerals as filters to separate ethanol from fermentation mixtures.



The trapped water molecules are strongly attracted to polar parts of the zeolite.

Zeolite (metal aluminium silicates) filters are also called molecular sieves if they separate mixtures without trapping by using a pore size that one molecule can pass through but others cannot. Different metal ions in zeolite structures produce different pore sizes.



Zeolite structure showing pores.



Use websites at [www.lmpc.edu.au/science](http://www.lmpc.edu.au/science) or Internet search engines to process data on the conversion of plant material to ethanol. Use the current cost of a barrel of oil on world petroleum markets to analyse (draw out and relate implications) the future importance of:

- petroleum
- conversion of plant material to ethanol
- oil shales and tar sands.

## MACRO

observe  
infer  
understand



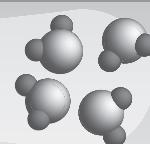
## SYMBOLIC

$H_2O$  formulas  
equations  
calculations



## MICRO

particles  
energy  
interactions



# Biopolymers

Most plastics are **non-degradable** polymers made from petrochemicals. Serious environmental problems are posed by the steady increase in plastics production and the resistance of plastics to degradation. Non-degradable plastics are accumulating globally at the rate of over 25 million tonnes per year. In 1992 nearly one million tonnes of plastics were consumed in Australia but only 6% of these were recycled.



Examine your solid waste disposal (garbage). Estimate the % of this volume that is plastic. \_\_\_\_\_

How does this compare with United States estimates that one fifth of the volume of solid waste in landfill sites is plastic? \_\_\_\_\_

Find out the plastics that are recycled in your area. Just because a plastic material has a recycling symbol it does not necessarily mean that there is a recycling program in your area.



- 1 World production of non-degradable plastics is over 100 million tonnes per year but accumulation in landfill sites and the environment is only about a quarter this rate. How is most plastic waste disposed of so it does not accumulate?  
\_\_\_\_\_
  
- 2 Explain a disadvantage of the main disposal method.  
\_\_\_\_\_

Check your answer.

It has been estimated that over one million marine animals are killed every year by either choking on plastics they mistook as food or becoming entangled in non-degradable plastic debris. In the oceans a LDPE plastic bag can last for nearly twenty years while a HDPE film container lasts over fifty years. If swallowed by a marine animal the non-biodegradable plastic is released back into the environment after the animal dies and the biodegradable polymers of its dead body decay.

A plastic bag in the ocean can act as a serial killer! The global Maritime Pollution Treaty (MARPOL) has forbidden the disposal of plastics at sea since 1994. Make sure you dispose of plastic responsibly, especially if you live near the coast or waterways.



Signs used by various councils in Sydney read:

‘This leads to Sydney Harbour or Part of the Lane Cove River catchment.’

Account for (state reasons for or report on) the use of these signs.

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Check your answer.

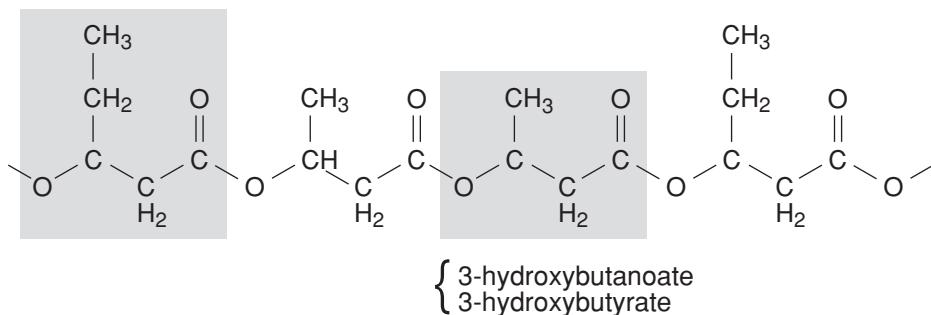
Many of the problems arising from careless disposal of plastic could be overcome by greater use of **biopolymers**. Biopolymers are naturally occurring polymers generated using renewable resources like microorganisms or plants. Most importantly biopolymers are biodegradable, that is, decomposed by living things. The biopolymer cellulose in wood is degraded by fungi and some bacteria while most animals (including yourself) and most bacteria produce enzymes capable of degrading the biopolymer starch to the sugar glucose.

Considerable effort is going into replacing non-degradable polymers with biodegradable biopolymers. eg. the environmental group Greenpeace has a credit card made from the biopolymer Biopol rather than commonly used PVC.

Polyhydroxyalkanoates (PHA) or ‘bacterial plastics’ such as Biopol are extracted from bacteria. Biopol is a mixture of polyhydroxybutyrate (PHB) and polyhydroxyvalerate (PHV) extracted from the bacterium *Alcaligenes eutrophus*. Biopol is a thermoplastic, stable in air and humid conditions, and able to degrade in anaerobic conditions such as landfills.

The bacteria are grown in a glucose and valeric acid rich solution. Just as some human beings placed in a food rich environment eat too much and store energy rich carbon compounds as fat so the bacteria store energy as PHB and PHV. The PHB-PHV **copolymer** can make up over 80% of the mass of dried bacteria. Hot liquid chloroform (trichloromethane)  $\text{CHCl}_3$  is used to dissolve the copolymer and evaporated off to leave copolymer granules. The copolymer is injection moulded into plastic items likely to be left in the environment such as golf tees, fishing line and nets and agricultural film sheets.

{ 3-hydroxyvalerate  
3-hydroxypentanoate



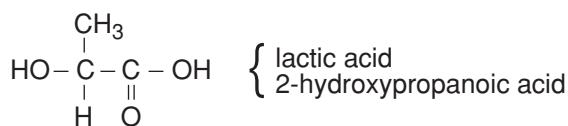
Biopol.

Plates made from PHA based plastics can be left in place to help heal fractured bones; after healing the PHA based plastic slowly and safely breaks down in the body. PHB has similar MP, molecular mass, crystallinity and tensile strength to petroleum derived polypropylene PP, the plastic used for climbing ropes and Australian currency notes.

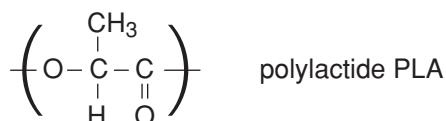


Should all non-biodegradable polymers be replaced with biodegradable polymers? Because PHB has similar properties to PP should Australian currency notes be made from biodegradable PHB instead of non-biodegradable PP?

Polylactic acid or polylactide (PLA) is made from carbohydrates such as corn starch, waste potato starch and cheese waste.



Many units of lactic acid monomer joined together produce polylactic acid/polylactide:

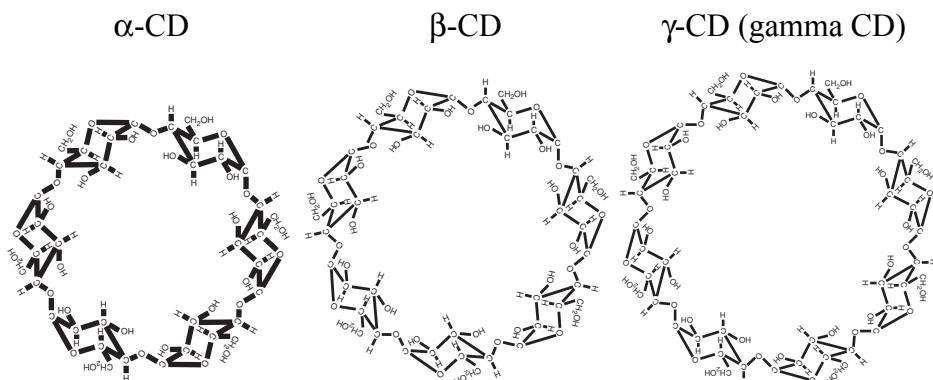


The bacteria used are similar to the bacteria that change lactose sugar in milk to lactic acid in order to make yoghurt. Fossil fuel is still used to grow and collect the corn, potatoes and milk but the amount of fossil fuel required is about half of that needed to produce petrochemical based polymers. PLA polymers can be composted and burn like paper or cellulose producing few byproducts and little ash. PLAs have been used in fabrics for clothing, carpets and outdoor awnings.

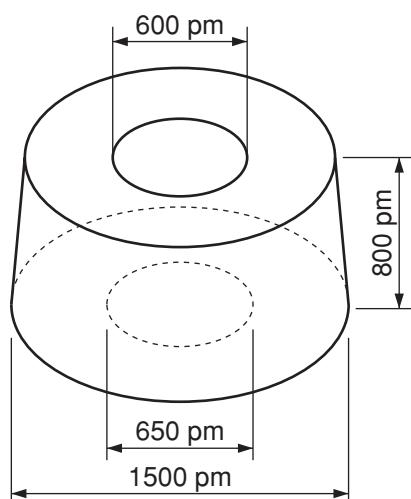


Go outside and see if you can find an old spider web. Around lights that attract insects or outside windows are good places to look. Being careful of spiders, collect a small amount of material from an old web on your fingers. Test its strength then try to wash it off your fingers with water.

- 3 Protein based polymers (PBPs) are what provide the strength of a spider web, the elasticity of valves in a 100 year old human heart and the adhesion of an oyster shell on a rock. Research into PBPs concentrates on medical applications especially as adhesives for wounds and surgery cuts. PBPs can usually be broken down by salt water – PBP plastics ending up in the ocean would not only degrade but at the same time add protein nutrient to food chains in the marine ecosystem.
- 4 Cyclodextrins (CDs) are produced by bacterial action on starch. These are small polymers of 6, 7 or 8 glucose units which have an unusual shape.

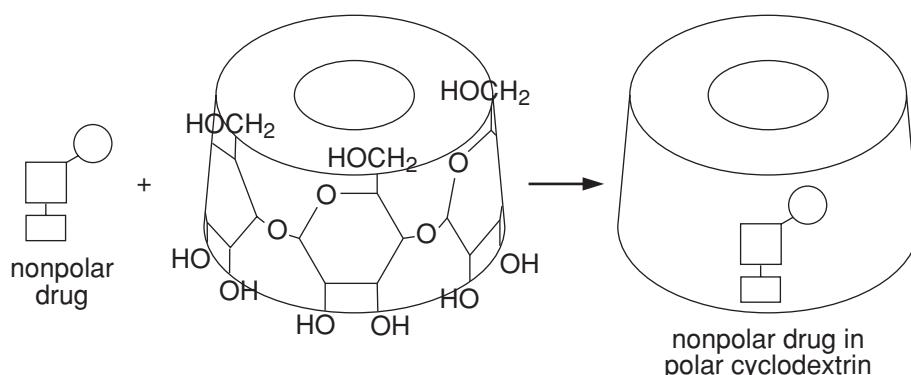


The insides of these small polymers are rich in C–H and non-polar while the outsides have many C–OH and are polar.



Approximate dimensions of  $\beta$ -cyclodextrin.

Molecules of low water solubility can dissolve in the hydrophobic internal cavity. CDs can transfer **drugs** of low water solubility, isolate unpleasant odours or bitter tastes in food and extend the activity of **agrochemicals** against insect pests and plant diseases.



Cheap biopolymers such as cellulose and starch can be partly changed by chemical reaction to give a more useful product:

- 1 Rayon (viscose) is chemically treated and regenerated cellulose.
- 2 Cellulose acetate is used for photographic film and overhead projector transparencies
- 3 Methylcellulose is used as a thickener in foods and to increase the viscosity of water and to slow down single celled organisms observed through a microscope
- 4 Monostarch phosphate and distarch phosphate are food thickeners.

These chemically modified biopolymers are not as biodegradable as the natural biopolymers they are made from.



Complete Exercise 2.3.



To learn more about applications of biopolymers go to  
[www.lmpc.edu.au/science](http://www.lmpc.edu.au/science)

## Possible future research directions

At present the production price of biopolymers is five to fifteen times the price of petrochemical polymers. As uses for biopolymers increase and larger industrial works are built, comparable in capacity to industrial works for petrochemical polymers, their production price should decrease.

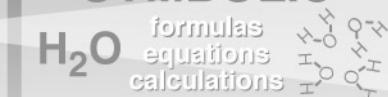
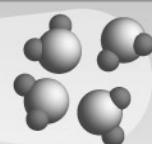
However to obtain the million ton scale of product needed to reduce price large natural producers such as crop plants rather than bacteria will need to be used.

Biopolymers cost about US\$5-15/kg compared with about US\$1/kg for synthetic plastics from petroleum. If biopolymers could be produced by crop plants the way food oils (US\$0.50/kg) and corn starch (US\$0.25/kg) are, then prices could be well below that of petroleum based plastics.

To do this **genetic engineering** (= **genetic modification** = **genetic manipulation**) will be required to transfer suitable genetic material into plants. Spider web silk genes have already been transferred to the common bacterium *E. coli* and produced protein-based polymers (PBPs). These genes could be transferred to a crop plant and express themselves, that is produce protein polymer, in leaves or other parts of the crop plant not used for food. Harvesting PBPs from leaves would be much cheaper than carrying out the expensive process of fermentation using *E. Coli* bacteria.

Complete Exercise 2.4: *Biopolymers in use*.



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Suggested answers

## Identifying cellulose

Testing plant material for cellulose with concentrated sulfuric acid and then iodine solution is not a satisfactory test because the dark blue colour produced could be due to the presence of starch in the plant material.

Correct spelling of chemical names is important in chemistry because a single letter mistake can refer to another chemical eg. cellulose and cellulase are different – cellulose is a carbohydrate polymer but cellulase is an enzyme protein.

## Condensation polymers

- Cellulose is similar to hydrocarbons because it contains C–C bonds and C–H bonds.
- Cellulose contains C–O–H and C–O–C bonds which are not in hydrocarbons. Cellulose molecules are attracted to one another by hydrogen bonds between OH groups. Hydrogen bonding between cellulose molecules is much stronger than the dispersion forces that occur between hydrocarbon molecules.
- High density polyethene HDPE is most like cellulose because it also consists of linear molecules.

The by-product in the formation of nylon is hydrogen chloride HCl.

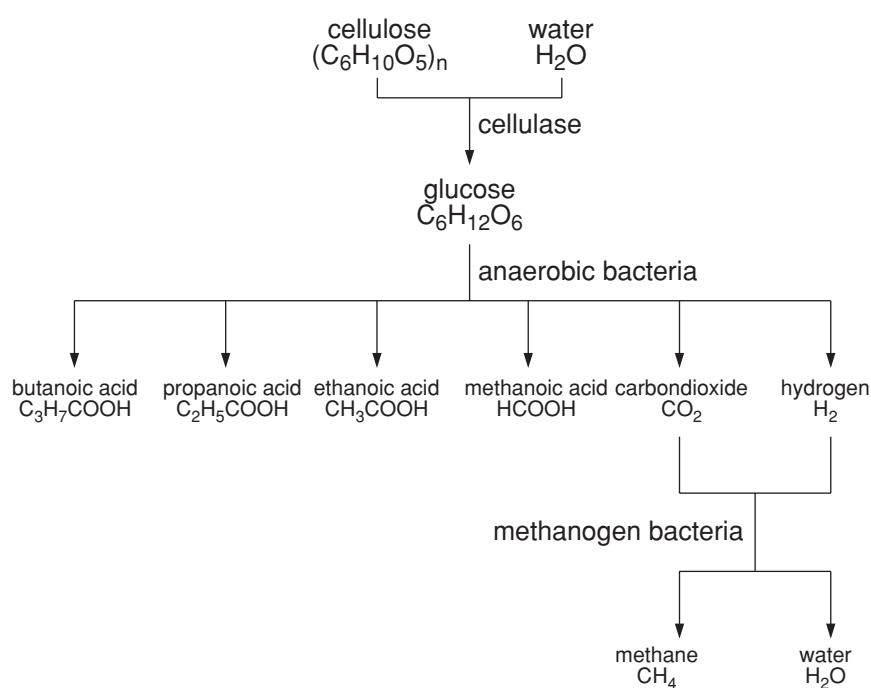
## Modelling starch and cellulose molecules

- 1 Starch is a spiral shaped molecule.
- 2 Straight lengths joined at points should distort less than spirals.
- 3 Test should apply same force in same conditions and compare amount of distortion of the two different models.
- 4 The sulfuric acid appears to have changed the linear structure of cellulose to produce the spirals which can interact with iodine producing a dark blue colour.

## Biomass to raw material conversion

- 1 Exothermic as energy is released.
- 2 Methanogen bacteria would be found near the anaerobic bacteria that produce the raw materials they need – carbon dioxide and hydrogen. Methanogen bacteria would also be found near the anaerobic bacteria probably at the bottom of the marsh well away from air.

Flow chart showing how cellulose can be changed to methane and alkanoic acids



## Converting plant material to ethanol

- 1 Amylase is an enzyme which hydrolyses the polymer starch to form the monomer *glucose*.
- 2 Cellulase is an enzyme which hydrolyses the polymer *cellulose* to form sugar monomers.
- 3 The names of *enzymes* usually end in the letters ‘ase’.
- 4 The names of carbohydrates such as glucose, sucrose, amylose and cellulose usually end in the letters ‘ose’.
- 5 Enzymes from yeast are used to convert glucose to *ethanol*.
- 6 The method which is used for waste wood uses the enzyme *cellulase* or *sulfuric acid*.

- 7 Biomass conversion of cellulose using genetically engineered yeast. Genetic engineering involves techniques developed in the last twenty years.
- 8
  - a) The Manildra Group use wheat starch waste left over after extraction of protein gluten from wheat.
  - b) CSR at Sarina use cane sugar containing waste such as molasses.
- 9
  - biomass cellulose to glucose to bioethanol
  - city waste contains a lot of materials based on cellulose such as paper, cotton, plant based food
  - paper and food scraps.

## **Efficiency of conversion of plant material**

Sugar cane grow best in the tropical climate of Brazil. Sugar beet grows best in cold temperate climates.

(Sugar cane is one of the most efficient photosynthesisers—it can convert an estimated 3% of the light received to chemical energy in glucose. The rapid growth of sugar cane will produce a higher yield per area than sugar beet. These factors are more important than the lower efficiency of conversion of plant carbohydrate to ethanol).

## **Biopolymers**

Most plastic waste is spread around the environment or burnt instead of disposal in landfill. Some is recycled.

Spreading around the environment creates visual pollution and threatens wildlife. Burning of plastics can release harmful substances into the environment such as hydrogen halide gases and dioxins.

Signs such as ‘This leads to Sydney Harbour’ or ‘Part of the Lane Cove River catchment’ are to make people conscious that rubbish left in gutters will be carried by water to the harbour or rivers.



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Exercises – Part 2

Exercises 2.1 to 2.4

Name: \_\_\_\_\_

## Exercise 2.1: Making polymers

Describe a process currently used industrially to produce a polymer:

- a) from petrochemicals

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- b) from biologically produced chemicals

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## **Exercise 2.2: Ironing, cellulose and water**

Important fabrics such as cotton, calico and linen are composed of cellulose fibres. Fabrics crease. To remove the creases these fabrics need to be either sprayed with water and then ironed or ironed with a steam iron that sprays the fabric with water. The water added in ironing to cellulose fabrics acts as a plasticiser.

- a) Use your knowledge of chemistry to predict what happens to:
- cellulose molecules when they are sprayed with water or steam

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- cellulose molecules when they have the water removed from them by heating

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- dry cotton is creased and wet cotton is creased.

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- b) Which one of the three predictions could you best test with an experiment?

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- c) Carry out an appropriate experiment and report your results:

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- 4 Look at the scale on a steam iron. How resistant are cellulose fabrics to heat compared with synthetic fabrics?

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### **Exercise 2.3: Using the internet for information on progress in development and use of a biopolymer**

Use a search engine such as google.com or northernlight.com to gather information on one of the newly developed biopolymers.

a) Name of biopolymer chosen: \_\_\_\_\_

b) Name of enzyme or organism used to synthesise the biopolymer: \_\_\_\_\_

c) Progress in development of the biopolymer:

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d) Use(s) of the biopolymer:

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e) Properties of the biopolymer relevant to use or potential use:

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## **Exercise 2.4: Biopolymers currently in use**

Biopolymer	Use	Food processing	Pharmaceuticals	Cosmetics
xanthan	thickener	*		*
alginate	dispersant	*	*	
gelatin	stabiliser	*		
carrageenan	humectant	*		
hyaluronic acid	lubricant			*

- a) Use the information to find a product in your home that contains one of these biopolymers.
- i) Name of biopolymer

---

- ii) Name of product

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- iii) Dictionary definition of its use

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- b) Look at the other components of the product. Predict why this biopolymer has been added to the product.

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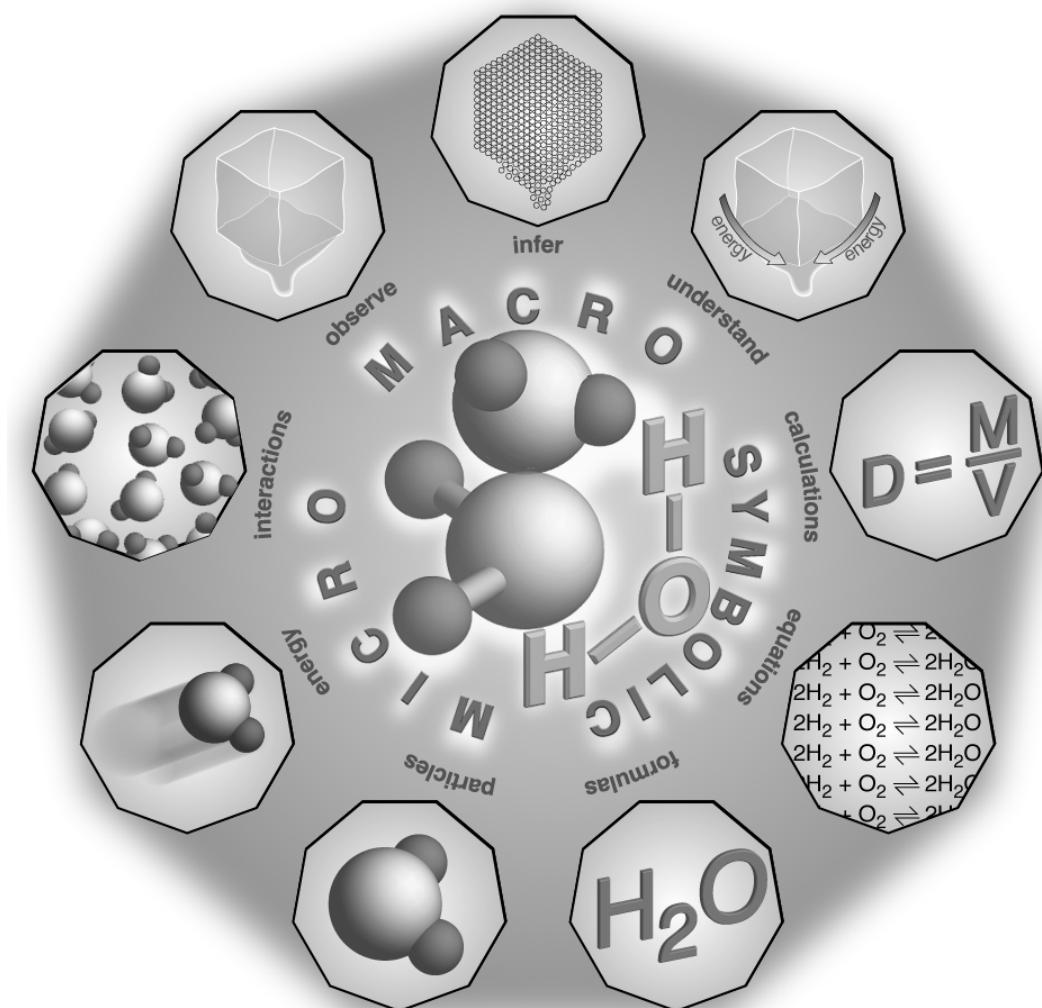
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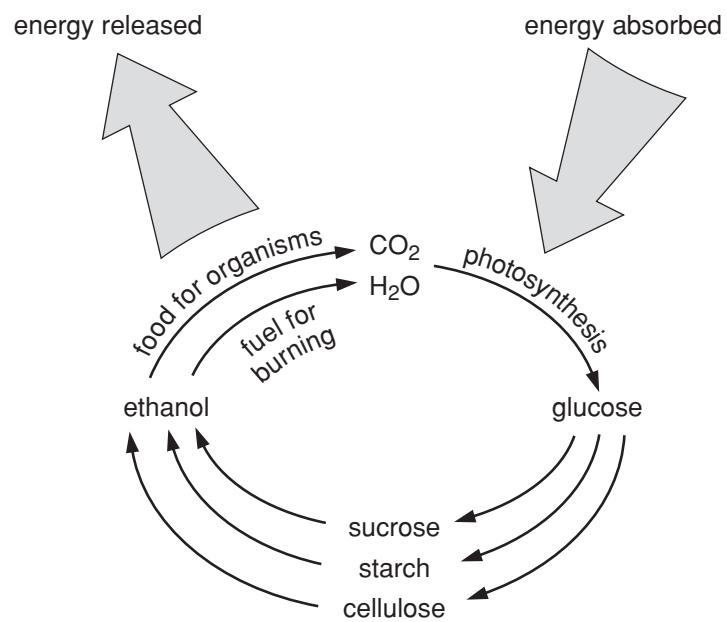
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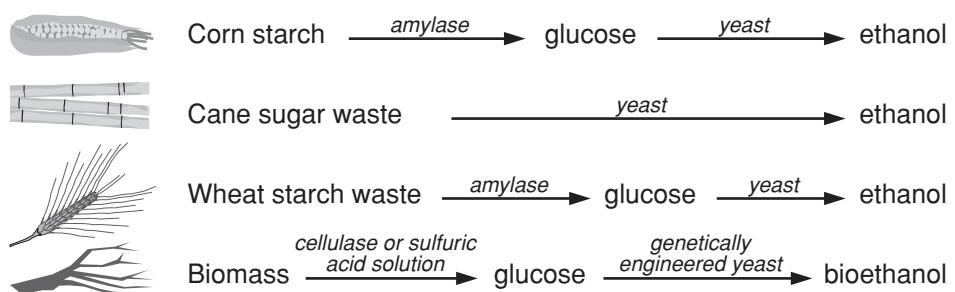
# The identification and production of materials

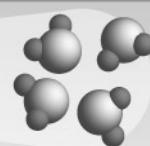
## Part 3: Renewable ethanol





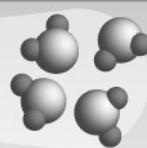
### Ethanol – a renewable fuel



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

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infer  
understand**SYMBOLIC** $H_2O$  formulas  
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calculations**MICRO**particles  
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interactions

# Introduction

Ethanol is the main fuel produced from plant material, a renewable resource. As fossil fuels which are non-renewable resources are depleted, ethanol and other products from renewable resources will be of increasing importance. Ethanol and ethene are easily interconverted and provide the most important link between biomass based chemicals and petroleum based chemicals.

In Part 3 you will be given opportunities to learn to:

- describe the dehydration of ethanol to ethene and identify the need for a catalyst in this process and the catalyst used
- describe the addition of water to ethene resulting in the production of ethanol and identify the need for a catalyst in this process and the catalyst used
- describe the uses of ethanol as a solvent and relate this to the polar nature of the ethanol molecule
- outline the uses of ethanol as a fuel and explain why it can be called a renewable resource
- describe conditions under which fermentation of sugars is promoted
- summarise the chemistry of the fermentation process
- define the molar heat of combustion of a compound and calculate the value for ethanol from first-hand data
- assess the potential of ethanol as an alternative fuel and discuss the advantages and disadvantages of its use.

In Part 3 you will be given opportunities to:

- process information from secondary sources such as molecular model kits, digital technologies or computer simulations to model
  - the addition of water to ethene
  - the dehydration of ethanol

- plan, choose equipment and perform a first-hand investigation to gather information about the range of substances which can be dissolved by ethanol
- process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane
- process information from secondary sources to summarise the use of ethanol as an alternative car fuel, evaluating the success of current usage
- solve problems, plan and perform a first-hand investigation to carry out the fermentation of sucrose and monitor mass changes
- present information from secondary sources by writing a balanced equation for the fermentation of glucose to ethanol
- 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.

Extracts from *Chemistry Stage 6 Syllabus*. Board of Studies NSW, originally issued 1999. The most up-to-date version is to be found at  
[http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

**MACRO**

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**SYMBOLIC**

$H_2O$  formulas  
equations  
calculations



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## Ethanol

### Ethanol and ethene conversion

Any country which has a source of ethanol or ethene can establish a chemical industry capable of producing a wide range of chemicals.

Countries such as Brazil (with climate and land suitable for growing extensive crops) can base the chemical industry on producing ethanol from plant material. Countries around the Persian Gulf where two-thirds of the world's known petroleum reserves are located or countries with major petroleum refineries such as Singapore can base the industry on ethene.

Sulfuric acid, phosphoric acid and heated ceramic solids can be used to catalyse conversions between ethanol and ethene.

To understand why conversion between ethanol and ethene involving **hydration** or **dehydration** is so easy, carry out the activity below.



In this activity you will be representing a chemical change using a molecular model kit.

#### What you will need:

A molecular model kit or maltesers and toothpicks and a red marker pen or coloured jelly jubes/marshmallows and toothpicks.

Use different coloured atoms for C (usually black), O (usually white) and H (usually red) if using a molecular model kit.

Or, use maltesers for C, maltesers with most of the chocolate removed to represent O and red marks on the end of a toothpick to represent H.

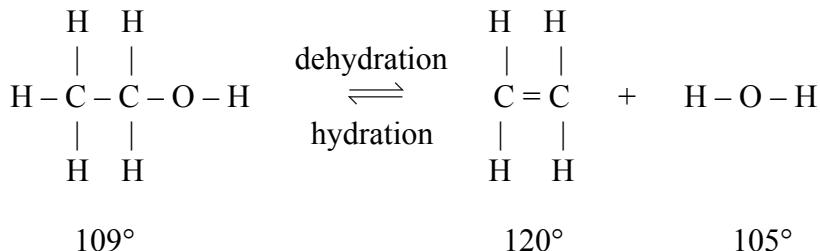
Or, use different coloured jelly jubes/marshmallows to represent C, O and H. C and O should be about the same size but make the H smaller.

### What you will do:

Make a 3-dimensional model each of ethanol, ethene and water.

The 2-dimensional drawings below showing angles of  $90^\circ$  and  $180^\circ$  (for ease of printing) are not the angles in actual 3-dimensional models.

The approximate angles you should use between bonds in your 3-dimensional models are shown below the 2-dimensional formulas.



- 1 Using the type of diagrams shown in Part 3 of the *Energy* module pages 5 and 6, draw diagrams to show the 3-dimensional nature of these molecules.
- 2 In Part 4 of the Preliminary *Energy* module (see pages 11-14) you calculated the energy change for a chemical reaction from bond energy values. Use the methods from the *Energy* module to calculate the energy change for the reaction. Bond energy values needed are given below in  $\text{kJ mol}^{-1}$ :  
 $\text{C}-\text{C}$  346,  $\text{C}-\text{H}$  414,  $\text{O}-\text{H}$  463,  $\text{C}-\text{O}$  358,  $\text{C}=\text{C}$  614.

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- 3 State the  $\Delta H$  for the dehydration of ethanol.

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- 4 State the  $\Delta H$  for the hydration of ethene:

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- 5 Which of these two processes is endothermic?

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- 6 Explain why the reverse process, the exothermic process, does not occur spontaneously. Why does an exothermic process need energy for the reaction to start?

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- 7 Both the dehydration of ethanol and hydration of ethene reactions require the presence of a catalyst. Heated clay or porous ceramic material can act as catalysts. These solid catalysts have polar sites that attract the electron rich C=C and polar OH groups of water. The close proximity of the molecules and heat which provides activation energy speed up the reaction. Explain why a catalyst speeds up both the forward and the reverse reaction.

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- 8 In industry solid catalysts such as aluminium oxide and conditions of 70 atmosphere pressure and 300°C are used. Explain how high pressure and high temperature can increase rate of a reaction.

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Check your answers.

# Ethanol the solvent

After water, ethanol is probably the most important solvent for industrial applications and consumer products. Ethanol is the least toxic to humans of all the alcohols so most consumer products that list alcohol contain ethyl alcohol (ethanol).



Most alcohols are volatile, flammable liquids. The most toxic is methyl alcohol (methanol) CH<sub>3</sub>OH. Alcohols are less damaging to the skin than most other solvents.

Exercise 3.1 requires you to survey the chemical labels in your home and list all products containing alcohol (or ethanol). You will be asked to record the names of any compound ending in -ol (eg. cholesterol, glycerol) as these are practically always alcohols.



Did you find most of the alcohols listed in products were ethanol?  
Suggest two reasons why ethanol is the most common alcohol used.

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Check your answer.

The use of pure ethanol is strictly controlled by governments. This is because ethanol is the alcohol in alcoholic drinks. A person drinking 100 mL or more of alcohol per day often has, or is developing, a health problem. Smaller amounts of daily alcohol consumption can cause damage to an unborn child. To control consumption of alcohol and to raise revenue, governments impose a special tax called excise on the sale of alcoholic drinks. There are also special controls on the amount of alcoholic drinks a person can brew (beer), ferment (wine) or distill to increase the alcohol concentration (spirits).

Methylated spirits or **denatured** alcohol is 90-95% ethanol, 0-5% methanol, 5% water and small amounts of chemicals to make the liquid distasteful. The denatured form of ethanol is useful as a solvent and cleaning aid and is sold cheaply without excise. The chemicals added are to try to stop alcoholics from drinking methylated spirits for the ethanol. The most bitter compound known, trade name Bitrex®, is sometimes added. As little as 30 ppm of Bitrex® makes the liquid too bitter to be tolerated by most humans.



Complete Exercise 3.1: *Chemical labels*.

# An open ended investigation

In this open ended investigation you are required to plan, choose equipment and perform a first-hand investigation to gather information about the range of substances which can be dissolved by ethanol.

For practical work, instead of ethanol (very difficult to obtain in pure form) you are asked to use methylated spirits.



Methylated spirits is highly inflammable and toxic if ingested (drunk or eaten). Avoid inhalation – use it in a well ventilated area. Skin irritant on prolonged contact.

Waste solutions may be disposed of down a sink hole to the sewer. Most importantly, keep methylated spirits away from sources of heat, flame and spark.

This open ended investigation has two parts, A and B.

## Part A:

Use information resources to find the solubility of pure chemicals in ethanol.

Here is a list of resources you could try:

- books at home
- books at a public, school or TAFE library
- websites on the worldwide web. A search engine could be useful in finding appropriate sites; if you have difficulties try a search engine search using MSDS for material safety data sheets.

MSDSs are information sheets which chemical suppliers must make available when they supply chemicals. At the beginning of a MSDS, just above the list of physical properties, there is often information about solubility in alcohol (ethanol).

- your teacher may allow you to have access to the CD ROM with the Chemical Safety in Schools package supplied to NSW schools in July 2000.

This CD ROM contains the CHEMWATCH chemical database and management system with over 20 000 material safety data sheets. Although the CD ROM is marked for use with IBM compatible and Macintosh systems the MSDSs part can only be accessed using an IBM compatible computer.

## **Part B**

Use chemicals you have at home and test their solubility in methylated spirits.

You will need to design a procedure that is:

- fair
- valid (leading to effective results and worthwhile conclusions) and
- reliable (trustworthy).

Here are some tips before you begin:

- 1 If possible use test tubes—they are easy to see through and can be effectively shaken
- 2 You may need a wooden skewer to push solid to the bottom of the test tube before adding the solvent
- 3 When testing solubility of a liquid in a solvent add more solvent than liquid solute. If the two liquids are immiscible (do not mix) it will be easier to tell which is the solvent (as it will have the largest volume).
- 4 Instead of mixing the substance directly with methylated spirits you could take an inert fabric eg. cotton sheet, and mark it in sections with a variety of liquids and solids.

Cut the sheet into squares of the same size and then add the separate squares to methylated spirits in different test tubes.

Shake all the samples in the same way, remove the sheet and dry in air to see which of the marks has dissolved.



Once you have mentally worked out what procedure you will use in Part A and Part B, turn to exercise 3.2. Draft your plan.

Do NOT perform the investigation until your plan has been returned to you with comments from your teacher.

Your full report of the investigation is Exercise 6.1 in Part 6 of this module.

Exercise 6.2 is based upon your experiences in carrying out this open ended investigation.

# Solvent properties and molecular structure

Some physical properties of straight chain alkanols

Structural formula	Molecular mass	MP (°C)	Water solubility (g/100 g water)
CH <sub>3</sub> OH	32	-98	infinite
CH <sub>3</sub> CH <sub>2</sub> OH	46	-114	infinite
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> OH	60	-126	infinite
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	74	-90	7.9
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	88	-79	2.3
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	102	-45	0.6
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	116	-34	0.2
CH <sub>3</sub> CH <sub>2</sub> OH	130	-15	0.05

Each of these alkanols consists of:

- a hydrophilic (water loving) OH group that can hydrogen bond with water and, because it is polar, attract ions and polar molecules
- a hydrophobic (water fearing) or **lyophilic** (fat loving) non-polar hydrocarbon chain that can attract non-polar molecules.

The first three members of the homologous series, methanol, ethanol and 1-propanol mix with water in all proportions.

Going further down the homologous series the water solubility of the alkanols decreases as the hydrocarbon chain becomes a large part of each molecule.



Explain why ethanol can dissolve a wide range of substances such as salts, polar molecules and non-polar molecules.

Check your answer.

# Ethanol – a renewable resource

In 1908, when Henry Ford was designing his Model T Ford, the first mass produced car, he designed the engine to run on alcohol. However plentiful supplies of petroleum removed the incentives to produce ethanol for **internal combustion engines**.

If an engine uses 10-20% **anhydrous** ethanol in petrol the engine can use the same carburettor or fuel injection system as for 100% petrol. An engine designed to run on distilled alcohol which is 96% ethanol and 4% water requires a different carburettor. Both type of engines produce less pollutants than a 100% petrol engine.

If the ethanol is produced from cellulose biomass rather than starch or sugar, it is often called **bioethanol**.

A full fuel-cycle study carried out by the US Department of Energy at the end of 1997 included the energy required to grow and harvest corn, distill ethanol from starch fermentation mixtures and transport it to petrol stations.

This study showed a reduction in fossil energy use of 50-60% and greenhouse gas emissions of 35-46% compared with conventional petrol. Reduction in greenhouse emissions and fossil energy use were calculated to be even greater if bioethanol was produced from the cellulose of corn plants.

- 1 Write a balanced equation for the complete combustion of ethanol.



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- 2 Name the two main products of the complete combustion of ethanol.

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- 3 What types of energy are released in the combustion of ethanol?

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- 4 Write a balanced equation for photosynthesis.

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- 5 Name the two reactants required for photosynthesis.

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- 6 What type of energy is absorbed in photosynthesis?

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Check your answers.

- 7 Draw a labelled cycle diagram to explain why ethanol can be called a renewable resource.

Check your answers.



## Ethanol as a car fuel

In this activity you will be evaluating current usage of ethanol as an alternative car fuel. Evaluating means ‘determining the value of’.

Evaluating current usage requires you to obtain up-to-date information. Check the date of publication of any source that you use.



- 1 Which should be the more reliable source of information? A book first published in 1992 and reprinted in 1998 or a second book first published in 1992 and revised in 1996?

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- 2 Do not assume all websites are equal. A website may have been last revised in 1996 while another may have been revised in 1999. Which should give information closest to current usage?

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- 3 Consider the type of web site you are accessing:
- .com indicates a business
  - .org indicates a non-profit organisation
  - .edu indicates an educational establishment
  - .au indicates an Australian web site
  - .br indicates a Brazilian web site – the information could be in Portuguese
  - No country symbol indicates a USA site

Which type of site do you think would give the most reliable

information?

Justify (support) your answer.

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- 4 After researching information using books, magazines, newspapers and the Internet summarise your information. Which source was most useful?

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- 5 Evaluate the success of current usage of ethanol as an alternative car fuel.

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Check your answers.



This information is needed to complete Exercise 3.3

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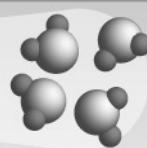
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**SYMBOLIC**

H<sub>2</sub>O

formulas  
equations  
calculations



**MICRO**

particles  
energy  
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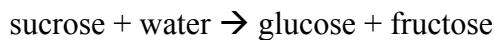
## Fermentation

Fermentation is controlled chemical change catalysed by enzymes from organisms such as yeast or bacteria. Fermentation producing ethanol is easily carried out using any plant material containing sugar and yeast.

Next time you come across an old bunch of grapes have a close look at the surface of the grapes. You'll probably be able to see a dull fuzzy layer on parts of some grapes. These are yeast moulds waiting for an opportunity to penetrate the grape skin and get in to have a feed on the sugars within! The chemical action of yeasts on grape juice produce the alcohol and chemical flavours of wines. Different yeasts can produce different chemical flavours.

Sour grapes in a bunch of sweet grapes are the ones that have had their surface penetrated by yeast and have started to ferment. The sourness is due to an acid **intermediate** produced as sugar changes to ethanol.

The yeast organisms can act on a variety of sugars. For example cane sugar, sucrose, C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> is hydrolysed to form glucose C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> and fructose C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>.



Glucose and fructose are isomers (same molecular, different structural formulas). Both glucose and fructose can be changed to ethanol and carbon dioxide. The pathways used by organisms to change chemicals are called **metabolic pathways**.

A lot of genetic engineering research involves introducing genes for a metabolic pathway from one organism into another organism. This is known as **metabolic engineering**. Each step in a metabolic pathway usually requires a specific enzyme. Each specific enzyme is produced by a specific gene or genes. Studying metabolic pathways is an important part of the option *The biochemistry of movement* of the Stage 6 Chemistry syllabus.

Fermentation of plant material rich in starch uses organisms that contain enzymes able to change starch to sugars: starch + water → sugars



The sugars are then fermented to alcohols.



After fermentation the mixture can be distilled to make spirits eg. whisky from fermented barley or corn, vodka from fermented potatoes.

The different flavours of alcoholic drinks come from hundreds of by-products. Reactions involving organic compounds rarely give 100% conversion to the anticipated products. By-products are typical of organic reactions. Different types of grapes and fermentation conditions result in different by-products and a huge variety of wines.



- 1 When pure glucose  $C_6H_{12}O_6$  undergoes fermentation only two products are formed – ethanol  $C_2H_5OH$  and carbon dioxide  $CO_2$ .  
glucose → ethanol + carbon dioxide

Write a balanced equation for this fermentation reaction.

---

- 2 Fermentation can only be carried out in solution. Name the important solvent required for all fermentation reactions.
- 
- 

- 3 Each separate step in changing sugars to ethanol and carbon dioxide is catalysed. The catalysts work best at a temperature of about  $30^{\circ}C$ . What type of catalysts are these and where do they come from?
- 
- 

- 4 Unfortunately for the yeast organisms they die of alcoholic poisoning once the concentration of ethanol reaches about 15% v/v! Most wines are up to about 12% ethanol by volume. How are alcoholic drinks with much higher concentrations, such as brandy, obtained from wine?
- 
- 

Check your answers.

# Mass changes in fermentation



## What you will need:

- a balance capable of weighing to at least the nearest gram
- a gas tight container (in which to carry out the fermentation) with a tube passing to a smaller container
- 25 g of sucrose (= cane sugar = table sugar)  $C_{12}H_{22}O_{11}$
- 1 g of table salt
- 7 g dried yeast (found in the bread making or flour section of a supermarket – usually in 7g, 12g or 28 g packets)
- 250 mL of water
- a warm area to place the equipment ( $30^{\circ}\text{C}$  is a good temperature)
- limewater  $\text{Ca}(\text{OH})_2\text{(aq)}$  to half fill the smaller container.



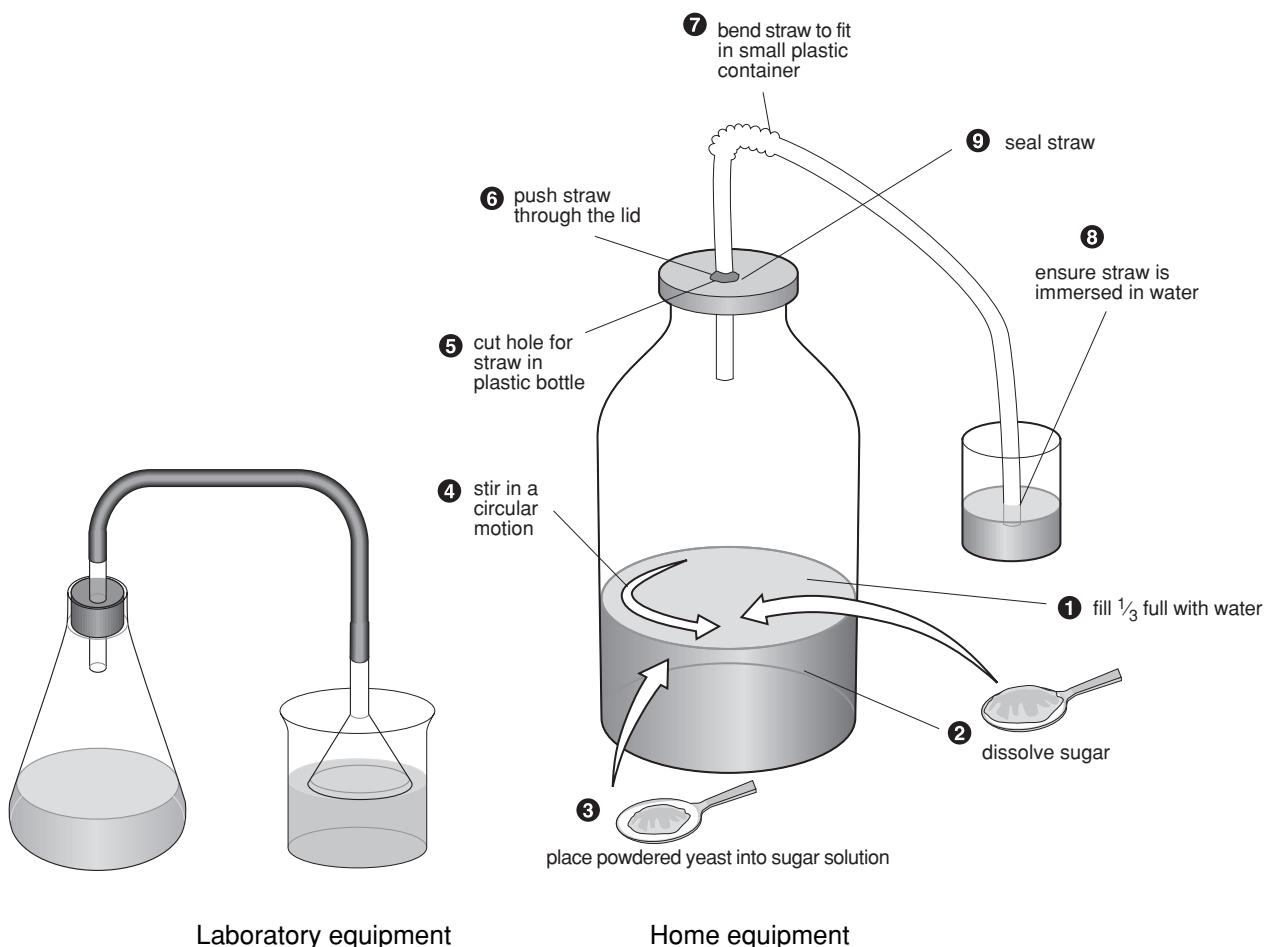
Keep lime and limewater away from eyes and skin. Lime or limewater in eyes must be immediately washed away with lots of water.

Limewater is made by adding a small amount of lime (a chemical obtainable from a hardware store, bricklayer or builder) to a sealable container half filled with water. (Do not use lime from a nursery or agricultural supplier—this is usually powdered limestone, calcium carbonate  $\text{CaCO}_3$ ).

Shake the lime with the water then add more water until the container is almost full. Some of the solid lime  $\text{Ca}(\text{OH})_2$  will dissolve to form a water solution  $\text{Ca}(\text{OH})_2\text{(aq)}$ . Prepare the limewater at least one day before you start the activity because  $\text{Ca}(\text{OH})_2\text{(s)}$  is not very soluble in water and takes a while to form  $\text{Ca}(\text{OH})_2\text{(aq)}$ .

Seal the container and always keep it topped up with water to minimise contact with air. When the limewater is needed it is decanted as a colourless, transparent solution and the container resealed.

Limewater turns cloudy when exposed to  $\text{CO}_2$  because  $\text{Ca}(\text{OH})_2\text{(aq)} + \text{CO}_2\text{(g)} \rightarrow \text{CaCO}_3\text{(s)} + \text{H}_2\text{O(l)}$ . The small particles of  $\text{CaCO}_3\text{(s)}$  formed reflect light like clouds do.



Laboratory equipment

Home equipment

### Method

- 1 Place the fermentation mixture of sugar, water, salt and yeast into the larger container and swirl to mix. Weigh the container and contents and attached equipment for transferring gas.
- 2 Half fill the smaller container with limewater. Weigh the container of limewater.
- 3 Put the two containers in a warm area.
- 4 Place the end of the gas transferring equipment so that any gas produced in the large container enters the limewater about 1 cm below the limewater surface.
- 5 Record the appearance of the fermentation mixture and limewater in the results table.
- 6 Repeat the weighings and observations daily at least every second day for a week.

## Results

Date	Fermentation mixture		Limewater	
	mass (g)	appearance	mass (g)	appearance

## Conclusions



- 1 Is there any connection between change in mass of the fermentation mixture and change in mass of the limewater?

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- 2 Explain the change in mass of the fermentation mixture using an appropriate chemical equation.

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- 3 Explain the change in mass of the limewater using an appropriate chemical equation.

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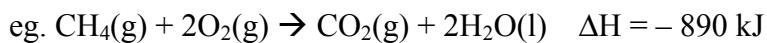
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Check your answers.

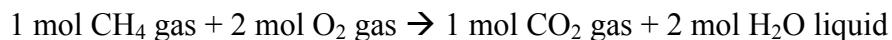
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understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Molar heat of combustion

Because all combustions are exothermic,  $\Delta H$  is always a negative value.



The heat change  $\Delta H$  is for the equation representing moles, in this case:



Note that  $\Delta H = -890\text{ kJ/mol}$  of  $CH_4$  but  $\Delta H = -445\text{ kJ/mol}$  of  $O_2$

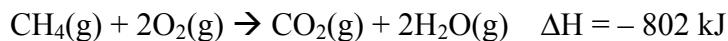
- 1 Calculate  $\Delta H$  per mol of  $CO_2(g)$  and  $\Delta H$  per mol of  $H_2O(l)$



- 2 Do not try this. This is a ‘thought experiment’.

What do you feel if your skin is exposed to gaseous water in the form of steam which condenses to liquid water on your skin?

- 3 In some texts you might see the correct equation and  $\Delta H$  value as:



Explain why this correct  $\Delta H$  value is different from the correct value given previously as  $-890\text{ kJ}$ .

- 4 Use the information in the equations above to work out how much heat is released when two moles of gaseous water condense to two moles of liquid water



Check your answers

When you burn methane in a burner the water produced with the carbon dioxide in the flame is also gas. If the gaseous products cool to their states at room temperature the gaseous water condenses releasing more energy. Heat of combustion is defined for water produced in the liquid state.

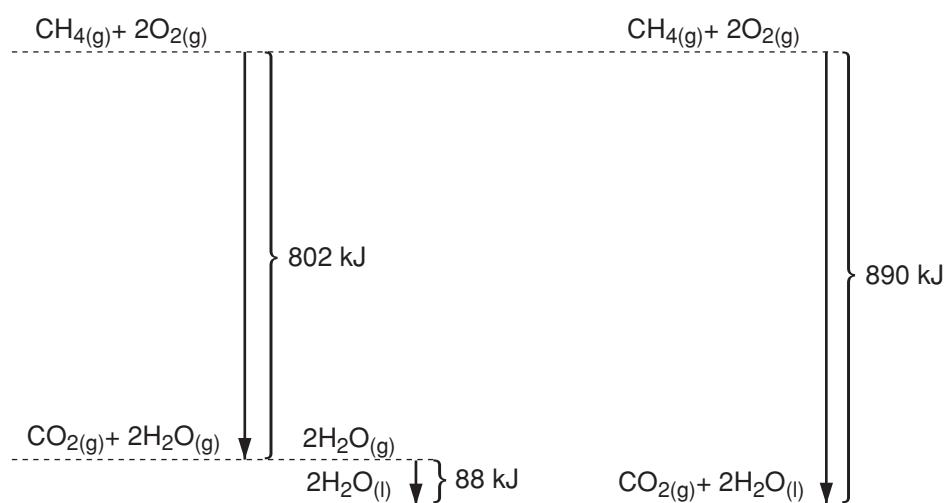


Diagram illustrating  $\Delta H$  for heat of combustion as two steps or one step

The molar heat of combustion is the heat change when one mole of the substance is combusted to form products in their standard states at  $10^5$  Pa pressure and  $25^\circ\text{C}$  (298 K).

- 1 Give the states of matter at  $10^5$  Pa and  $25^\circ\text{C}$  for:
  - a) carbon dioxide \_\_\_\_\_
  - b) water \_\_\_\_\_.
- 2 Explain why the molar heat of combustion of methane is 890 kJ and not 802 kJ.  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



Check your answers.

Note that when you write about a heat of combustion in a sentence it can be given as a positive value on the understanding that all combustions are exothermic. This is demonstrated in the words of question 2 above.

If the  $\Delta H$  is in equation form  $\Delta H =$  always a negative value for combustion. Thus for methane the molar heat of combustion:

$$\Delta H = -890 \text{ kJ.}$$

The molar heat of combustion is represented by  $\Delta_c H^\ominus$  and is measured in  $\text{kJ mol}^{-1}$ .

For methane  $\Delta_c H^\ominus = -890 \text{ kJ}$

If a table lists the heats of combustion for a number of compounds such as alkanes the values given can be positive if the heading is  $-\Delta_c H^\ominus$ .

Alkane	$-\Delta_c H^\ominus (\text{kJ mol}^{-1})$
methane	890
ethane	1560
propane	2220
n-butane	2877

Molar heats of combustion of alkanes (for state at  $10^5 \text{ Pa}$  and  $25^\circ\text{C}$ )



In the symbols  $-\Delta_c H^\ominus$  the  $\ominus$  indicates  $10^5 \text{ Pa}$  and  $25^\circ\text{C}$ .

What is indicated by

a)  $-$

\_\_\_\_\_

b)  $\Delta_c$

\_\_\_\_\_

c)  $H$

\_\_\_\_\_

d)  $\Delta?$

\_\_\_\_\_

Check your answers.

# Measuring $\Delta_c H^\circ$ of liquid alkanols



## What you will need

Choose resources from the following

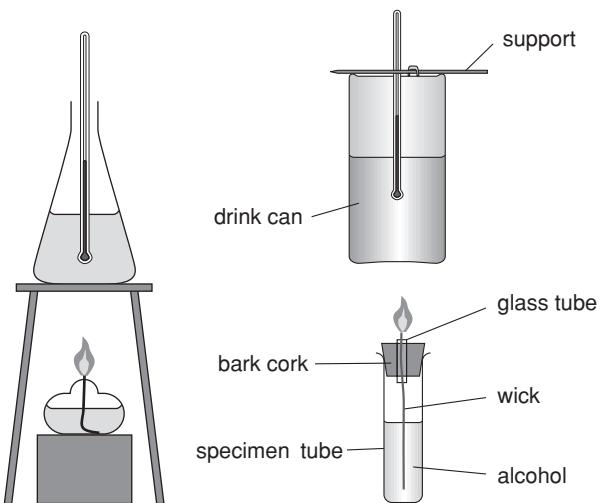
- at least three different liquid alkanols including ethanol (or methylated spirits)
- an alcohol burner



Alkanols are flammable. Keep the bulk supply well away from the burner and the matches.

A laboratory equipment setup and home equipment set up are shown on the next page. Look at both these diagrams before looking for appropriate equipment.

- a means of measuring the mass of burner to at least 0.01 g or a means of measuring the volume of alkanol used to 0.2 mL and identify a data source of alkanol densities
- a container to heat 250 mL of water such as a 500 ml conical flask or an empty aluminium drink can
- a means of measuring 250 ml of water to at least the nearest 5 mL
- a thermometer measuring to at least 0.5 of a Celsius degree
- a box of matches
- a means of supporting the container of 250 mL of water about 5 cm above the top of the burner flame.



### What you need to do:

- 1 Make measurements to complete the results and calculations tables.
- 2 You will need to devise a procedure using the resources chosen to make the measurements. If you are not sure what to do read the Activity 4 of Part 4 of the Preliminary module *Energy* – determining the heat of combustion for some hydrocarbons.
- 3 Set out the procedure as a series of steps in the space for Exercise 3.4.



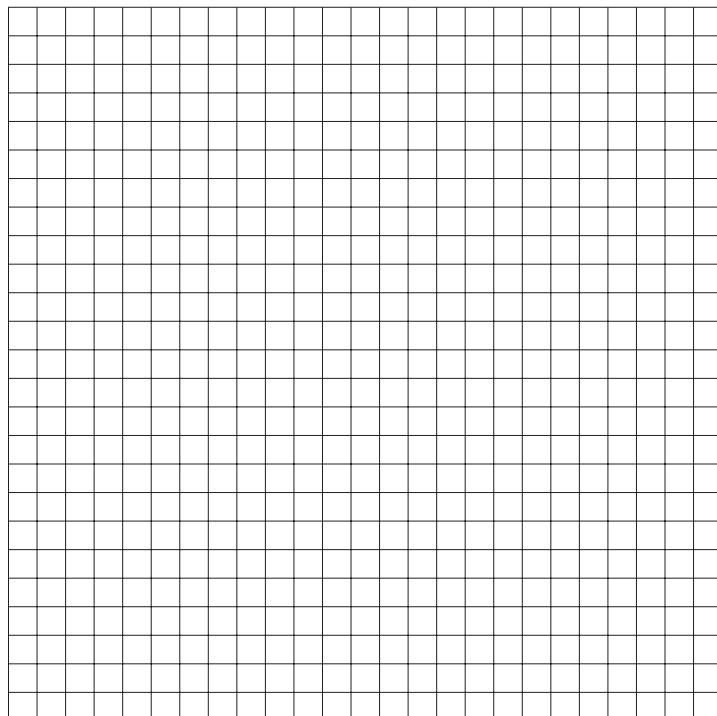
### Results:

Alkanol	ethanol		
volume of water heated (mL)			
mass of water heated (g)			
initial burner mass (g)			
final burner mass (g)			
mass of alkanol used (g)			
initial water temperature ( $^{\circ}\text{C}$ )			
maximum water temperature ( $^{\circ}\text{C}$ )			
change in water temperature ( $^{\circ}\text{C}$ )			

Alkanol	Ethanol		
heat released $\Delta H = m_{\text{water}} \times 4.18 \times \Delta T$ (J)			
heat released/g $\Delta H/g = \Delta H/\text{mass of alcohol}$ (J)			
heat release/mole = $(\Delta H/g) \times \text{molar mass} = -\Delta_c H$ (J)			

## Graph

Draw a graph of molar heat of combustion (vertical axis) versus (molecular mass). Label the axes. Draw a straight line of best fit. **Extrapolate** the straight line beyond the data you have measured and calculated.



- 1 Explain why there is a constant difference between successive alkanols in their molecular mass. Can you associate a particular group of atoms with this constant difference?

---

---

- 2 Explain why there is a steady increase in the molar heat of combustion as molecular mass increases. Can you associate a particular group of atoms with this steady increase?

---

---

- 3 Explain why the values you calculated for molar heat of combustion are  $-\Delta_c H$  values and not  $-\Delta_c H^\circ$  values.

---

Check your answers.

# Comparing practical and theoretical values

The molar heat of combustion values calculated in the previous activity are based on practical measurements using simple equipment.

In the last Preliminary Module *Energy* Part 4 you learnt how to use bond energy values to calculate the molar heat of combustion values for hydrocarbons. The theoretical values calculated were based on bond energy measurements when gaseous molecules change to gaseous atoms.

Some chemists concentrate on calculations based on practical measurements while other chemists concentrate on theoretical calculations. All chemists are trained to do practical calculations and theoretical calculations. Many of the advances in chemistry come from comparing the results of practical calculations and theoretical calculations.

In the following activity you will compare the results of:

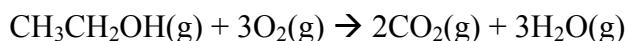
- your practical calculations using simple equipment,
- theoretical calculations using bond energies and
- practical calculations using equipment such as bomb calorimeters.



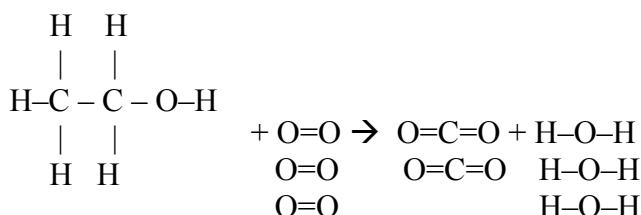
The sample calculation below for combustion of ethanol uses the theoretical calculation method from *Energy* Part 4.

Bond	Bond energy (kJ/mol)
C–C	346
C=C	614
C≡C	839
C=O	804
C–O	358
C–H	414
O=O	498
O–H	463

Because bond energies are for gaseous molecules all reactants and products are considered as gases.



The bonds present are:



Bonds broken	Bonds formed
5 x C–H	4 x C=O
1 x C–C	6 x H–O
1 x C–O	
1 x O–H	
3 x O=O	

Energy in/absorbed/ $\Delta H = +$	Energy out/released/ $\Delta H = -$
$(5 \times 414) + 346 + 358 + 463 + (3 \times 498)$ = 4731	$(4 \times 804) + (6 \times 463)$ = 5994

$$\Delta H = 4731 - 5994 = -1263 \text{ kJ}$$

Heat of combustion is for:

- liquid ethanol so heat absorbed in vaporising 1 mole of ethanol = 43 kJ is added to give  $-1263 + 43 = -1220 \text{ kJ}$
- formation of liquid water so heat released by condensation of 3 moles of water =  $3 \times -44 \text{ kJ} = -132 \text{ kJ}$  is added to give  $-1220 - 132 = -1352 \text{ kJ}$

Molar heat of combustion of ethanol using bond energies =  $-1352 \text{ kJ}$

Alkanol	Structural formula	$-\Delta_c H^\circ$ (kJ mol <sup>-1</sup> )
methanol	CH <sub>3</sub> OH	726
ethanol	CH <sub>3</sub> CH <sub>2</sub> OH	1367
1-propanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> OH	2021
1-butanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	2676
1-pentanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	3331
1-hexanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	3984
1-heptanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	4638
1-octanol	CH <sub>3</sub> CH <sub>2</sub> OH	5294

$\Delta_c H$  values obtained using equipment such as bomb calorimeters.

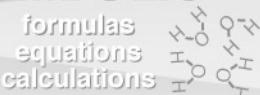
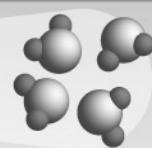
Now compare the ethanol results for the different methods.

Method	Molar heat of combustion (kJ mol <sup>-1</sup> )
practical calculation, simple equipment	
theoretical calculation, bond energies	1352
practical calculation, bomb calorimeter	1367



The information in this table is needed to answer Exercise 3.5.



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# Appendix

**OPTIONAL ACTIVITY: Fermentation to make ginger beer**

Wear safety goggles or glasses after you have made the ginger beer and are checking or handling the bottles. This recipe produces about 2% v/v ethanol.

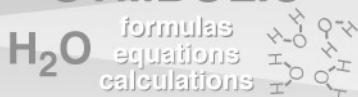
**You will need:**

- a lemon
- sugar
- cream of tartar
- ginger root
- dried yeast
- a clean container that can hold at least 10 L of liquid such as a bucket
- clean plastic bottles to hold a total of 8 L. Glass champagne bottles could be used as these are pressure resistant. Bottles must be corked to release pressure build up, not screw-capped.

**What to do:**

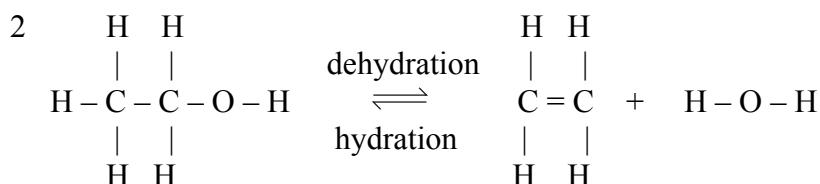
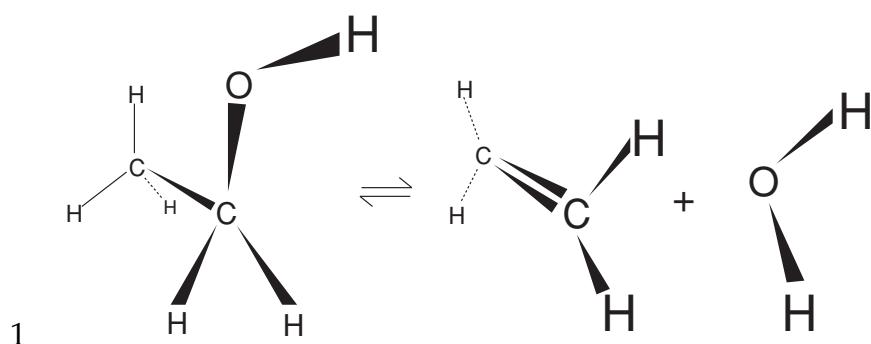
- 1 Add the juice of one lemon, 300 g of sugar, 7 g cream of tartar, 15 g of lightly crushed ginger root and 2 L of boiling water to the clean container.
- 2 Cool to room temperature, take about 50 mL of the liquid mixture into a cup and stir in 7 g of dried yeast.
- 3 Float a slice of toasted bread on top of the mixture in the container and pour the yeast mixture from the cup on to it.
- 4 Leave for a day. Remove any floating surface material with a fine strainer. Pour container liquid through the fine strainer into bottles. Cork (not screw caps).

- 5 After two days remove corks to release excess pressure buildup.
- 6 Leave one more day before drinking any of the ginger beer.

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## Suggested answers

### Ethanol and ethene conversion



Bonds broken	Bonds formed
5 x C–H	4 x C–H
1 x C–C	1 x C=C
1 x C–O	2 x O–H
1 x O–H	

#### Energy in

$$(5 \times 414) + 346 + 358 + 463 \\ = 3237$$

$$\Delta H = 3237 - 3196 = 41 \text{ kJ}$$

#### Energy out

$$(4 \times 414) + 614 + (2 \times 463) \\ = 3196$$

3  $\Delta H = 41 \text{ kJ}$  per mole of ethanol

- 4  $\Delta H = -41 \text{ kJ}$  per mole of ethene
- 5 The dehydration of ethanol is endothermic.
- 6 Energy is released during reaction but to start reacting the ethene and water need sufficient energy to exceed the activation energy.
- 7 A catalyst provides an alternative pathway with a lower activation energy. The pathway is the same but direction different for forward and reverse reactions.
- 8 High pressure increases the chances of collision. High temperature slightly increases the chances of collision while significantly increasing the likelihood that the colliding molecules will exceed the activation energy and react.

## Ethanol the solvent

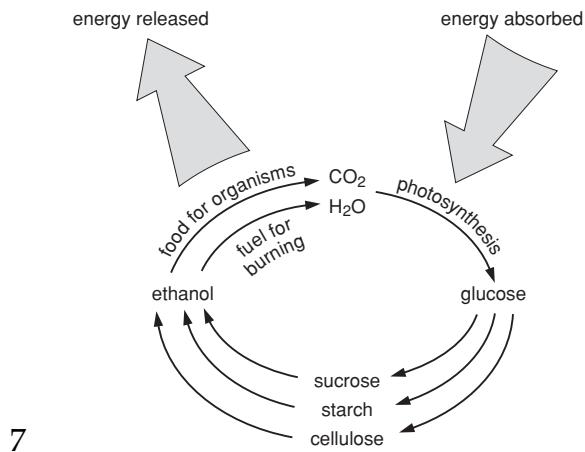
Ethanol is the least toxic alcohol, cheap and water soluble.

## Solvent properties and molecular structure

Ethanol has a polar OH group that attracts salt ions and polar molecules and a non-polar hydrocarbon chain that attracts non-polar molecules.

## Ethanol – a renewable resource

- 1  $\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$
- 2 The two main products of complete combustion of ethanol are carbon dioxide and water.
- 3 Heat and light are two forms of energy released in the combustion of ethanol.
- 4  $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
- 5 Two reactants required for photosynthesis are carbon dioxide and water.
- 6 Light energy is absorbed in photosynthesis.



7

## Use of ethanol as a car fuel

- 1 The book revised in 1996 should be more up-to-date than 1992 information reprinted in 1998.
- 2 The 1999 revision should give information closer to current usage.
- 3 An .edu site usually offers more independent analysis than a commercial .com site which is more likely to have a financial interest or a vested interest .org site.
- 4 Your summary should include information about:
  - plant material fermented
  - how ethanol is used – 10-20% anhydrous ethanol with petrol or 96% ethanol with modified carburettor
  - cost and subsidies compared with the fuel replaced.
- 5 Currently ethanol is about half the car fuel used in Brazil and an increasing part of car fuel in the US. Both these countries have extensive arable land and no food shortages. Countries with substantial oil reserves and little arable land such as around the Persian Gulf do not use ethanol. In Australia petranol, a mixture of petrol and ethanol, is sold near locations where ethanol is produced.

## Fermentation

- 1  $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- 2 Water is the solvent required for most fermentation reactions.
- 3 Catalysts used in fermentation are enzymes from yeast or bacteria.
- 4 Distillation produces a liquid with a higher concentration of alcohol than wine.

## Monitoring mass changes in fermentation

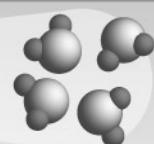
- 1 Decrease in mass of fermentation mixture due to loss of CO<sub>2</sub> should be about the same as the increase in mass of limewater by reaction with CO<sub>2</sub>.
- 2 C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> + H<sub>2</sub>O → 2 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> → 4C<sub>2</sub>H<sub>5</sub>OH + 4CO<sub>2</sub>  
CO<sub>2</sub> is a gas that escapes thus decreasing mass of the fermentation mixture.
- 3 Ca(OH)<sub>2</sub> + CO<sub>2</sub> → CaCO<sub>3</sub> + H<sub>2</sub>O  
CO<sub>2</sub> gas absorbed increases mass of limewater.

## Molar heat of combustion

- 1 ΔH = -890 kJ per mol of CO<sub>2</sub>(g) and -445 kJ per mol of H<sub>2</sub>O(l)
- 2 Heat released from condensation.
- 3 ΔH = -890 kJ is for formation of liquid water while ΔH = -802 kJ is for formation of gaseous water.
- 4 The difference between ΔH = -890 kJ and ΔH = -802 kJ is the condensation of two moles of gaseous water condense to liquid water releasing an extra 88 kJ. Thus 2H<sub>2</sub>O(g) → 2H<sub>2</sub>O(l) ΔH = -88 kJ
  - 1 a) carbon dioxide gas
  - b) water liquid
  - 2 Molar heat of combustion is defined for formation of water in its state at 10<sup>5</sup> Pa and 25°C, that is as a liquid.
    - a) – indicates the value is exothermic
    - b) <sub>c</sub> indicates combustion
    - c) *H* indicates heat
    - d) Δ indicates change.

## Measuring Δ<sub>c</sub>H° of liquid alkanols

- 1 Successive members of a homologous series differ by a CH<sub>2</sub> group thus there is a molecular mass difference of 14 between successive members.
- 2 The next member of a homologous series has an extra C and two extra Hs to react with oxygen and release a fixed amount of energy.
- 3 The measurements were not all carried out at 10<sup>5</sup> Pa and 25°C.

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# Exercises – Part 3

Exercises 3.1 to 3.5

Name: \_\_\_\_\_

## Exercise 3.1: Chemical labels

Survey chemical labels in your home. List products containing alcohol, ethanol or an –ol name.

Product	Names of alcohols

## **Exercise 3.2: Draft plan for open ended investigation**

**Part A:**

**Part B:**

### **Exercise 3.3: Ethanol as an alternative fuel**

Assess (make a judgment of the value of) the potential of ethanol as an alternative fuel. List the advantages and disadvantages.

### **Exercise 3.4: Procedure used to measure $\Delta_c H^\ominus$ of liquid alkanols**

## **Exercise 3.5: Comparing practical and theoretical values**

<b>Method</b>	<b>Molar heat of combustion (kJ mol<sup>-1</sup>)</b>
practical calculation, simple equipment	
theoretical calculation, bond energies	1352
practical calculation, bomb calorimeter	1367

Suggest reasons why the practical calculation using simple equipment usually gives a different result from the other methods.

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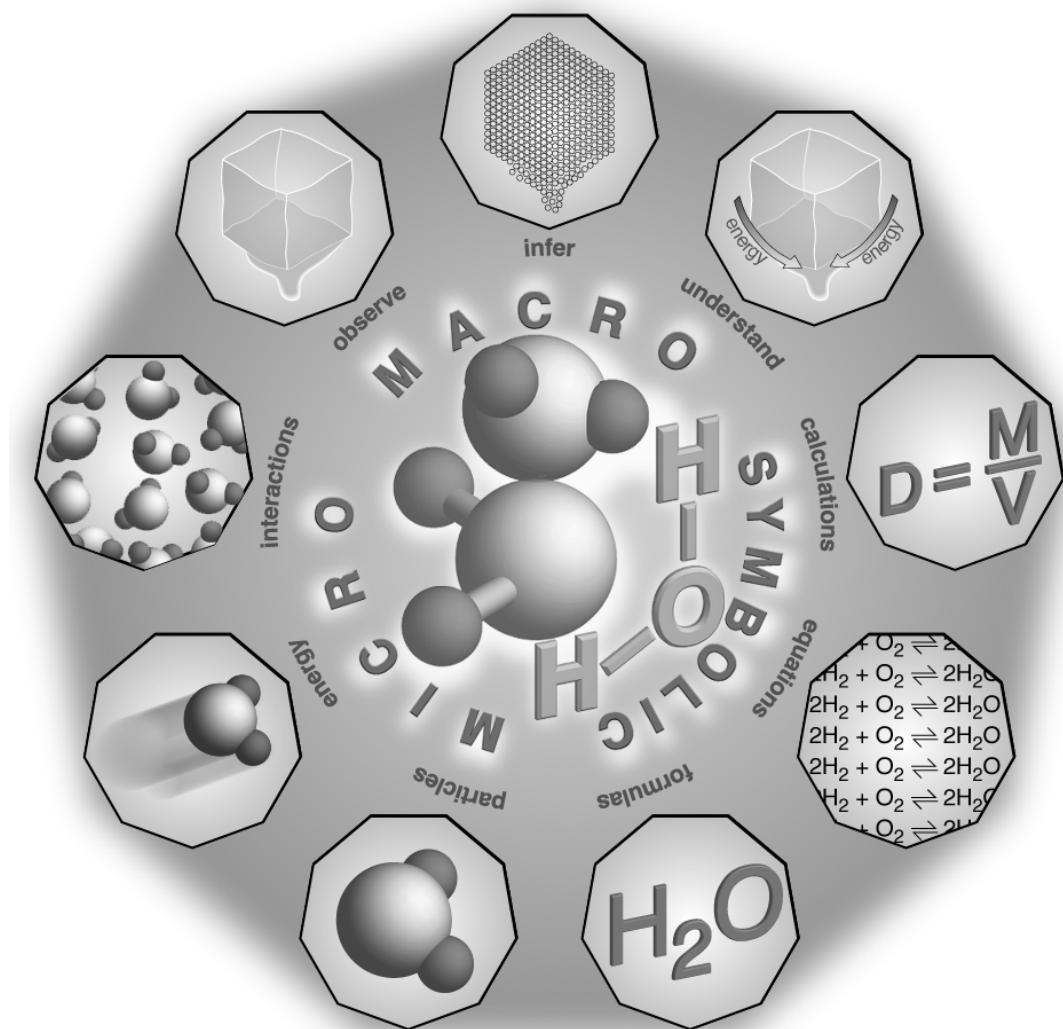
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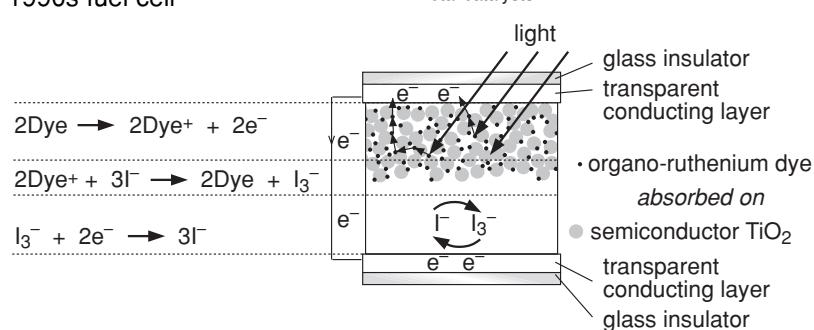
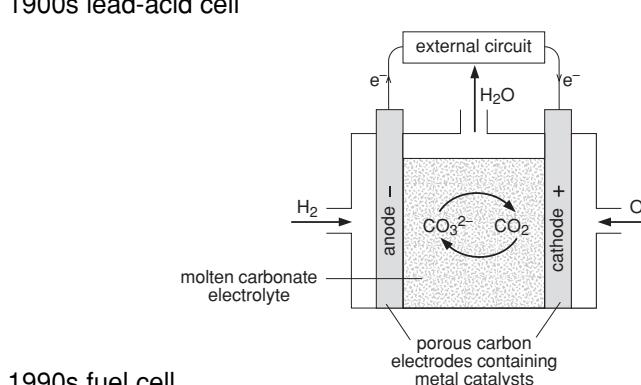
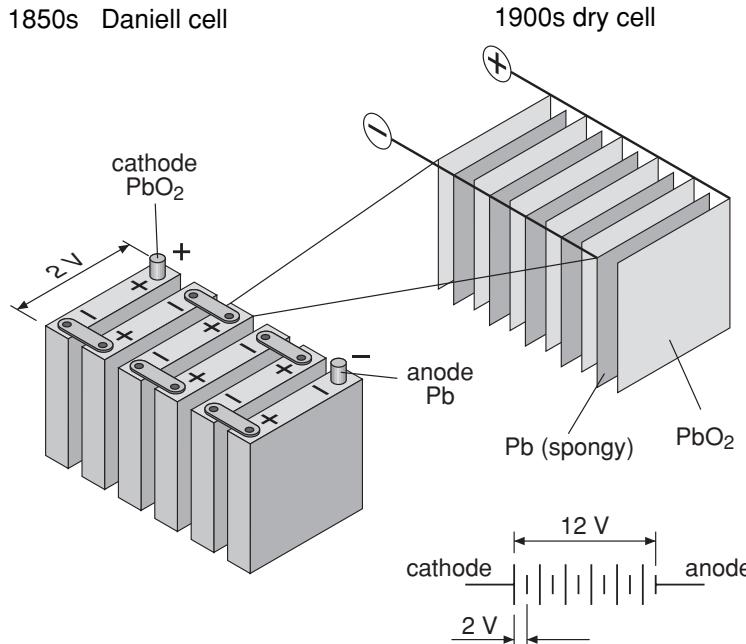
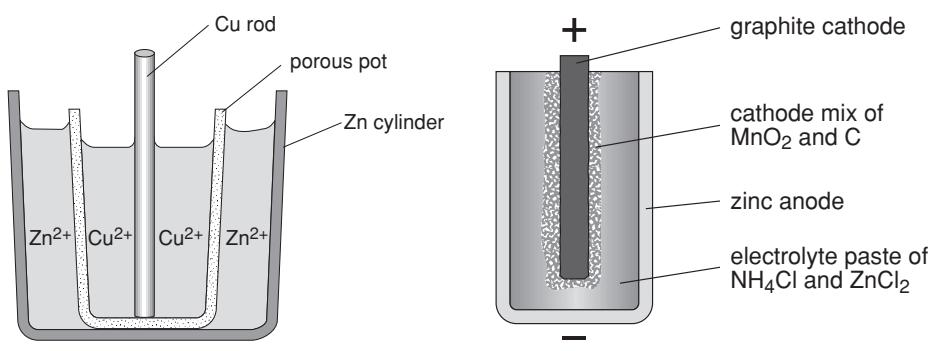
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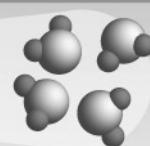


# The identification and production of materials

## Part 4: Electrochemistry



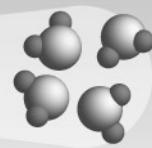


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# Introduction

Electrochemical methods are important in making available energy in its most useful form – as electricity (electrical energy). Electricity is the most versatile form of energy easily converted into kinetic energy, heat, light, chemical energy and sound. Furthermore, modern communication methods and information storage and retrieval are based on the availability of electrical energy. If a source of electrical energy needs to be compact and portable, electrochemical batteries are usually the first choice. Many metal uses such as electroplating, metal extractions from compounds and metal purifications involve electrochemical methods.

The electron transfer reactions that you will study in this part also occur in the photosynthesis that changes light energy to chemical energy, the respiration reactions in cells that provide energy for life and the combustion reactions that provide humanity with most of its energy.

In Part 4 you will be given opportunities to:

- explain the displacement of metals from solution in terms of transfer of electrons
- identify the relationship between displacement of metal ions in solution by other metals to the relative activity of metals
- account for changes in the oxidation state of species in terms of their loss or gain of electrons
- describe and explain galvanic cells in terms of oxidation/reduction reactions
- outline the construction of galvanic cells and trace the direction of electron flow
- identify the use of the terms anode, cathode, electrode and electrolyte to describe galvanic cells
- describe the industrial use of electrolysis for refining a named metal identifying
  - oxidant
  - reductant

- electrolyte used
- conditions under which the electrolysis must occur and the reason for these conditions
- identify an example of the use of electroplating and explain why the process is used.

In Part 4 you will be given opportunities to:

- perform a first-hand investigation to identify the conditions under which a galvanic cell is produced
- 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
- gather, process and present information on the structure and chemistry of a dry cell or lead-acid cell and evaluate it in comparison to:
  - button cell
  - mercury
  - vanadium redox cell
  - lithium
- liquid junction photovoltaic device (eg. the Gratzel cell)

in terms of:

- chemistry
- cost and practicality
- impact on society
- environmental impact
- solve problems and analyse information to calculate the potential  $E^\ominus$  requirement of named electrochemical processes using tables of standard potentials and half equations.

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[http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

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# Metals and electrons

In the module, *Metals*, you learnt that:

- a metal atom has a small number of electrons in its outer valence shell
- when a metal atom M reacts it usually loses all its outer valence shell electrons to form a cation:  $M \rightarrow M^{n+} + n e^-$
- metals vary in their reactivity and can be arranged in a metal activity series from most active to least active:  
K Na Li Ba Ca Mg Al Cr Zn Fe Co Ni Sn Pb Cu Hg Ag Pt Au
- metal reactions with other chemicals can be summarised using the metal activity series:

K Na Li Ba Ca Mg Al Cr Zn Fe Co Ni Sn Pb Cu Hg Ag Pt Au

-----dilute acids react-----→

--water reacts--→ --- steam reacts--→

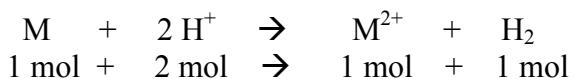
--oxygen fast--→--oxygen slow reaction --→ very slow--→

--alkali--→                        alkali--→

- equations can be written as full formula equations  
 $Mg + 2HCl \rightarrow MgCl_2 + H_2$   
or as net ionic equations  
 $Mg + 2 H^+ \rightarrow Mg^{2+} + H_2$
- the equation for the reaction of a metal with an acid ( $H^+$ ) can be expressed as two half equations:



- the coefficients of a balanced equation show the mole relationship between reactants and products



## Revision of aspects of electrochemistry



- Write a half equation to show formation of a copper(II) ion from copper.

---

- Write a half equation to show formation of an  $\text{Al}^{3+}$  from Al.

---

- Write a full formula equation to show the reaction of magnesium metal with oxygen gas to form ionic magnesium oxide  $\text{MgO}$ .

---

- Write a full formula equation to show the reaction of magnesium with sulfuric acid  $\text{H}_2\text{SO}_4$  to form magnesium sulfate  $\text{MgSO}_4$  salt and a gas.

---

- In the equations for questions 3 and 4 above the magnesium atom undergoes a reaction that can be written as a half equation. Write the half equation for the change that occurs to magnesium atoms.

---

- Two moles of aluminium reacts with six moles of hydrochloric acid to form two moles of aluminium chloride  $\text{AlCl}_3$  and three moles of hydrogen gas. Express this information as a balanced equation.

---

- Write the half equation in which a lithium atom forms a  $\text{Li}^+$ .

---

- Write the half equation in which hydrogen ions form hydrogen gas.

---

- Combine the two half equations from questions 7 and 8 to get an ionic equation for the reaction of lithium metal with acid.

---

Check your answers.

# Displacement of metals from solution

The simplest way to make a solution containing a particular metal ion is to dissolve one of its salts in water. All nitrate and acetate salts are water soluble, as are most chlorides (exceptions:  $\text{Ag}^+$ ,  $\text{Pb}^{2+}$ ) and most sulfates (exceptions:  $\text{Ba}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Ag}^+$ ).

If a variety of metals are immersed in a variety of metal salts and the results tabulated in order of metal activity a pattern can be demonstrated.

+ = reaction

- = no reaction

		Metals					
		Mg	Zn	Fe	Pb	Cu	Ag
Metal ions	$\text{Mg}^{2+}$	-	-	-	-	-	-
	$\text{Zn}^{2+}$	+	-	-	-	-	-
	$\text{Fe}^{2+}$	+	+	-	-	-	-
	$\text{Pb}^{2+}$	+	+	+	-	-	-
	$\text{Cu}^{2+}$	+	+	+	+	-	-
	$\text{Ag}^+$	+	+	+	+	+	-



- 1 The results show that when a metal is placed in a solution of its own ions \_\_\_\_\_
- 2 The most reactive metal in this table is \_\_\_\_\_
- 3 The least active metal in this table is \_\_\_\_\_
- 4 An active metal reacts with less active \_\_\_\_\_ ions.
- 5 The most reactive metal ion in this table is the \_\_\_\_\_ ion.
- 6 The least reactive metal ion in this table is the \_\_\_\_\_ ion.
- 7 If a metal atom is very reactive then its ion is much \_\_\_\_\_ reactive.

Check your answers.

## Observing the reaction between iron atoms and copper(II) ions



### What you need:

- iron nail (if rusty, clean surface with iron wool)
- solution of copper(II) ions eg. copper(II) sulfate solution or a solution of copper(II) acetate prepared by dissolving copper carbonate in vinegar; copper that has been exposed to the atmosphere (but not near salt water) for a long time can be covered with green carbonate
- small transparent container to hold the nail partly in and partly out of the solution.

### What you will do:

- 1 Pour the copper(II) solution into the container
- 2 Position the iron nail partly in and partly out of the solution
- 3 Observe and record observations after 5 minutes, an hour and a day.  
In particular note any colour changes.

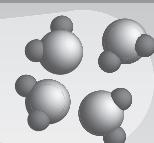
### Results:



### Conclusions:

- 1 Number the statements below into a sequence to explain your observations.
  - A solution of light green  $\text{Fe}^{2+}$  ions is oxidised by oxygen from the air to yellow  $\text{Fe}^{3+}$  ions.
  - The part of the iron nail in the solution becomes thinner as iron atoms  $\text{Fe}$  dissolve to form light green iron(II) ions  $\text{Fe}^{2+}$ .
  - The blue solution of copper(II) ions loses colour as blue  $\text{Cu}^{2+}$  ions react to form dark metallic copper  $\text{Cu}$ .
- 2 Write a balanced equation underneath the word equation:  
iron atoms + copper ions  $\rightarrow$  iron ions + copper atoms

Check your answers.

**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Oxidation and reduction

## Oxidation/reduction reactions

An oxidation/reduction reaction involves electron transfer from one particle (atom, molecule or ion) to another particle (atom, molecule or ion). eg. from iron atom to copper(II) ion in  $Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$

**Oxidation** is loss of electrons.

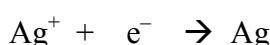
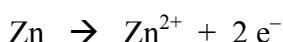
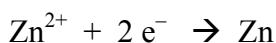
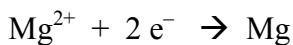
mnemonic: OIL = Oxidation Is Loss

**Reduction** is gain of electrons

mnemonic: RIG = Reduction Is Gain



Sorting oxidation and reduction half equations. As you read the following half equations from left to right you should be able to decide which represent oxidation and which represent reduction. Place OX after an oxidation half equation and RED after a reduction half equation.





Explain why oxidation-reduction reactions can be called:

- a) redox reactions

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- b) electron transfer reactions

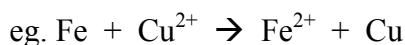
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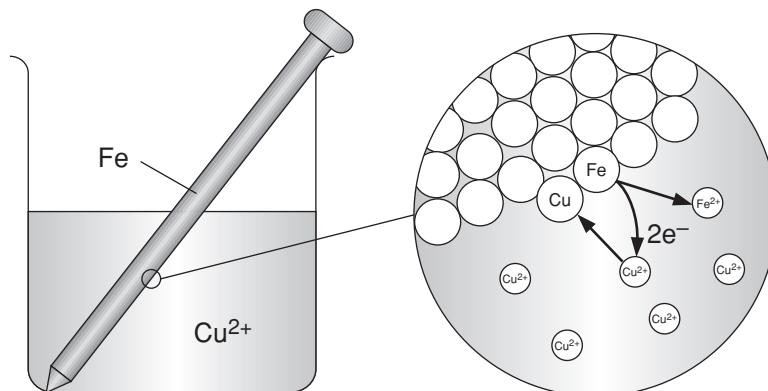
Check your answers.

## Oxidants and reductants

When a redox reaction occurs the reduction (gain of electrons) and oxidation (loss of electrons) occur simultaneously (at the same time).



An iron atom transfers two electrons to a copper ion. This produces an iron(II) ion and a copper atom.



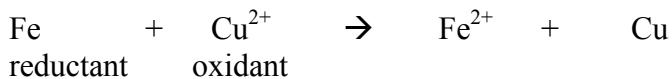
The chemical species that causes the oxidation (loss of electrons) is called the oxidising agent or **oxidant**.  $\text{Cu}^{2+}$  has caused the iron atom to lose two electrons so in this reaction  $\text{Cu}^{2+}$  is the oxidant.

The chemical species that causes reduction (gain of electrons) is called the reducing agent or **reductant**. Fe has caused the copper(II) ion to gain two electrons so in this reaction Fe is the reductant.

When the reaction is expressed as two half equations

$\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$  the oxidation half equation showing loss of electrons shows the reductant undergoing oxidation.

$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$  the reduction half equation showing gain of electrons shows the oxidant undergoing reduction.



Every redox reaction requires a species able to donate electron(s) – the reductant and a species able to accept electron(s) – the oxidant.



You must learn to use the terms oxidation, reduction, oxidant and reductant correctly and frequently to progress in your study of electrochemistry.  
Complete the table then check your answers.

Reaction	Oxidation	Reduction	Oxidant	Reducant
$\text{Mg} + \text{Zn}^{2+} \rightarrow \text{Mg}^{2+} + \text{Zn}$	$\text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-$	$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$	$\text{Zn}^{2+}$	
$\text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu}$	$\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$			$\text{Zn}$
$\text{Mg} + 2\text{H}^+ \rightarrow \text{Mg}^{2+} + \text{H}_2$		$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$	$\text{H}^+$	

From the examples of redox reactions you have studied so far you may already realise that:

- metals can act as reductants
- positive metal ions can act as oxidants.



### Reacting zinc and iodine

This activity requires:

- finely divided zinc Zn(s); this can be obtained by shaking out powder from the bottom of a plastic bag that contained galvanised nails or by running a metal file down the side of a galvanised nail many times.



Make sure the galvanised nails are not labelled with the word cadmium – cadmium is a very toxic metal.

- a dilute iodine solution I<sub>2</sub>(aq); prepared by adding one drop of iodine tincture to every two millilitres of water
- a small test tube to hold the iodine solution.

Add some of the finely divided zinc to the iodine solution and shake. Wait for the zinc particles to settle then observe if the iodine solution has changed colour. If there is no colour change shake again or add more finely divided zinc.



If zinc acts as a reductant write an oxidation half equation for its reaction.

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If zinc was the reductant what chemical was the oxidant? Write a reduction half equation for the oxidant reaction:

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Add the two half equations to obtain a full equation:

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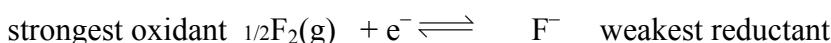
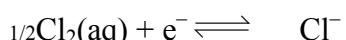
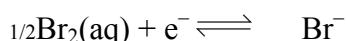
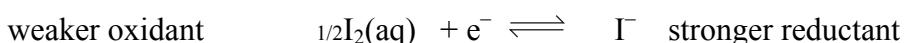
Check your answers.

This reaction demonstrates that non-metals such as a halogen, as well as oxygen, can react as oxidants.

In the halogen group the order of oxidant strength is:

fluorine > chlorine > bromine > iodine.

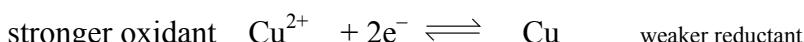
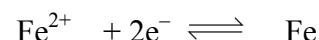
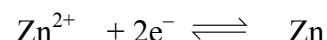
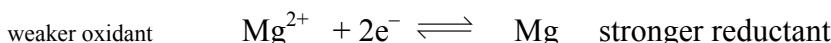
Half equations for halogen/halide ion reaction can be arranged in order:



Note that halide ions act as reductants in the reverse order:

iodide > bromide > chloride > fluoride.

Half equations for metal ion/metal reaction can also be arranged in order:

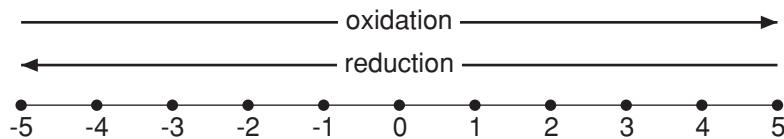


Later on you will see how non-metal and metal half equations can be brought together in a single table of reduction potentials.

# Oxidation state (oxidation number)

Oxidation states (or numbers) are positive or negative numbers allocated using agreed rules. They have been used to widen the definition of oxidation and reduction so that:

- oxidation is an increase in oxidation number
- reduction is a reduction in oxidation number.



Any equation where you can show a change in oxidation number can be regarded as a redox equation.

## Rules for allocating oxidation number (OxN)

- 0 for atoms in elements eg. Mg, O<sub>2</sub>
- equal to the charge of a monatomic ion eg. 2 for Mg<sup>2+</sup>, -1 for I<sup>-</sup>
- -2 for oxygen (except in peroxides such as H<sub>2</sub>O<sub>2</sub> where OxN = -1)  
eg. such as
- 1 for hydrogen (except in metal hydrides such as Li<sup>+</sup>H<sup>-</sup> where H<sup>-</sup> has OxN = -1)
- the algebraic sum of OxNs in a molecule must be zero eg. H<sub>2</sub>O  
(2 x 1 for two hydrogens) + (-2 for oxygen) = 0
- the algebraic sum of OxNs in an electrically neutral formula for an ionic compound must be zero eg. Ca(OH)<sub>2</sub> 2 for Ca<sup>2+</sup> + 2 x -2 for two oxygens + 2 x 1 for two hydrogens = 2 - 4 + 2 = 0
- the algebraic sum of OxNs in a polyatomic ion is equal to the charge on the ion eg. in NH<sub>4</sub><sup>+</sup>, N must have OxN = -3 so that -3 +(4 x 1) = +1; in NO<sub>3</sub><sup>-</sup>, N must have OxN = 5 so that 5 +(3 x -2) = -1

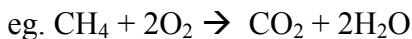
Changes in the oxidation state of a species can be accounted for in terms of an imagined loss or gain of electrons.

In NH<sub>4</sub><sup>+</sup> the fact that N has an OxN of -3 does not mean the N atom has a charge of -3. N is just more electronegative than H and can be imagined to attract three electrons more strongly than three of the hydrogens (the fourth H has no electron as it attached to a NH<sub>3</sub> molecule as a H<sup>+</sup> ion).

In NO<sub>3</sub><sup>-</sup> the N is less electronegative than O and can be imagined to attract its five valence shell electrons less strongly than the oxygens do. Thus in NO<sub>3</sub><sup>-</sup> the N has an OxN of +5.

The OxN does not indicate the presence of positive and negative ions. It is simply a tool or accounting device that enables you to work out if an element has been oxidised or reduced.

Oxidation numbers are particularly useful for determining if a full formula equation represents a redox reaction.

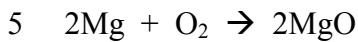
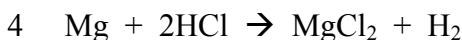
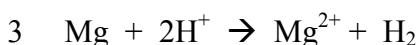
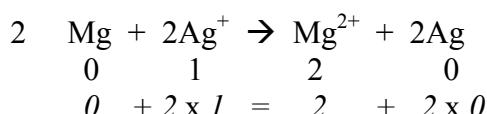
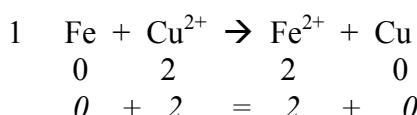


In  $\text{CH}_4$  carbon has an OxN of  $-4$  while in  $\text{CO}_2$  its OxN is  $+4$ . This increase from  $-4$  to  $+4$  indicates the carbon has undergone oxidation. The oxygen on the LHS is in the element with  $\text{OxN} = 0$  while the O in the compounds  $\text{CO}_2$  and  $\text{H}_2\text{O}$  has  $\text{OxN} = -2$ . This reduction in OxN indicates oxygen has undergone reduction. This must be a redox reaction in which the C is oxidised and the O is reduced.

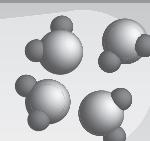
In the precipitation  $\text{Ag}^+ + \text{NO}_3^- + \text{Na}^+ + \text{Cl}^- \rightarrow \text{AgCl(s)} + \text{Na}^+ + \text{NO}_3^-$   
OxNs are           1     5-2     1     -1     1     -1     1     5-2  
Because no OxNs change this is not a redox reaction.



Write the oxidation numbers under each element in the equations below. The first two are examples of what to do. If you are not sure why a certain OxN is allocated then read through the rules for allocating OxN again.  
*Check that the equations are balanced by comparing the total OxN on the LHS with the RHS*



Check your answers.

**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Galvanic cells

Luigi Galvani was an Italian professor of anatomy whose investigations in the late 1700s led to major advances in physics and biology as well as chemistry. He found that the muscle fibre of frog legs would contract when the connected nerves were touched with a source of static electricity. This led to the idea that electricity in the nerves of animals stimulated muscle action. In later experiments he found a greater response when the nerve was touched with two different metals and he constructed a crude source of electricity from two different metals and fluid from a dissected frog.

This development of a source of electric current was extended by the Italian physicist Alessandro Volta in 1800. He constructed a cell made of silver and zinc disks separated by cardboard soaked in salt water. By piling the cells on top of one another he produced a pile (known as Volta's pile) which was the first source of continuous electricity. Piles of cells (batteries) provided the technology used to separate new elements from compounds and stimulated the development of versatile ways of using electric energy.

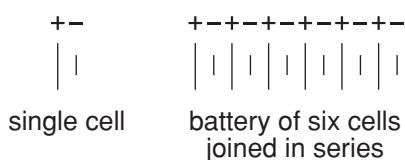


Use a dictionary to match words derived from Galvani and Volta – galvanise, galvanometer, volt, voltage, voltmeter and voltameter – with meanings.

Term	Meaning
	coat with zinc
	potential difference or electromotive force
	instrument measuring voltage
	unit of potential difference or electromotive force
	instrument measuring small currents
	measures quantity of electricity by decomposition

Check your answers.

A galvanic or voltaic cell is a device for delivering an electric current produced by a chemical reaction. Such a device is commonly called a battery. Strictly a battery is a series of cells joined together to provide a higher voltage. In practice single cells that give between 1 and 2 V are often labelled as batteries. Six 2 V cells in series produce a 12 V car battery while six 1.5 V cells in series make up a 9 V battery.



## Investigating galvanic cells

### 1 Making a galvanic cell



#### What you will need:

- two different metals eg. steel paper clip and brass drawing pin or zinc galvanised nail and copper wire
- an **electrolyte** solution eg. a citrus fruit juice solution such as in a lemon which has been rolled and massaged by hand to enable the citric acid solution to move freely; cut the fruit in half or a solution of acid such as vinegar in a container
- to detect the current produced you will need a multimeter able to measure to at least 0.2 V or since you are dealing with a very low voltage source you can use a sensitive moist tongue.

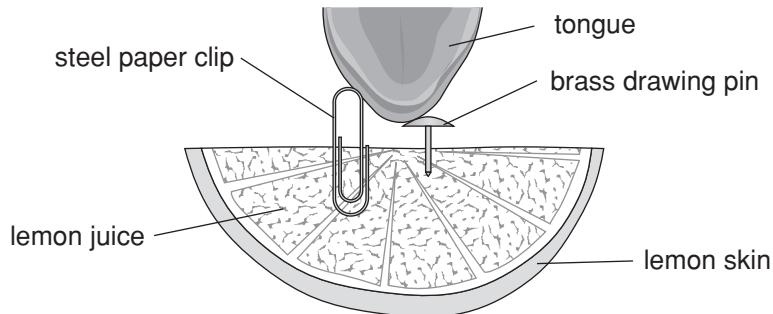
If you do not have the required equipment but have an amalgam filling in one of your teeth you could do the activity described in the box below instead. This only requires some aluminium foil.

#### What you will do:

Set up the two metals so that they are not touching but are close and immersed in an electrically conducting electrolyte solution.

If you are using a multimeter place a probe on each of the metals. If the multimeter is read by a needle moving over a scale and the needle moves away from the scale then swap the probes over.

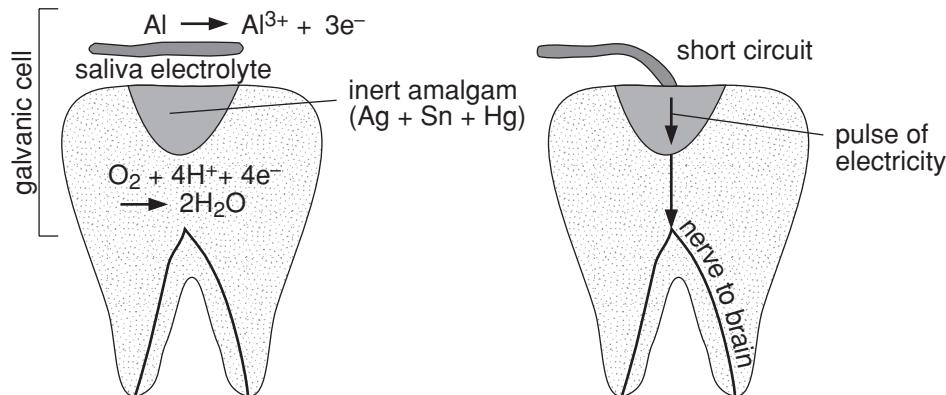
If you are using your tongue, lightly touch the moist tip to form a 'bridge' between the two metals. If you do not notice anything moisten your tongue again and try another part of your tongue.



If you have a metal tooth filling and a piece of aluminium foil you can create a galvanic cell in your mouth. The saliva in your mouth acts as an electrolyte solution. When you successfully create a galvanic cell in your mouth you will know from the electricity travelling along a nerve! If you are very sensitive or do not have a metal filling you may like to seek out a friend to help you.

If you are pain resistant and devoted to advancing scientific knowledge you might like to investigate:

- positioning of the aluminium foil
- whether having some table salt dissolved in saliva on the top of a tooth increases the effect.



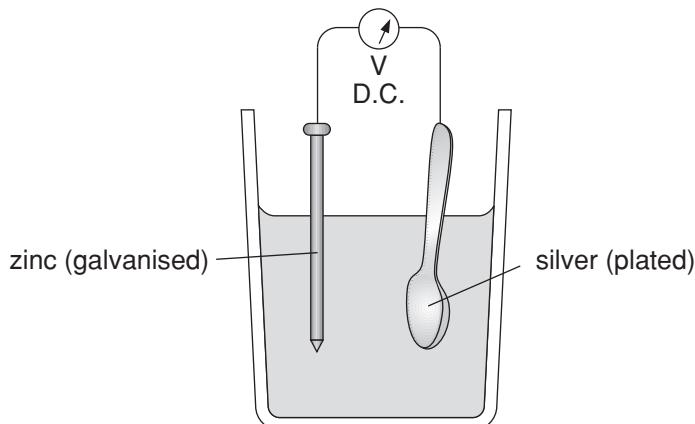
## 2 Measuring the difference in potential between different metals

### What you will need:

- A variety of metals such as steel paper clip, brass drawing pin, copper wire, iron nail, zinc galvanised nail, silver plated cutlery, nickel plated jewellery.
- An electrolyte solution to place the metals in e.g. vinegar (5%w/w acetic acid solution) or a salt solution (make about 5%w/w salt).
- Multimeter able to measure to at least 0.2 V DC (direct current).

### What you will do:

- 1 Place the different metals the same distance apart. Measure the potential (voltage) difference between pairs of different metals.
- 2 What happens when the two metals are the same?
- 3 Which metal combination gives the greatest voltage?



Measuring the difference in potential between zinc and silver.

### Conclusions:



From the results of your first-hand investigations you should be able to complete the sentences below:

To produce a galvanic cell the following are required:

- two different \_\_\_\_\_ which cannot be touching
- an \_\_\_\_\_ solution (conducting solution) in which ions are free to move and so conduct electric charge.
- For a galvanic cell to provide a useful flow of electrons the two \_\_\_\_\_ need to be connected by a conducting wire.

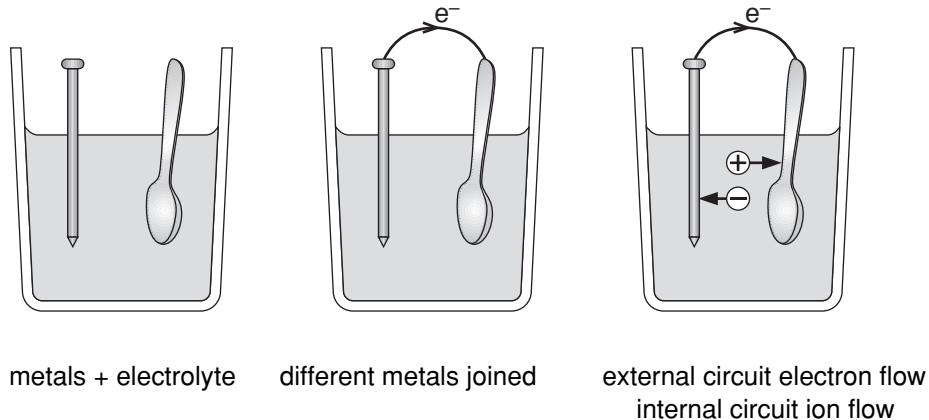
Check your answers.

## What is a galvanic cell?

A **galvanic cell** physically separates a reductant and an oxidant so that electrons cannot go directly from the reductant to the oxidant. Instead the electrons must move along an electrical conductor such as a copper wire connecting the reductant half with the oxidant half of the cell.

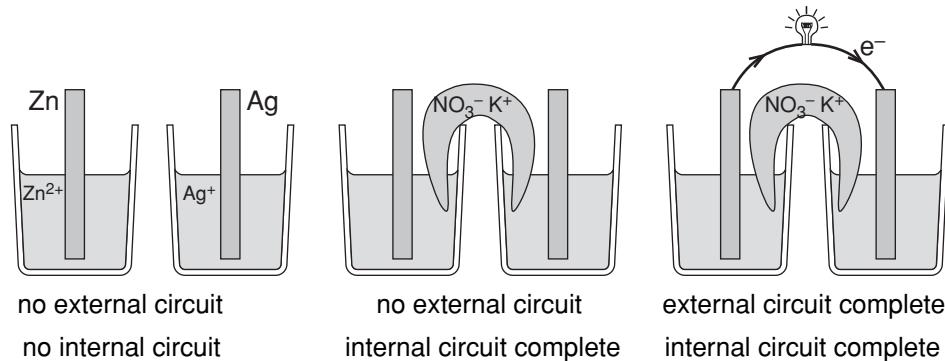
The moving electrons can be used to produce kinetic energy with an electric motor, heat and light energy with a light globe, and other energy conversions.

The simplest galvanic cell consist of two different metals in contact with an electrolyte solution. If the two different metals are joined by an electrical conductor electrons flow from the more active metal to the less active metal.



A buildup of negative charge on the silver spoon and a buildup of positive charge on the zinc coated nail would quickly prevent further flow of electrons in the external circuit. Flow of ions in the electrolyte internal circuit cancels negative charge on the silver and positive charge on the zinc. Electron flow continues in the external circuit as long as ion flow is possible in the internal circuit.

Another galvanic cell arrangement uses the two different metals in two different containers of their ions. To complete the electric circuit an electrically conducting salt bridge is used. The salt bridge can be a filter paper or cotton wool soaked in a salt solution such as potassium nitrate solution.  $\text{K}^+$  and  $\text{NO}_3^-$  ions moving through the water solution allow flow of electric charge between the two containers.



## Electrodes

The material transferring electrons to or from an electrolyte solutions is called an **electrode**.

Metals and graphite are used as electrodes because they are good electrical conductors.



Would you use a metal of high, medium or low activity for an electrode in a water solution? Give a reason in your answer.

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Check your answer.

The electrodes need to be connected by an **electrolyte** which can transfer electric charge, usually by the movement of positive cations and negative anions in solution. The solution may be in a paste (as in a dry cell, that is conventional battery) or **gel** or porous solid designed to minimise movement of the liquid contents.

The electrolyte used in salt bridges is usually potassium nitrate because all  $\text{K}^+$  and all  $\text{NO}_3^-$  salts are soluble. When these ions move into the two containers joined by the salt bridge they do not react with any other ions to form insoluble precipitates.

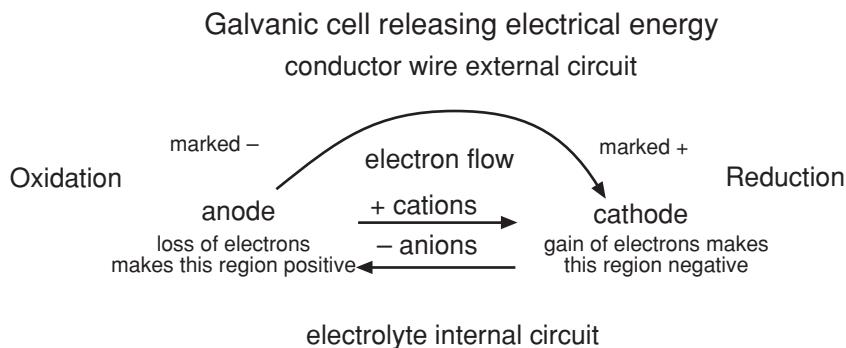
The **anode** is always defined as the electrode at which oxidation occurs.

The **cathode** is always defined as the electrode at which reduction occurs.

The oxidation at the anode involves loss of electrons to the external circuit. Thus the anode acts as a source of negative electrons and so is marked – in a battery (galvanic cell). The loss of electrons leaves the anode region positive so that it attracts negative anions in the electrolyte.

The reduction at the cathode involves gain of electrons from the external circuit. Thus electrons move from the anode, marked –, through the external circuit to the cathode, marked +, in a battery (galvanic cell). This gain of electrons by the cathode region makes it negative so that it attracts positive cations in the electrolyte.

While electrons are moving through the external circuit ions are moving between the electrodes inside the cell. The movement of anions to the anode and cations to the cathode inside the cell completes the electric circuit. Electrons cannot move through water or electrolyte solutions.



Do you remember the mnemonic OIL RIG for oxidation is loss (of electrons) and reduction is gain (of electrons)? Successful chemistry students know a number of mnemonics, some they have learnt from other people while other mnemonics have been created by the students to aid their memory. Here are some other mnemonics to help you.

AN OX (first two letters of anode and oxidation) and RED CAT (first two letters of reduction and cathode) are mnemonics to help you remember the anode and cathode definitions.

An alternative mnemonic is:  
anode and oxidation both start with vowels (a and o)  
cathode and reduction both start with consonants (c and r).

Always remember that for any cell involving electrical energy:

ANode OXidation

REDUction CAThode

## Daniell cell

The Daniell cell was developed in 1836 and provided most of the electricity used in the 1800s to operate extensive morse code telegraph systems and the first telephone systems. This cell uses the reaction between zinc metal and copper sulfate.

The physical arrangement of reactants can be represented as  $\text{Cu} \mid \text{Cu}^{2+} \parallel \text{Zn}^{2+} \mid \text{Zn}$  using a convention agreed to by IUPAC. The single vertical line represents the boundary between phases, in this case solid and solution; the double vertical line represents a salt bridge or a porous barrier through which ions can move to complete an electrical circuit.

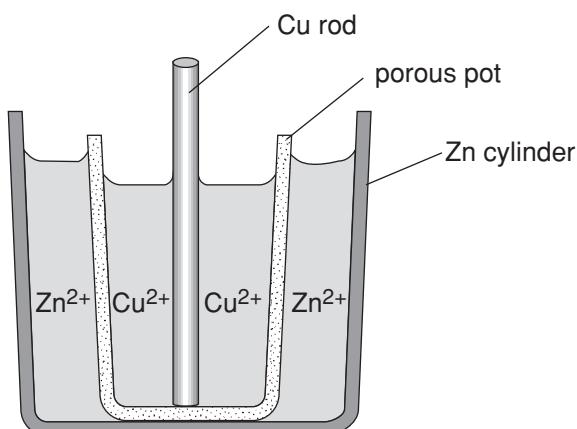
The Cu|Cu<sup>2+</sup> and Zn<sup>2+</sup>|Zn arrangements are called half cells.

Reduction occurs in the copper half cell: Cu<sup>2+</sup> + 2e<sup>-</sup> → Cu

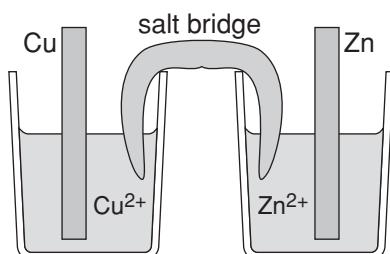
Oxidation occurs in the zinc half cell: Zn → Zn<sup>2+</sup> + 2e<sup>-</sup>

A galvanic cell always has a reduction half cell and an oxidation half cell.

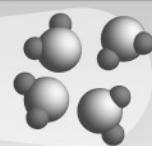
In the Daniell cell the zinc is called an active electrode because it actually reacts and gradually dissolves. The copper is an inert electrode; it becomes thicker as copper atoms are deposited on its surface.



Daniell cell used in the 1800s:



Daniell cell set up in a school laboratory

**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

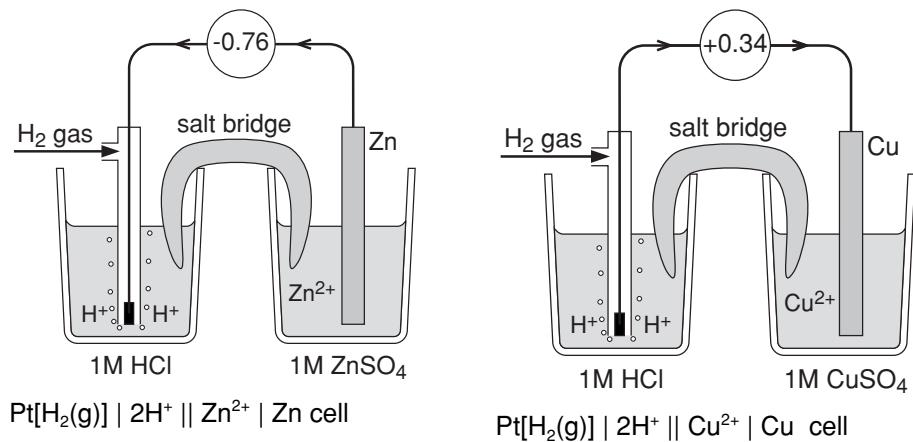
# Measurement of standard potentials

The potential of a chemical to undergo reduction or oxidation can be measured electrically.

If the measurements are carried out under standard conditions – temperature 25°C, gases at 10<sup>5</sup> Pa pressure and solution concentrations 1 mol L<sup>-1</sup>. The values obtained are called standard potentials. The numerical values are expressed compared to a hydrogen electrode. A hydrogen electrode Pt[H<sub>2</sub>(g)] | 2H<sup>+</sup> consists of hydrogen gas at 10<sup>5</sup> Pa pressure bubbling over a platinum electrode in a 1 mol L<sup>-1</sup> H<sup>+</sup> solution.

Any chemical which is an electrically conducting solid can act as an electrode eg. the zinc metal and the copper metal in a Daniell cell.

If the oxidant or reductant is a liquid, gas or in solution, it is placed in contact with an inert conducting electrode such as platinum, graphite or stainless steel. Electrons can be lost or gained by the liquid, gas or solution chemicals through the electrode.



Standard potential measurements made using different half cells joined to a hydrogen electrode half cell can be organised into a table. View the table now by turning to the *Appendix*.

In other texts you may find the order of the equations inverted but the  $E^\ominus$  values should be the same voltage for the same equation in this table.

Knowing that active metals such as lithium and potassium are strong reductants write ‘strong reductants’ at the top right hand corner of the table. Going down the right hand side the reductants become weaker. Write ‘weak reductants’ at the bottom right hand corner.



Knowing that active non-metals such as fluorine, chlorine and oxygen are strong oxidants label the ‘strong oxidants’ and ‘weak oxidants’ corners of the left hand side of the table.

Check your answers.

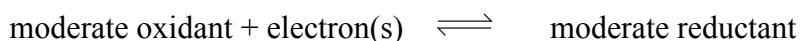
The table can be used to predict whether a reaction is likely to occur.

Consider the reaction of acids containing  $H^+$  with metals to release  $H_2$  gas.  $H^+$ , a moderate oxidant will react with any reductant above it on the RHS of the table. Thus metals from Pb upwards on the RHS are predicted to react with acids releasing hydrogen gas. Copper is *below*  $H^+$  and is predicted not to react; experiments verify that copper does not displace hydrogen gas from acid solutions.

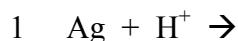
A metal will react with ions of a less active metal. Note that:

- going down the RHS of the table the metals *decrease* in reductant strength
- going down the LHS of the table the metal ions *increase* in oxidant strength.

The layout of the table you are using has



Use the table to predict what will happen when the reactants below are mixed. If you predict no reaction write no reaction after the arrow. If you predict reaction then complete the equation and balance it.



Check your answers.

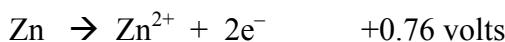
# Predicting potential differences

The voltage obtainable from a galvanic cell can be predicted using the table of standard potentials.

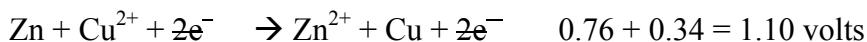
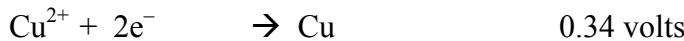
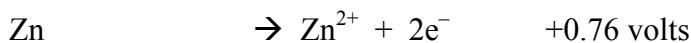
Consider the Daniell cell  $\text{Cu} \mid \text{Cu}^{2+} \parallel \text{Zn}^{2+} \mid \text{Zn}$  where the half cell reactions are  $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$  and  $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$ .

The table equations are provided in the format oxidant +  $\text{e}^- \rightarrow$  reductant.

The equation  $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$  is the reverse of this format and so its  $E^\ominus$  value has to have its sign reversed giving

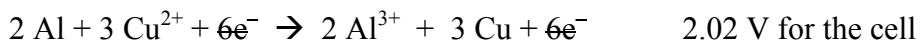
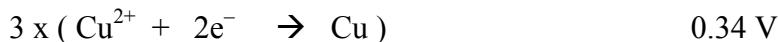
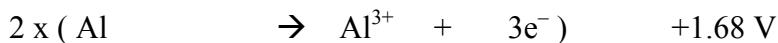


Adding the two half equations and their  $E^\ominus$  values, one for oxidation and the other for reduction, gives the full equation and predicted cell voltage. Add the LHSs, put in the arrow, then add the RHSs. Cancel anything that is common to both sides of the equation, in this case  $2\text{e}^-$ .



Often you will need to multiply a half equation by 2 or 3 so that the number of electrons is the same when adding the oxidation and reduction half equations together. When you do this the half cell voltages do not change. The voltage is a property of the reactant that does not depend on the number of particles.

For example the reaction of aluminium with copper(II) ions.

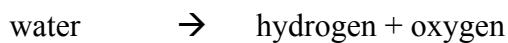


A galvanic cell reacting aluminium metal and copper(II) ions is predicted to produce 2.02 volts. In practice the voltage obtained would probably be a little different. This could be due to conditions other than standard, impure metal, surface coating of oxide on metal, and so on.

When addition of two half cell  $E^\ominus$  values gives a positive cell voltage the reaction is expected to occur spontaneously. The cell is a galvanic cell in which chemical energy is changed to electrical energy.

If the addition of half cell values gives a negative cell voltage the reaction will not occur spontaneously. For the reaction to occur electrical energy has to be put into the cell arrangement. The cell needs to become an electrolysis or **electrolytic cell**. Any electrical energy put in changes to chemical energy. The voltage of electrical energy applied to the cell for reaction to occur has to be greater than the calculated voltage.

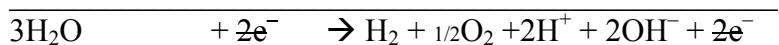
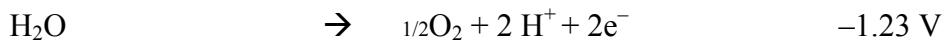
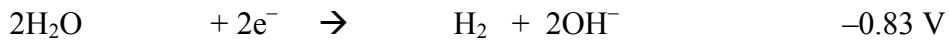
Consider the electrolysis of water to produce hydrogen and oxygen.



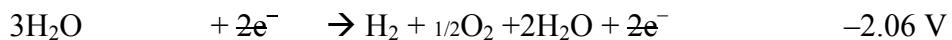
The relevant half cell equations are



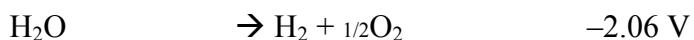
Multiplying the top equation by two and adding gives:



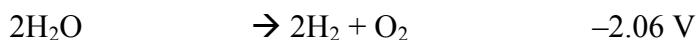
The  $\text{H}^+$  and  $\text{OH}^-$  on the RHS react to form water  $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$  giving



Removing  $2\text{H}_2\text{O}$  from the LHS and RHS simplifies to



It is preferable to have whole number coefficients in an equation so:



Note that during all this manipulation of equations the cell voltage does not change from  $-2.06 \text{ V}$ .

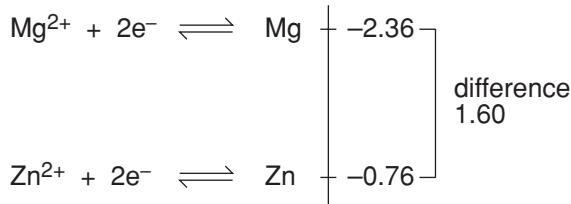
The negative value indicates that water decomposing to hydrogen and oxygen does not occur spontaneously. A voltage greater than  $2.06 \text{ V}$  has to be applied before decomposition of water occurs.

## Shortcut method

The voltage of a galvanic cell (a positive voltage) or the voltage needed to be exceeded to operate an electrolysis cell (a negative voltage) can often be worked out by inspection of the table of electrode potentials.

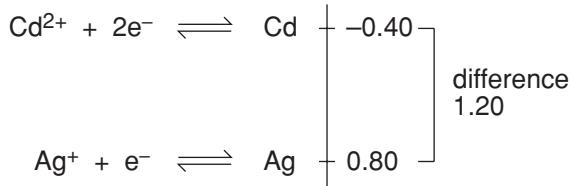
Example 1: What voltage can be obtained from a cell using magnesium and zinc half cells?

The  $E^\ominus$  values for magnesium and zinc half cells are  $-2.36$  and  $-0.76$  volts. The difference between these two values is  $1.60$  volts.



Magnesium is the more active metal and so will act as the reductant, undergo oxidation and thus be the anode. Zinc ions will undergo reduction at the zinc metal cathode.

Example 2: What voltage can be obtained from a cell using silver and cadmium half cells?

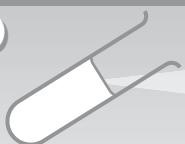
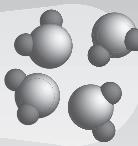


Example 3: What is the maximum voltage that could be obtained from chemicals shown in the table of standard potentials?

A cell reacting lithium and fluorine in theory could provide a voltage equal to the difference between  $-3.04$  and  $2.89$  volts, that is  $5.93$  volts.

In practice such a cell would be difficult to construct as lithium reacts with oxygen and water while fluorine reacts with most substances with which it makes contact. There is another way of getting higher voltages.

Most cells give one to two volts. By arranging cells in series the cell voltages are added together. A 9 V battery is a series of six 1.5 V cells.

**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Electrolytic cells

Electrolytic cells are arrangements where an input of electrical energy produces chemical energy. This is the reverse of a galvanic cell.

A voltage has to be supplied to an electrolytic cell greater than the  $E^\ominus_{cell}$  value.  $E^\ominus_{cell}$  values for electrolytic cells are negative indicating the reaction does not occur spontaneously but requires an input of energy.

Example:  $2H_2O \rightarrow 2H_2 + O_2 -2.06\text{ V}$

Electrolysis of water requires a voltage greater than 2.06 V.



When you carried out electrolysis of water in Part 4 of the first Preliminary Chemistry module *The chemical Earth* you were instructed to use a 9 V battery.

- 1 Explain why you could not use a single 1.5 V battery for this activity.

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- 2 Is there a way that you could use two 1.5 V batteries to carry out electrolysis of water?

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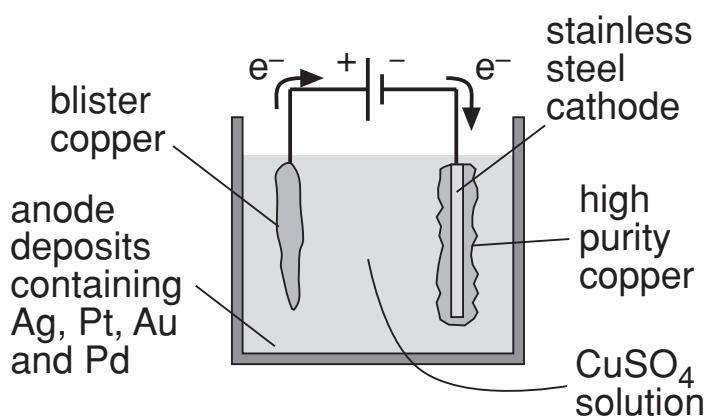
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Check your answers.

If the liquid in an electrolytic cell is a mixture of different substances many different electrolytic reactions are possible. When a metal is extracted from its ores other metals are present as impurities.

If electrolysis of a solution of metals is carried out the voltage applied has to be carefully controlled so that the preferred metal only is recovered free of other contaminating metals.

In Part 4 of the second Preliminary Chemistry module *Metals* the electrolytic refining of copper was covered. In this process blister copper from a smelter containing up to 2% other metals was electrolysed in a solution of  $\text{CuSO}_4$ . The impure blister copper is made the anode and stainless steel sheets are made the cathode. The voltage used to reduce  $\text{Cu}^{2+}$  ions to copper metal on the surface of the stainless steel cathode is carefully controlled so that copper only is deposited. If the desired voltage was exceeded  $\text{Zn}^{2+}$  and  $\text{Fe}^{2+}$  ions in the solution could be reduced as well as the  $\text{Cu}^{2+}$ . The more carefully the voltage is controlled, the purer is the copper deposited. Great care can produce a 99.999% pure cathode coating of copper.



Electrolytic refining of copper.



For the electrolytic refining of copper identify (recognise and name):

- a) the oxidant

\_\_\_\_\_

- b) the reductant

\_\_\_\_\_

- c) the electrolyte used

\_\_\_\_\_

- d) conditions under which the electrolysis must occur and the reasons for these conditions.

\_\_\_\_\_

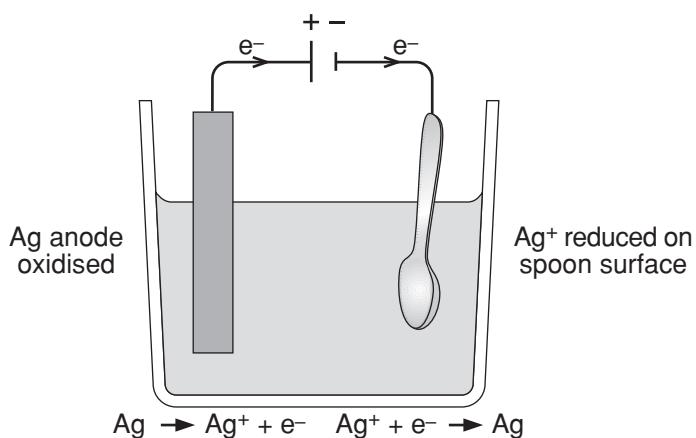
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\_\_\_\_\_

Check your answers.

# Electroplating

Electroplating is electrolysis used to coat a material with a metal. The material to be coated is the cathode and sits in an electrolyte containing ions of the metal to be plated. The anode can be made of the plating metal or an inert material that will not plate under the conditions used.



Silver electroplating.

Silverware is usually steel coated with a thin layer of silver. The silver plating improves appearance and prevents the steel from rusting. Jewellery is plated with gold, high quality screws with nickel, bathroom and kitchen taps with chromium and some industrial steels with cadmium. Plating coatings are thin and give cheaper metals corrosion protection, a more attractive appearance and a smoother surface.



For the silver plating illustrated above give:

1 the oxidant

---

2 the reductant

---

3 the electrolyte used

---

4 the reduction half equation and where it occurs

---

5 the oxidation half equation and where it occurs.

---

Check your answers.

## Comparing galvanic and electrolytic cells

When comparing galvanic and electrolytic cells it is important that you realise that they carry out opposite processes.

Galvanic cell:      chemical energy → electrical energy

Electrolytic cell:      electrical energy → chemical energy

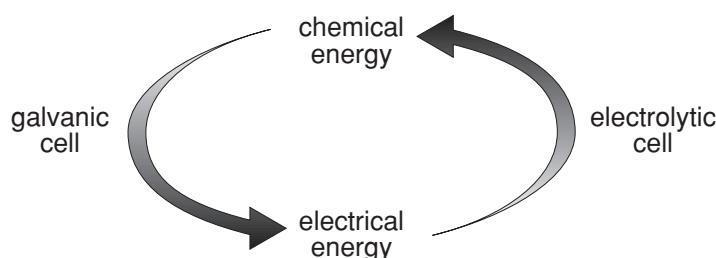
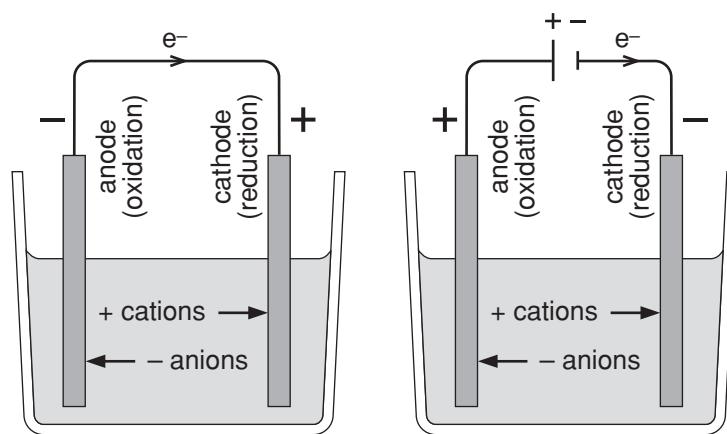
Consequently the electrodes are allocated different signs:

Galvanic cell      anode –      cathode +

Electrolytic cell      anode +      cathode –

In both types of cells:

- positive cations always move to the cathode because that is where the negative electrons go for reduction
- negative anions always move to the anode because that is where oxidation occurred leading to loss of negative electrons from the electrode to the external circuit.



**MACRO**observe  
infer  
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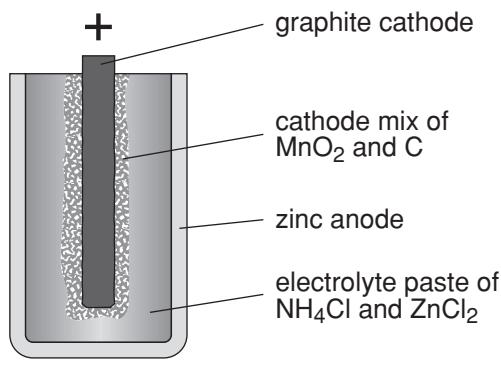
# Sources of electrochemical energy

## Primary (non-rechargeable batteries)

Primary cells are meant to be used until all available chemical energy has been changed to electrical energy then discarded properly.

### Dry cell / Leclanche cell / Zn-C / Zn-MnO<sub>2</sub> (1.5 V)

These are low cost and safe to use but have poor performance at low temperatures.



In the cathode reaction a manganese compound with oxidation state 4 (IV in roman numerals) is changed to a manganese compound with oxidation state 3 (III in roman numerals). Half equations with complex reactions like this will be simplified to:



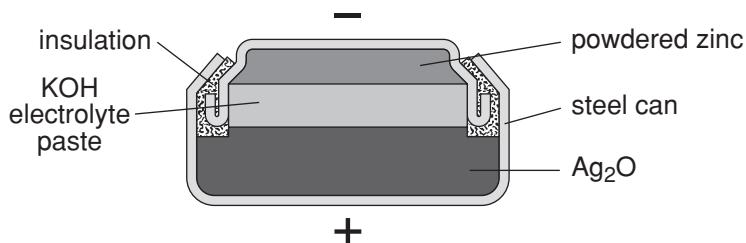
The heavy duty variety of dry cell uses higher quality synthetic MnO<sub>2</sub> and an electrolyte paste of the more expensive ZnCl<sub>2</sub>. This enables a higher current and better low temperature performance.

The alkaline variety of dry cell has a 7 M KOH electrolyte paste and different electrode reactions:



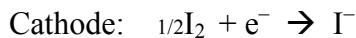
Alkaline cells are most efficient providing moderate continuous currents, have good low temperature performance, maintain a steady voltage and have a longer shelf life. However they are more expensive.

### Button cell / Zn-Ag<sub>2</sub>O (1.6 V)



Mercury button cells previously available are no longer produced because of obsolete technology and concern about release of mercury into the environment.

Lithium iodine button cells are used for heart pacemakers. The electrolyte is a conducting polymer containing Li<sup>+</sup>I<sup>-</sup> formed between the anode and cathode.



Lithium batteries using Li and FeS<sub>2</sub> are now available. These deliver 1.5 V, weigh less than an alkaline battery, deliver up to five times the power but are very expensive.



Use a table of atomic weights to explain why a 1.5 V lithium battery weighs much less than a 1.5 V dry cell.

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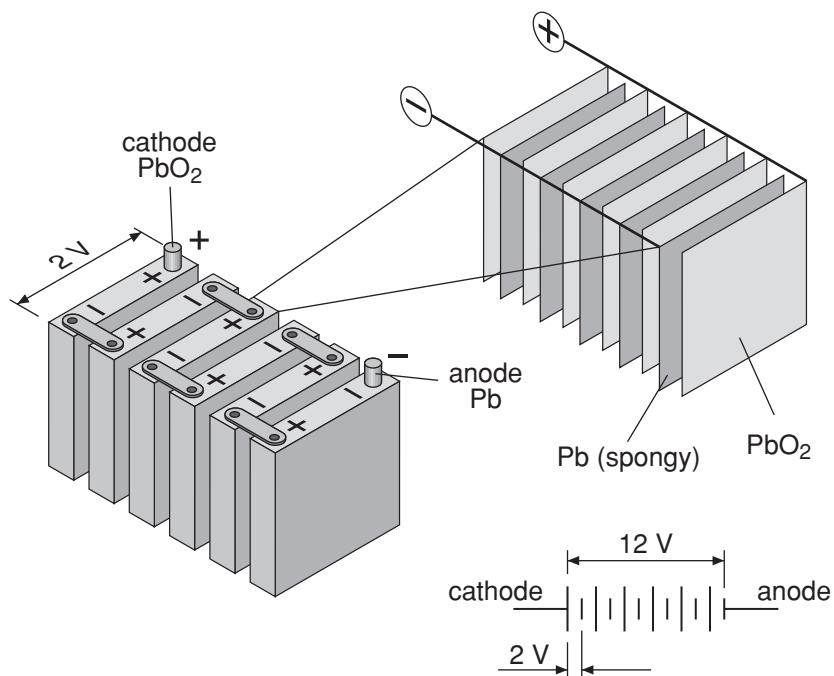
Check your answer.

# Secondary (rechargeable) batteries

These can be discharged and recharged hundreds or thousands of times. The average car battery lasts three to five years. Eventually the physical and chemical changes involved break down the structure of the battery.

## Lead-acid cell (2.0 V)

12 V car batteries are made up of six 2 V lead-acid cells. Lead grid plates of spongy lead and lead(IV) oxide are immersed in a 4 to 5 Molar sulfuric acid solution.



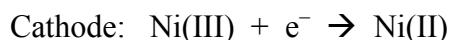
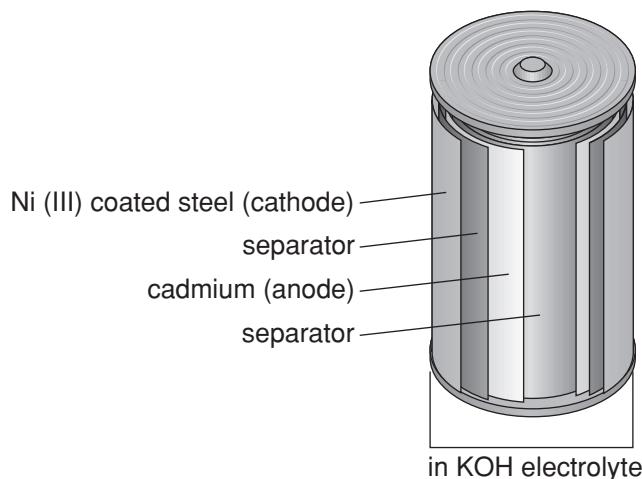
The larger the number of plates in a cell the larger the surface area for reaction. This increases energy output but if there are too many thin plates they are likely to break from physical shock and the battery fails.

Car batteries provide reliable, long life service and are able to provide a current of the order of 100 amperes so the starter motor can start the car engine. Liquid electrolyte makes it sensitive to orientation (doesn't work well on its side or upside down!). Loses electric charge especially if only partly charged. Modern lead-acid batteries are sealed because antimony in the lead prevents release of hydrogen and oxygen gas on recharging.

Battery lead is recycled.

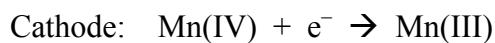
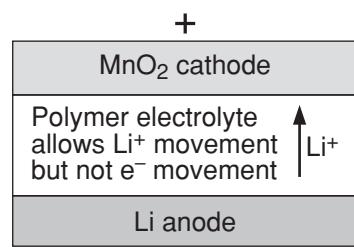
## Nickel-cadmium (Nicad) cell (1.2 V)

Lighter weight than lead-acid batteries but disposal of very toxic cadmium is of concern. Good high and low temperature performance and very resistant to shock and vibration. Can be stored indefinitely in any state of charge but consistent overcharging reduces capacity (called 'memory effect'). Cheapest rechargeable batteries available for photoflash units, cordless power tools and older mobile phones and older portable video cameras.



## Lithium-MnO<sub>2</sub> / Lithium ion (3.0V)

Button size (for calculators, watches and cameras) to lap-top computer size. High energy output for low mass but expensive.

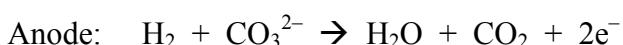
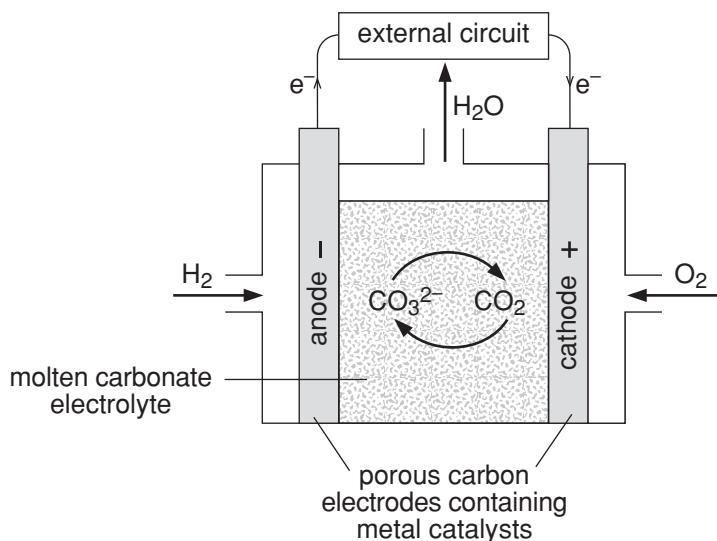


# Flow batteries

Gaseous or liquid reductant and oxidant flow either side of a separating membrane. The development of suitable separating membranes is the greatest challenge in this type of technology.

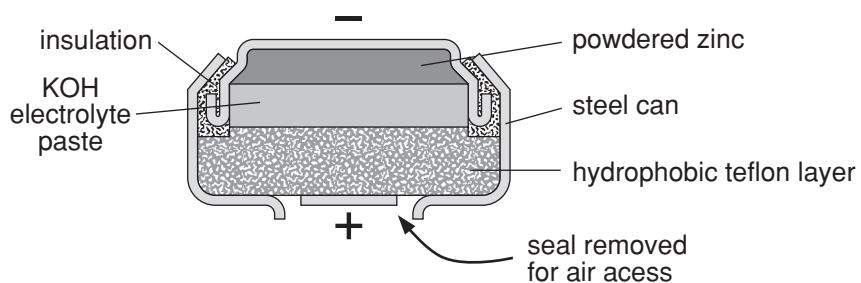
## Fuel cell

Uses combustion redox reactions carried out without burning. No combustion pollutants are produced and up to twice as much electrical energy is obtained compared with conventional production of electricity from combustion heat energy.



Electrode membranes have short life and are expensive. A fuel cell can't store electricity the way other batteries do. Electrical energy is only released when the reactants flow and this requires pumping systems.

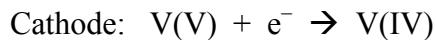
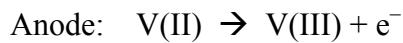
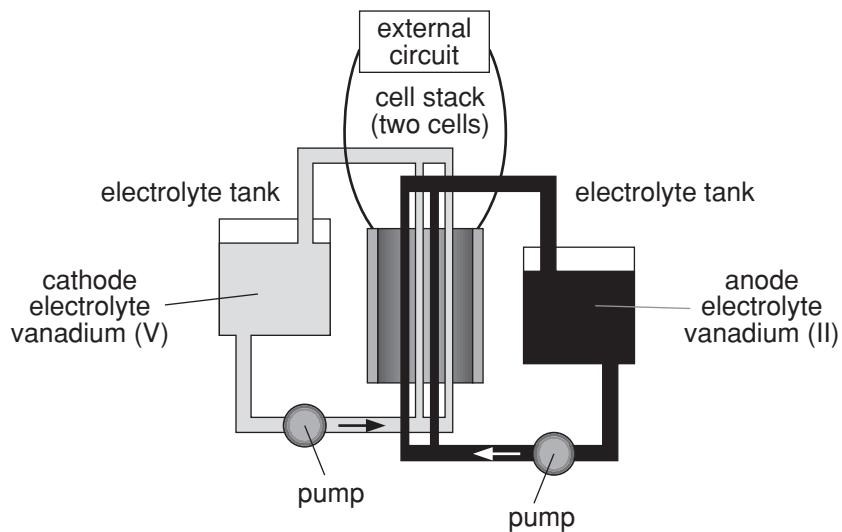
## Zinc-air cell – a hybrid battery and fuel cell (1.25 V)



The porous hydrophobic teflon polymer lets a flow of oxygen from the air in but keeps water out. This type has replaced many mercury button cells.

## Vanadium redox cell (1.26 V)

About 3 M aqueous solutions of vanadium ions flow through a porous graphite felt. Recharged by replacing the electrolyte solutions which can be recycled. Recycling involves recharging, ideally using solar or wind generated electrical energy.



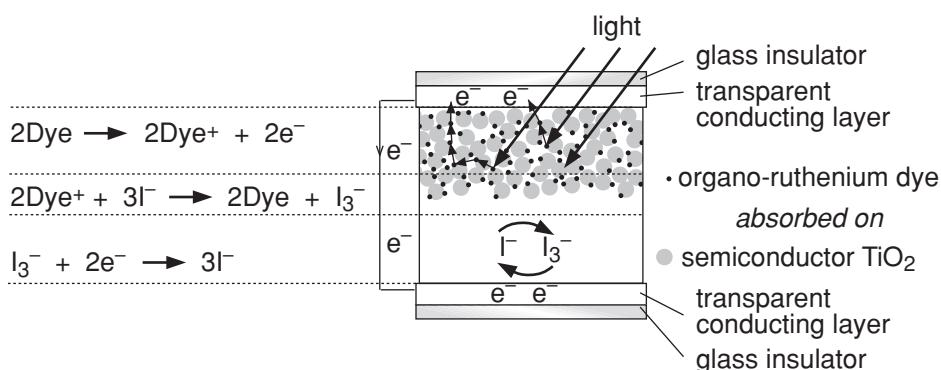
Invented by Professor Maria Skyllas-Kazacos at the University of New South Wales, Sydney, Australia. Undergoing commercial development.

## Gratzel cell (liquid junction photovoltaic device)

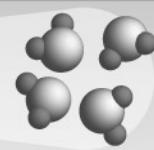
Photovoltaic devices such as silicon solar cells change intense solar light energy to electrical energy. Solar cells operating at 10% efficiency and covering one thousandth of the earth's surface could totally satisfy humanity's current energy needs.

Liquid junction photovoltaic devices work better in low intensity and changing light situations and could be used as walls and windows of buildings.

The cell shown below was developed by Professor Michael Gratzel, Photonics Laboratory, Laussane, Switzerland.



Exercise 4.1 at the end of this part gives some additional information about some of these cells. To complete this exercise you are required to gather, process and present information to compare different types of cells.

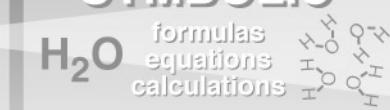
**MACRO**observe  
infer  
understand**SYMBOLIC** $\text{H}_2\text{O}$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Appendix

Table of standard potentials and half equations

<b>oxidant</b>	<b>+ electron(s)</b>	$\rightleftharpoons$	<b>reductant</b>	<b><math>E^\ominus</math> (volts)</b>
$\text{Li}^+$	$+ \text{e}^-$	$\rightleftharpoons$	Li	-3.04
$\text{K}^+$	$+ \text{e}^-$	$\rightleftharpoons$	K	-2.94
$\text{Ca}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Ca	-2.87
$\text{Na}^+$	$+ \text{e}^-$	$\rightleftharpoons$	Na	-2.71
$\text{Mg}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Mg	-2.36
$\text{Al}^{3+}$	$+ 3\text{e}^-$	$\rightleftharpoons$	Al	-1.68
$\text{H}_2\text{O}$	$+ \text{e}^-$	$\rightleftharpoons$	$1/2\text{H}_2(\text{g}) + \text{OH}^-$	-0.83
$\text{Zn}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Zn	-0.76
$\text{Fe}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Fe	-0.44
$\text{Cd}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Cd	-0.40
$\text{Ni}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Ni	-0.24
$\text{Pb}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Pb	-0.13
$\text{H}^+$	$+ \text{e}^-$	$\rightleftharpoons$	$1/2\text{H}_2(\text{g})$	0.00
$\text{Cu}^{2+}$	$+ 2\text{e}^-$	$\rightleftharpoons$	Cu	0.34
$1/2\text{O}_2(\text{g}) + \text{H}_2\text{O}$	$+ 2\text{e}^-$	$\rightleftharpoons$	$2\text{OH}^-$	0.40
$\text{Cu}^+$	$+ \text{e}^-$	$\rightleftharpoons$	Cu	0.52
$1/2\text{I}_2(\text{aq})$	$+ \text{e}^-$	$\rightleftharpoons$	I <sup>-</sup>	0.62
$\text{Fe}^{3+}$	$+ \text{e}^-$	$\rightleftharpoons$	$\text{Fe}^{2+}$	0.77
$\text{Ag}^+$	$+ \text{e}^-$	$\rightleftharpoons$	Ag	0.80
$1/2\text{Br}_2(\text{aq})$	$+ \text{e}^-$	$\rightleftharpoons$	Br <sup>-</sup>	1.10
$1/2\text{O}_2(\text{g}) + 2\text{H}^+$	$+ 2\text{e}^-$	$\rightleftharpoons$	$\text{H}_2\text{O}$	1.23
$1/2\text{Cl}_2(\text{aq})$	$+ \text{e}^-$	$\rightleftharpoons$	Cl <sup>-</sup>	1.40
$1/2\text{F}_2(\text{g})$	$+ \text{e}^-$	$\rightleftharpoons$	F <sup>-</sup>	2.89



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# Suggested answers

## Metals and electrons

- 1  $Cu \rightarrow Cu^{2+} + 2e^-$
- 2  $Al \rightarrow Al^{3+} + 3e^-$
- 3  $2Mg + O_2 \rightarrow 2MgO$
- 4  $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$
- 5  $Mg \rightarrow Mg^{2+} + 2e^-$
- 6  $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$
- 7  $Li \rightarrow Li^+ + e^-$
- 8  $2H^+ + 2e^- \rightarrow H_2$
- 9  $2Li + 2H^+ \rightarrow 2Li^+ + H_2$

## Displacement of metals from solution

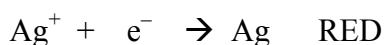
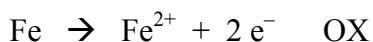
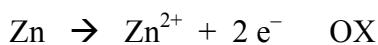
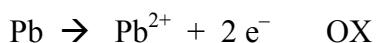
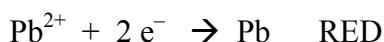
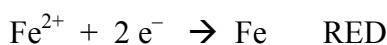
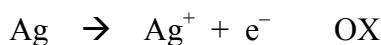
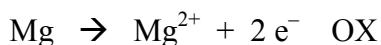
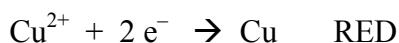
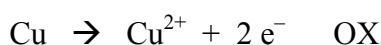
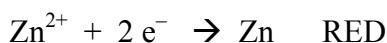
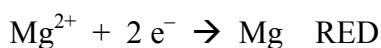
- 1 The results show that when a metal is placed in a solution of its own ions *no reaction occurs*.
- 2 The most reactive metal in this table is *magnesium*.
- 3 The least active metal in this table is *silver*.
- 4 An active metal reacts with less *active* metal ions.
- 5 The most reactive metal ion in this table is the *silver* ion.
- 6 The least reactive metal ion in this table is the *magnesium* ion.
- 7 If a metal atom is very reactive then its ion is much *less* reactive.

## Observing reaction between iron atoms and copper(II) ions

- 1 c a solution of light green  $\text{Fe}^{2+}$  ions is oxidised by oxygen from the air to yellow  $\text{Fe}^{3+}$  ions
- b the part of the iron nail in the solution becomes thinner as iron atoms Fe dissolve to form light green iron(II) ions  $\text{Fe}^{2+}$
- a the blue solution of copper(II) ions loses colour as blue  $\text{Cu}^{2+}$  ions react to form dark metallic copper Cu.
- 2 iron atoms + copper ions  $\rightarrow$  iron ions + copper atoms



## Oxidation/reduction reactions

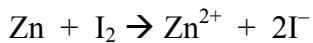
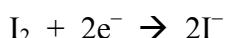


a) redox stands for REDuction-OXidation

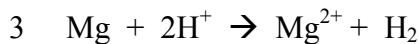
b) electron(s) are transferred from the chemical species that undergoes oxidation to the chemical species that undergoes reduction.

## Oxidants and reductants

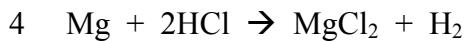
Reaction	Oxidation	Reduction	Oxidant	Reducant
$Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$	$Mg \rightarrow Mg^{2+} + 2e^-$	$Zn^{2+} + 2e^- \rightarrow Zn$	$Zn^{2+}$	Mg
$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$	$Zn \rightarrow Zn^{2+} + 2e^-$	$Cu^{2+} + 2e^- \rightarrow Cu$	$Cu^{2+}$	Zn
$Mg + 2H^+ \rightarrow Mg^{2+} + H_2$	$Mg \rightarrow Mg^{2+} + 2e^-$	$2H^+ + 2e^- \rightarrow H_2$	$H^+$	Mg



## Oxidation state (oxidation number OxN)



$$\begin{array}{cccc} 0 & 1 & 2 & 0 \\ 0 + 2 \times I = & & 2 + & 0 \end{array}$$



$$\begin{array}{ccccc} 0 & 1 & -1 & 2 & -1 & 0 \\ 0 + 2 \times (I-I) = & & & 2 + & (2 \times -I) + & 0 \end{array}$$



$$\begin{array}{ccccc} 0 & 0 & & 2 & -2 \\ 2 \times 0 + 0 = & & & 2 \times (2-2) & \end{array}$$

## Galvanic cells

Term	Meaning
galvanise	coat with zinc
voltage	potential difference or electromotive force
voltmeter	instrument measuring voltage
volt	unit of potential difference or electromotive force
galvanometer	instrument measuring small currents
voltameter	measures quantity of electricity by decomposition

## Investigating galvanic cells

To produce a galvanic cell the following are required:

- two different *metals* which cannot be touching
- an *electrolyte* solution (conducting solution) in which ions are free to move and so conduct electric charge
- For a galvanic cell to provide a useful flow of electrons the two *metals* need to be connected by a conducting wire.

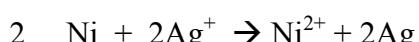
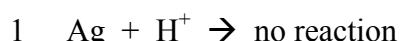
## Electrodes

Low activity. More active metal electrodes could react with the water.

## Measurement of standard potential

The table is labelled:

- ‘weak oxidants’ at the top left hand corner
- ‘strong oxidants’ at the bottom left hand corner

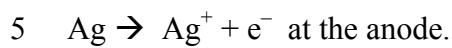


## Electrolytic cells

- 1 A single 1.5 V battery cannot supply a voltage greater than 2.06 volts needed to cause electrolysis of water.
- 2 Connect the two batteries in series (+ of one battery connected to – of the next battery) to provide  $1.5 + 1.5 = 3.0$  volts.
  - a)  $\text{Cu}^{2+}$  in solution  $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$
  - b) Cu in the blister copper  $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$
  - c)  $\text{Cu}^{2+}\text{SO}_4^{2-}$  solution
  - d) controlled voltage so that only  $\text{Cu}^{2+}$  is deposited at the cathode.

## Electroplating

- 1  $\text{Ag}^+$  in solution
- 2 Ag in the anode
- 3  $\text{Ag}^+\text{NO}_3^-$  solution
- 4  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$  at the cathode (metal to be plated)



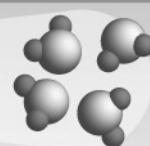
### **Primary (non-rechargeable batteries)**

A lithium cell  $\text{Li} \rightarrow \text{Li}^+ + \text{e}^-$  releases one mole of electrons from about 7 g (one mole) of lithium.

A zinc cell  $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$  releases one mole of electrons from about 33g of zinc.

The lithium cell is much lighter than a zinc cell.



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Exercise 4.1

Name: \_\_\_\_\_

**Exercise 4.1: Comparing sources of electrochemical energy**

Gather, process and present information to complete this table which compares five cells. Use the information provided in the section on *Sources of electrochemical energy*.

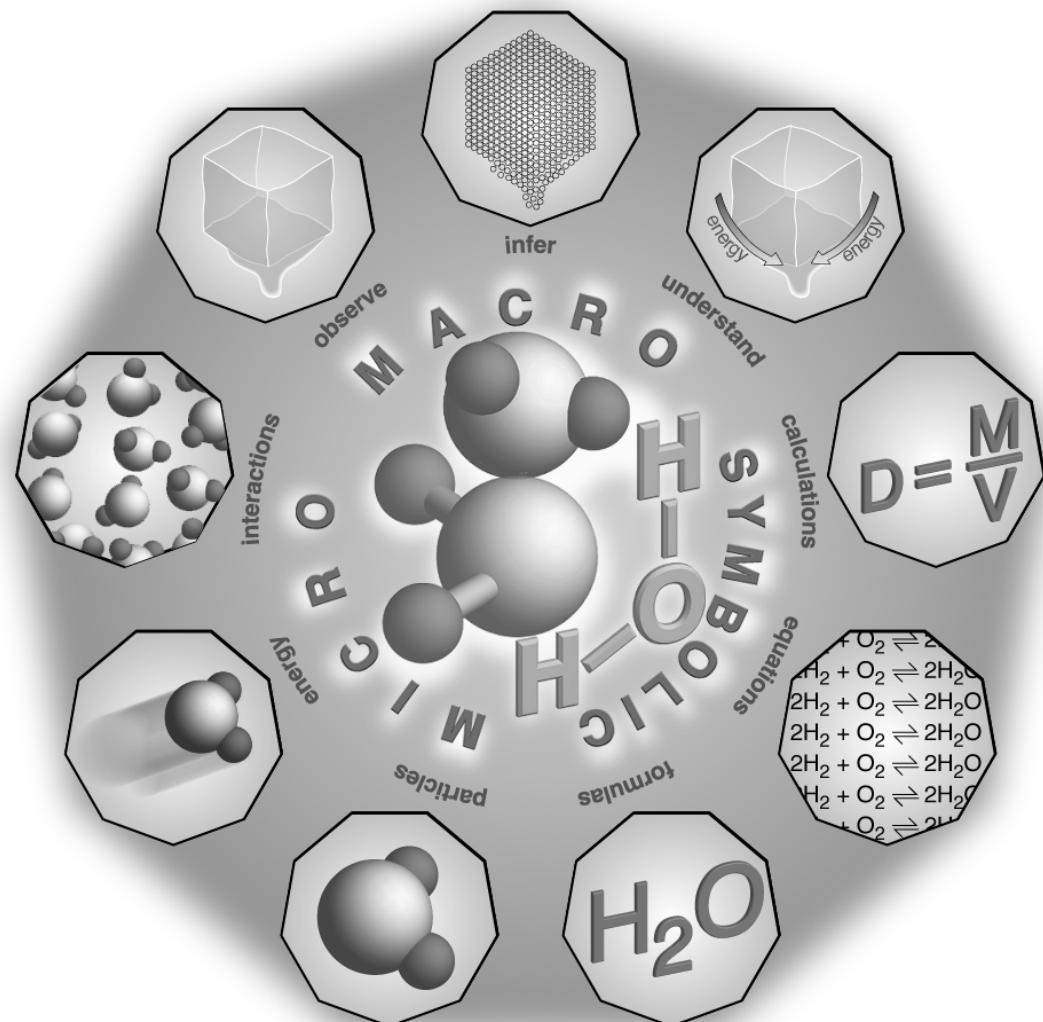
Cell	dry	lead-acid	button	Lithium ion	Vanadium
anode					
cathode	$MnO_2$			$MnO_2$	$VO_2^+$
electrolyte					
Energy density W-h/kg	90	30	125	150	–
cost and practicality					
society and environment impact					





# The identification and production of materials

## Part 5: Nuclear chemistry



1	H 1.008 Hydrogen	4	B 9.01 Beryllium	5	B 10.81 Boron	6	C 12.01 Carbon	7	N 14.01 Nitrogen	8	O 16.00 Oxygen	9	F 19.00 Fluorine	10	He 4.003 Helium																						
3	Li 6.94 Lithium	11	Mg 24.31 Magnesium	19	K 39.10 Potassium	20	Ca 40.08 Calcium	21	Sc 44.96 Scandium	22	Ti 47.87 Titanium	23	V 50.94 Vanadium	24	Cr 52.00 Chromium	25	Mn 54.94 Manganese	26	Fe 55.85 Iron	27	Co 58.93 Cobalt	28	Ni 58.69 Nickel	29	Cu 63.55 Copper	30	Zn 65.39 Zinc	31	Ga 69.72 Gallium	32	Ge 72.61 Germanium	33	As 74.92 Arsenic	34	Se 78.96 Selenium	35	Kr 79.90 Krypton
11	Na 22.99 Sodium	37	Rb 85.47 Rubidium	38	Sr 87.62 Strontium	39	Y 88.91 Yttrium	40	Nb 91.22 Niobium	41	Zr 92.91 Zirconium	42	Mo 95.94 Molybdenum	43	Tc [98.91] Technetium	44	Ru 101.1 Ruthenium	45	Rh 102.9 Rhodium	46	Pd 106.4 Palladium	47	Ag 107.9 Silver	48	Cd 112.4 Cadmium	49	In 114.8 Indium	50	Sn 118.7 Tin	51	Sb 121.8 Antimony	52	Te 127.6 Tellurium	53	I 126.9 Iodine	54	Xe 131.3 Xenon
55	Cs 132.9 Cesium	56	Ba 137.3 Barium	57-71	LANTHANIDES [226.0] Actinides	72	Hf 178.5 Hafnium	73	Ta 180.9 Tantalum	74	W 183.8 Tungsten	75	Os 186.2 Osmium	76	Re 190.2 Rhenium	77	Ir 192.2 Iridium	78	Pt 195.1 Platinum	79	Au 197.0 Gold	80	Hg 200.6 Mercury	81	Pb 204.4 Thallium	82	Bi 207.2 Lead	83	Po 209.0 Bismuth	84	At [210.0] Polonium	85	Rn [222.0] Radon				
87	Ra [223.0] Francium	88	Ra [226.0] Radium	89-103	Rf [261.1] Rutherfordium	104	Db 262.1 Dubnium	105	Sg [263.1] Seaborgium	106	Bh [264.1] Bohrium	107	Hs [265.1] Hassium	108	Mt [268] Meitnerium	109	Mt [268] Meitnerium	110	Uuu [268] Ununtrium	111	Uub [268] Ununbium	112	Uuu [268] Ununtrium	113	Uub [268] Ununbium	114	Uuq [268] Ununquadium	115	Uuh [268] Ununhexium	116	Uuh [268] Ununhexium	117	Uuo [268] Ununoctium	118	Uuo [268] Ununoctium	–	Ununhexium

57	La 138.9 Lanthanum	58	Ce 140.1 Ceium	59	Pr 144.2 Praseodymium	60	Nd 146.9 Neodymium	61	Pm [146.9] Promethium	62	Sm 150.4 Samarium	63	Eu 152.0 Europium	64	Gd 157.3 Gadolium	65	Tb 158.9 Terbium	66	Dy 162.5 Dysprosium	67	Ho 164.9 Holmium	68	Er 167.3 Erbium	69	Tm 168.9 Thulium	70	Yb 173.0 Ytterbium	71	Lu 175.0 Lutetium
89	Ac [227.0] Actinium	90	Th 232.0 Thorium	91	Pa 231.0 Protactinium	92	U 238.0 Uranium	93	Np [237.0] Neptunium	94	Pu [239.1] Plutonium	95	Am [241.1] Americium	96	Cm [244.1] Curium	97	Bk [249.1] Berkelium	98	Cf [252.1] Einsteinium	99	Es [252.1] Fermium	100	Fm [257.1] Mendeleyium	101	Md [258.1] Nobelium	102	No [259.1] Lawrencium	103	Lr [262.1] Lanthanum

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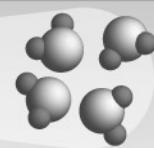
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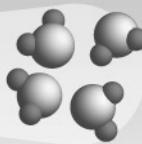
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# Introduction

Nuclear chemistry provides a range of materials to assist in tracing the movement of atoms especially in living things and both within and between the biosphere, lithosphere, hydrosphere and atmosphere. Major advances in understanding the bond breaking and movement of atoms in complex chemical reactions has come from the use of tracer isotopes of different elements.

In Part 5 you will be given opportunities to learn to:

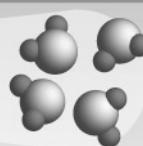
- distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable
- describe how transuranic elements are produced in nuclear reactors
- describe how commercial radioisotopes are produced in nuclear reactors
- identify instruments and processes that can be used to detect radiation
- identify one use of a named radioisotope
  - in industry
  - in medicine
  - to determine and/or verify reaction mechanisms in chemistry
- describe the way in which the above named radioisotopes are used and relate this to the chemical properties of the radioisotopes described.

In Part 5 you will be given opportunities to:

- process and analyse information from secondary sources by using a flow diagram to trace the sequence of fission products released during the decay of uranium
- process information from secondary sources to describe recent discoveries of elements

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

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[http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

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# Isotopes

**Isotopes** are atoms of the same element that have different atomic masses.

Mnemonic: 'iso' mean equal and the 'p' in isotope can be regarded as representing protons. Isotopes all have the same number of protons and therefore are all atoms of the same element. Isotopes differ in the number of neutrons and hence mass.

Any isotope can be represented by  ${}^A_Z E$

A represents the mass number = number of protons + neutrons

Z represents the atomic number = number of protons

E represents the symbol of the element with atomic number Z.

${}^A_Z E$  can be used to represent an atom or a nucleus. If  ${}^A_Z E$  represents a nucleus the charge on the nucleus,  $Z+$ , is not shown separately.

Chemical reactions involve rearrangement of atoms while nuclear reactions involve the rearrangement of protons and neutrons in nuclei to form new nuclei and therefore new atoms.

Chemical reaction	Nuclear reaction
atoms rearrange but don't change	atoms of one element typically change to atoms of another element
valence shell electrons are transferred or shared between atoms	protons and neutrons in a nucleus are rearranged or change in number
small amounts of energy involved	large amounts of energy involved
rate affected by temperature, catalyst and the type of compound an atom is in	rate affected by number of nuclei but not by temperature, catalyst or type of compound a nucleus is in
no measurable change in mass	measurable changes in mass



Of about 2000 isotopes that have been studied only 279 are stable! Most isotopes are unstable and emit radiation as they spontaneously release energy or **decay**. Each unstable isotope can be called a radioactive isotope, **radioisotope**, radioactive nuclide or **radionuclide**. The time required for the radioactivity level to be halved is known as the **half-life**. Half lives vary from less than a millionth of a second to more than a billion years!

Complete this table of selected isotopes.

Isotope name	Isotope symbol	Mass no. A (p+n)	Atomic no. Z (p)	A – Z (n)	Radio-activity emitted	Half-life d=days y=years
hydrogen-1	${}_1^1\text{H}$	1	1	0	–	–
hydrogen-2 or deuterium	${}_1^2\text{H}$	2	1	1	–	–
hydrogen-3 or tritium	${}_1^3\text{H}$	3	1	–	$\beta$	12.3 y
helium-4 or $\alpha$ -particle	${}_2^4\text{He}$	4	2	–	–	–
carbon-12	${}_6^{12}\text{C}$	–	6	6	–	–
carbon-14	${}_6^{14}\text{C}$	14	–	8	$\beta$	5720 y
	${}_8^{16}\text{O}$	–	–	–	–	–
	${}_8^{18}\text{O}$	–	–	–	–	–
cobalt-60	${}_{27}^{60}\text{Co}$	60	27	–	$\beta, \gamma$	5.3 y
	${}_{82}^{206}\text{Pb}$	–	82	–	–	–
radon-222	${}_{86}^{222}\text{Rn}$	222	–	136	$\alpha, \gamma$	3.8 d
radium-226	${}_{88}^{226}\text{Ra}$	226	–	–	$\alpha, \gamma$	1622 y
uranium-235	${}_{92}^{235}\text{U}$	235	92	–	$\alpha, \gamma$	$7 \times 10^8$ y
	${}_{95}^{241}\text{Am}$	–	–	–	$\alpha, \gamma$	458 y

Check your answers.

Note that  $\alpha$  or  $\beta$  emissions are often followed by a  $\gamma$  emission. Emission of an  $\alpha$  or  $\beta$  particle produces a nucleus with a more stable proton to neutron ratio. (Neutrons must be present in any nucleus containing more than one proton. They are important in overcoming the repulsion between the positively charged protons close together in a nucleus). However there is often excess energy in the arrangement of neutrons and protons after the  $\alpha$  or  $\beta$  particle is emitted. Gamma rays are emitted as the neutrons and protons rearrange to lower, more stable, energy levels.

Radiation emission occurs randomly. Which nucleus will decay next cannot be predicted. Changes in temperature, pressure, chemical form (atom, molecule or ion), concentration, do not affect rate of decay. Rate of decay is measured by half-life, time for half the nuclei to decay.

<b>Radiation</b>	<b>Symbol</b>	<b>Type</b>	<b>Example of emission</b>
alpha	$\alpha$	${}^4_2\text{He}$ particle	${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^4_2\text{He}$
beta	$\beta$	${}^0_{-1}\text{e}$ particle	${}^{14}_6\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^0_{-1}\text{e}$
gamma	$\gamma$	electromagnetic radiation	${}^{60}_{27}\text{Co} \rightarrow {}^{60}_{27}\text{Co} + \gamma$

An alpha particle consists of two protons and two neutrons and is equivalent to a helium nucleus  ${}^4_2\text{He}$ .

A beta particle is usually a negative electron with negligible mass  ${}^0_{-1}\text{e}$ .

A gamma emission is a high frequency and therefore high energy electromagnetic radiation pulse. Note that a new nucleus is not formed.



- 1 Complete the following radioactivity emissions by inserting  ${}^4_2\text{He}$ ,  ${}^0_{-1}\text{e}$  or  $\gamma$ .

- a)  ${}^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} +$
- b)  ${}^{131}_{53}\text{I} \rightarrow {}^{131}_{54}\text{Xe} +$
- c)  ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} +$
- d)  ${}^{24}_{11}\text{Na} \rightarrow {}^{24}_{11}\text{Na} +$
- e)  ${}^{32}_{15}\text{P} \rightarrow {}^{32}_{16}\text{S} +$

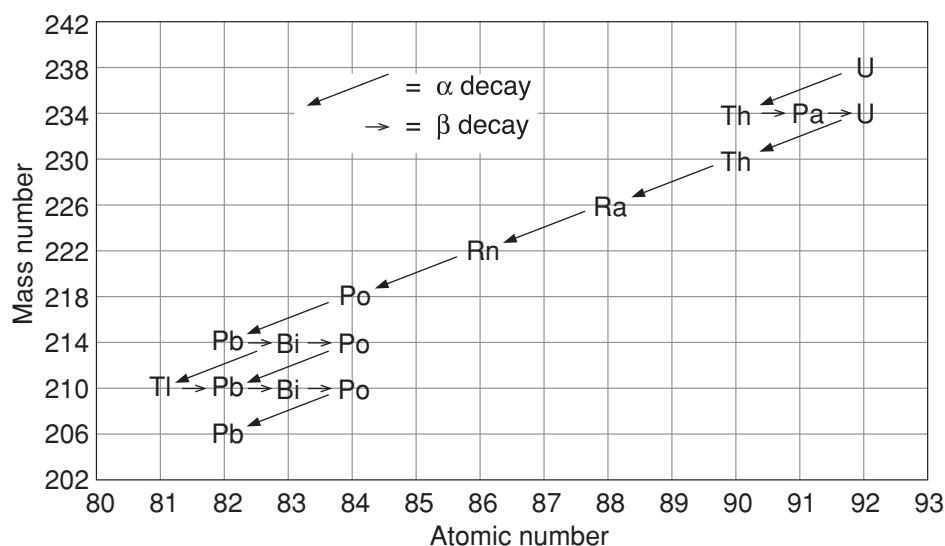
2 Complete the following sentences:

When an alpha particle or \_\_\_\_\_ is emitted the nucleus changes to that of a different element. Emission of a \_\_\_\_\_ lowers the energy level but does not produce a new nucleus.

Check your answers.

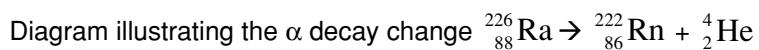
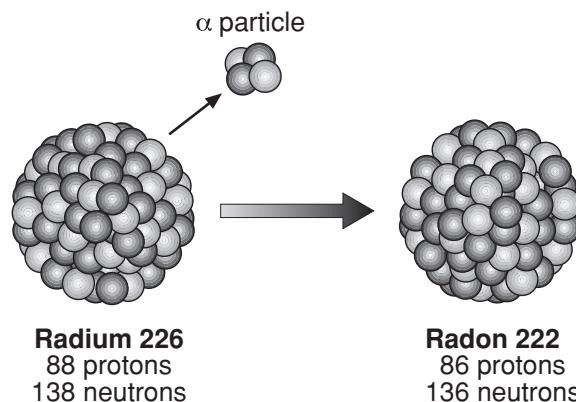
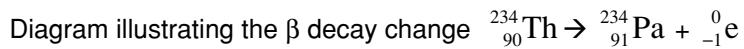
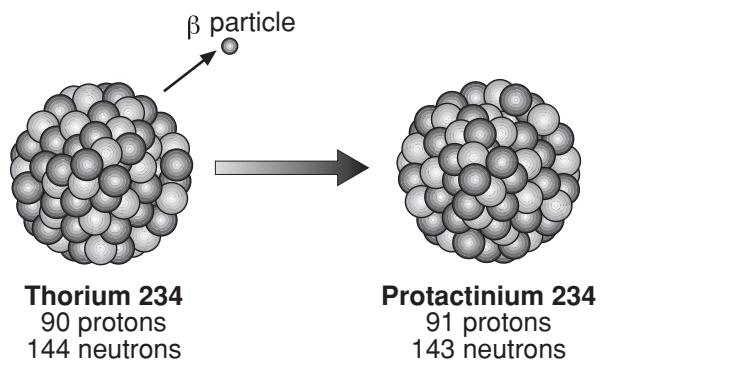
## Uranium decay series

Uranium in nature consists of 99.3%  $^{238}_{92}\text{U}$  and 0.7%  $^{235}_{92}\text{U}$ . These isotopes go through a series of decays to ultimately form stable lead isotopes. The uranium-238 decay series is shown below:

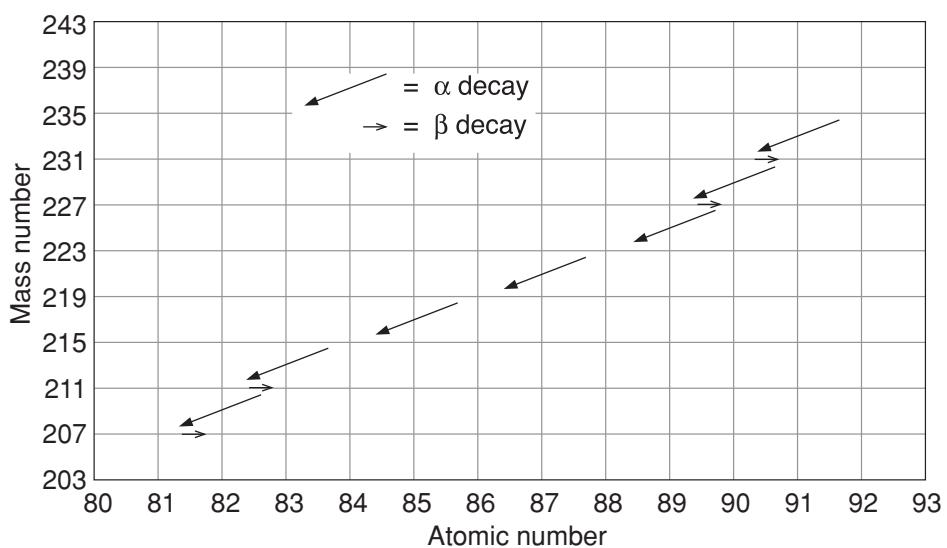


The overall change is  $^{238}_{92}\text{U} \rightarrow ^{206}_{82}\text{Pb} + 8 ^4_2\text{He} + 6 ^0_{-1}\text{e}$  Note that:

- each  $\alpha$  emission reduces atomic mass by 4 (loss of four **nucleons** from the nucleus) and atomic number by 2 (loss of two protons)
- each  $\beta$  emission does not change atomic mass (mass of electron is negligible compared to proton or neutron) but increases atomic number because a neutron changes to a proton and an electron:  
$$^1_0\text{n} \rightarrow ^1_1\text{p} + ^0_{-1}\text{e}$$
- each step also emits at least one  $\gamma$  ray (not shown in the diagrams), and often more than one, as the neutrons and protons rearrange to lower energy levels.



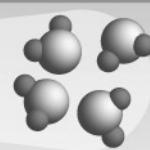
Complete the labelling of the uranium-235 decay series using symbols from the periodic table.



Write an equation for the overall change

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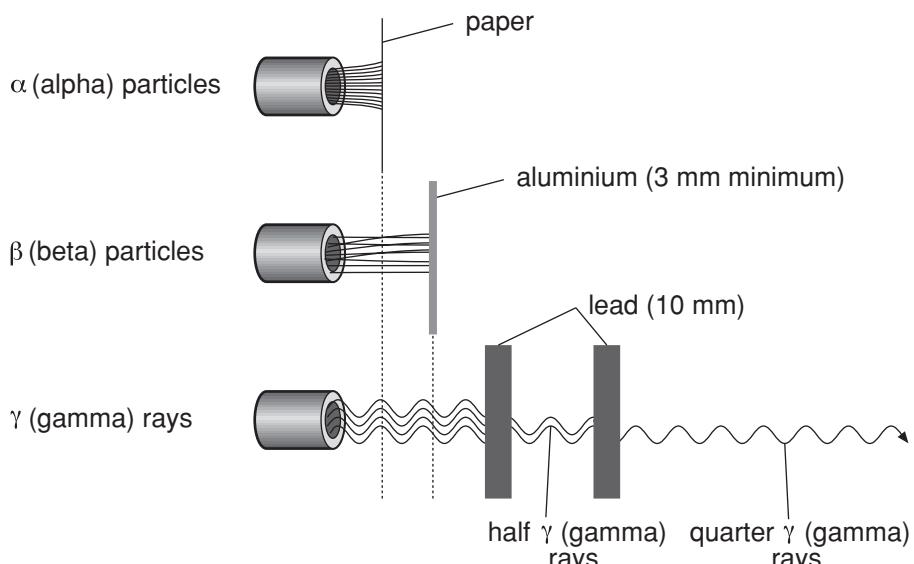
Check your answers.

**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

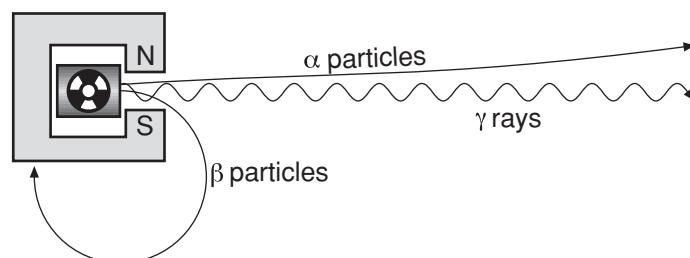
# Detecting radiation

Emitted radiation interacts with the electrons in surrounding atoms. To measure the radioactivity of a sample these interactions are counted over time.

Alpha, beta and gamma emissions can be distinguished between by comparing their penetrating power



or paths in a magnetic field.



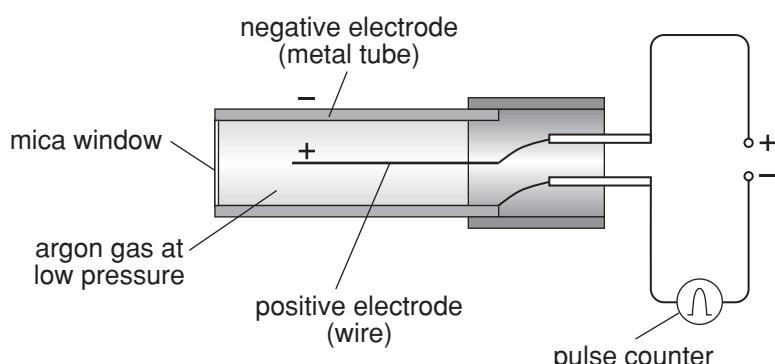
The large alpha particles can only travel a few cm through air because they hit many atoms. This causes extensive ionisation (formation of positive ions and free electrons) in the air. Smaller beta particles can travel about one metre in air and cause less ionisation. Gamma rays travel many metres through air and cause much less ionisation.

The penetrating distance is often measured for water because water is the main constituent of living organisms. On average alpha particles penetrate about 0.03 mm (about the thickness of a single cell) beta particles about 2 mm and gamma rays about 100 mm through water.

High energy radiation that causes emission of electrons from atoms is called **ionising radiation** and is potentially harmful to living things. Low energy radiation that only causes excitation of electrons to higher shells is known as **non-ionising radiation**. Non-ionising radiation is much less likely to damage living things.

Radiation type	
non-ionising	ionising
lower energy	higher energy
light emission	ionisation to + ions and – electrons
detect with scintillation counter	detect with Geiger-Muller counter

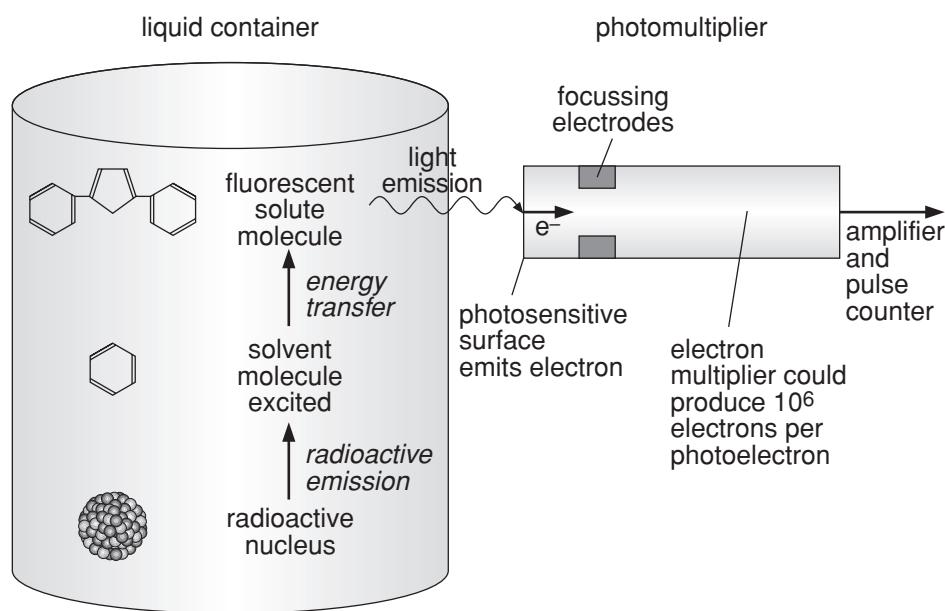
The main way of detecting ionisation is by a Geiger Muller tube. Radiation enters a thin window at the end of a sealed metal tube containing low pressure argon gas. The radiation ionises argon gas producing electrons and positive ions which move to oppositely charged electrodes. The small pulse of electricity produced is amplified and counted by attached electronic circuits.



Geiger-Muller counter for high energy ionising radiation

Ionising radiation can also be detected by changes in silver halide crystals in photographic film, discharge of electroscopes and condensation of vapour to liquid in cloud chambers.

Radioactive emissions too weak to ionise surrounding atoms can be detected by scintillation counters. A weak emission transfers energy to an atom by raising an electron to an outer energy level further from the positive nucleus. When the electron in this excited atom drops back to a level closer to the nucleus light is emitted. A photocell produces a pulse of electric current when hit by the light.



Scintillation counter for low energy non-ionising radiation.

Certain organic solutions can dissolve radioactive biological samples and emit light for each radioactive emission. The amount of light emitted by the organic molecules is proportional to the amount of radioactivity emitted. This method is often preferred in investigating biological systems as higher energy ionising radiation would form ions which can interfere with the normal chemical reactions in cells.

## Balancing nuclear equations

A nuclear equation showing nuclear decay (emission of  $\alpha$ ,  $\beta$  or  $\gamma$ ) or reaction between particles such as  $^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{236}_{92}\text{U}$  must be balanced

- for mass (upper numbers) and
- for charge (lower numbers).

For  $^{235}_{92}\text{U} + ^1_0\text{n} \rightarrow ^{236}_{92}\text{U}$      $235 + 1 = 236$  and  $92 + 0 = 92$

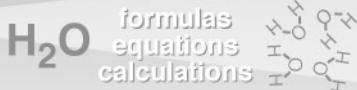
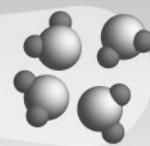
For  $^1_0\text{n} \rightarrow ^1_1\text{p} + ^0_{-1}\text{e}$      $1 = 1 + 0$  and  $0 = 1 + (-1)$

For  $^{236}_{92}\text{U} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3 ^1_0\text{n}$      $236 = 141 + 92 + 3 \times 1$  and  $92 = 56 + 36 + 3 \times 0$

Therefore all these equations are balanced. As you do with chemical equations always check that an equation is balanced after it is completed.

Complete Exercise 5.1: *Nuclear fission* and Exercise 5.2: *New elements*.



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Applications of radioisotopes

The chemical behaviour of a radioisotope is practically the same as the chemical behaviour of a non-radioactive isotope of the same element.

Radioactive **tracers** are radioisotopes used to signal the passage of an atom through a system.

In biological systems low energy emitting radioisotopes detectable by scintillation counters are often preferred to high energy emitting radioisotopes that could interfere with the biochemistry of the organisms.

Carbon-14 is a low energy beta emitter. If a plant is allowed to photosynthesise in an atmosphere of carbon dioxide containing carbon-14,  $^{14}CO_2$ , the chemical pathway followed by the carbon-14 is easily traced. The  $^{14}CO_2$  is used by the plant in the same chemical ways as normal carbon dioxide,  $^{12}CO_2$ .

Similarly radioactive hydrogen-3 (called tritium) can be used to trace the pathways of hydrogen in biological reactions.

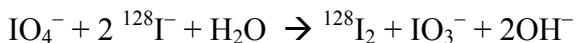
Some elements have no suitable radioisotopes. For example the three radioisotopes of oxygen have half-lives of the order of a minute so their radiation levels drop too rapidly for long term detection. More complex and expensive equipment, a mass spectrometer, can be used to separate isotopes according to mass but this technique and the effort required in preparing samples usually makes it less convenient than using radioisotopes.

The equation for photosynthesis is sometimes shown as  $6CO_2 + 12H_2^{18}O \rightarrow C_6H_{12}O_6 + 6^{18}O_2 + 6H_2O$  to emphasize that:

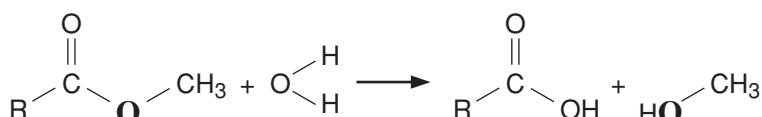
- the oxygen atoms in the oxygen gas come from water and not from carbon dioxide. The  $6H_2O$  on the RHS is 'new' water, formed from O in the  $CO_2$  – it is not water from the LHS.
- the mechanism for the reaction was understood using  $^{18}O$  isotope (which was traced by mass spectroscopy, not by radioactivity)



- 1 Explain what information using radioactive iodine-128 gives about the mechanism of this reaction.



- 2 The following ester hydrolysis reaction investigation involves using the  $^{18}\text{O}$  isotope. The  $^{18}\text{O}$  isotope, represented by **O**, is not radioactive but can be detected by using a mass spectrometer. Use the information provided to deduce (draw a conclusion about) which bond in the ester  $\text{RCOOCH}_3$  is broken to form the acid  $\text{RCOOH}$  and methanol  $\text{HOCH}_3$ .



Check your answers.

The most widely used radioisotope in medicine is technetium-99m.  
[The m after an isotope number indicates it is in a metastable state;  
energy is released as a  $\gamma$ -ray when the isotope changes to a stable form  
 $^{99\text{m}}\text{Tc} \rightarrow {}^{99}\text{Tc} + \gamma$ ]

Technetium-99m is used in over half of all nuclear medicine procedures because :

- the nucleus has a half-life of six hours which is long enough to investigate changes in a human body but minimises exposure to radiation
- the electronic structure can change to produce a number of oxidation states. This enables production of a wide range of biologically active chemicals. Different chemicals containing technetium-99m can be made to target different body organs or tissues.
- low energy gamma rays emitted by the  $^{99\text{m}}\text{Tc}$  cause little damage to the body and are easily detected by a gamma ray sensitive camera.

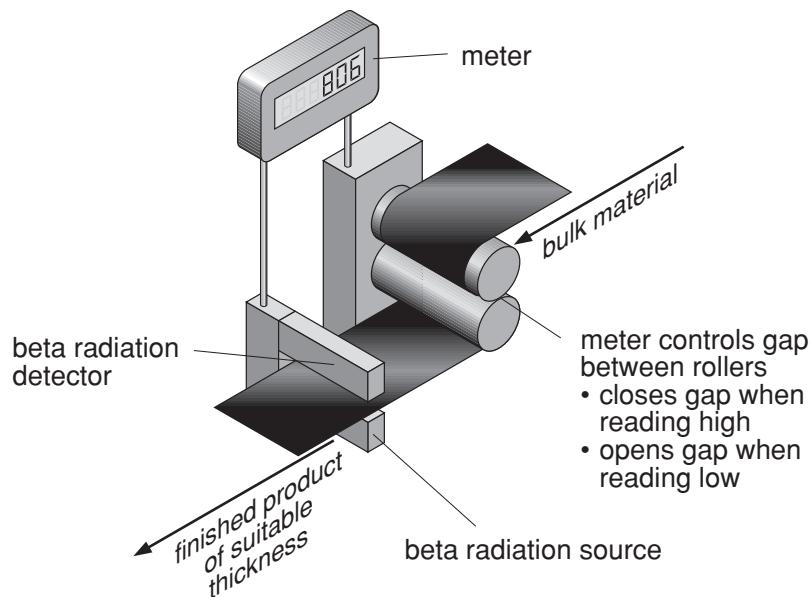
Technetium-99m is produced in a generator consisting of a glass tube surrounded by lead. The generator contains molybdenum-99 which is one of the products of **nuclear fission** in a **nuclear reactor**. The  $^{99}\text{Mo}$ , with a half life of 66 hours, changes to  $^{99\text{m}}\text{Tc}$  which can be washed out of the molybdenum with a salt solution. The  $^{99\text{m}}\text{Tc}$  is then chemically attached to a biological molecule which will concentrate in the targeted organ.

Cobalt-60 is a  $\gamma$ -emitter with a half life of just over 5 years. The cobalt is in an inert (chemically unreactive) form inside a container designed to shield workers from its energetic gamma radiation. In industry  $^{60}\text{Co}$  has a number of uses:

- gamma sterilisation of hospital supplies that would be damaged by heat sterilisation
- gamma sterilisation of food to destroy microorganisms thus preventing spoilage and extending shelf life
- sterilisation of insect pests such as carpet beetles
- as a source of radiation to destroy cancer cells which are more susceptible to radiation than ordinary cells
- detection of cracks and flaws in metal such as in castings and welds; the gamma radiation passing through the object is recorded on a film just as X-rays are recorded after passing through a human body
- as a radioactive source in automated thickness gauges.

Automatic thickness gauges use a gamma source such as Co-60 for thick materials.

A very thin material such as the plastic film produced below only needs a less penetrating source such as Sr-90.



Automated thickness gauge using a beta source.



Write a balanced equation for the  $\alpha$  emission by Am-241. (Used in house smoke alarms. Smoke absorbs ionisation produced by  $\alpha$  particles. The resultant reduction in current flowing through a detector triggers the alarm.)

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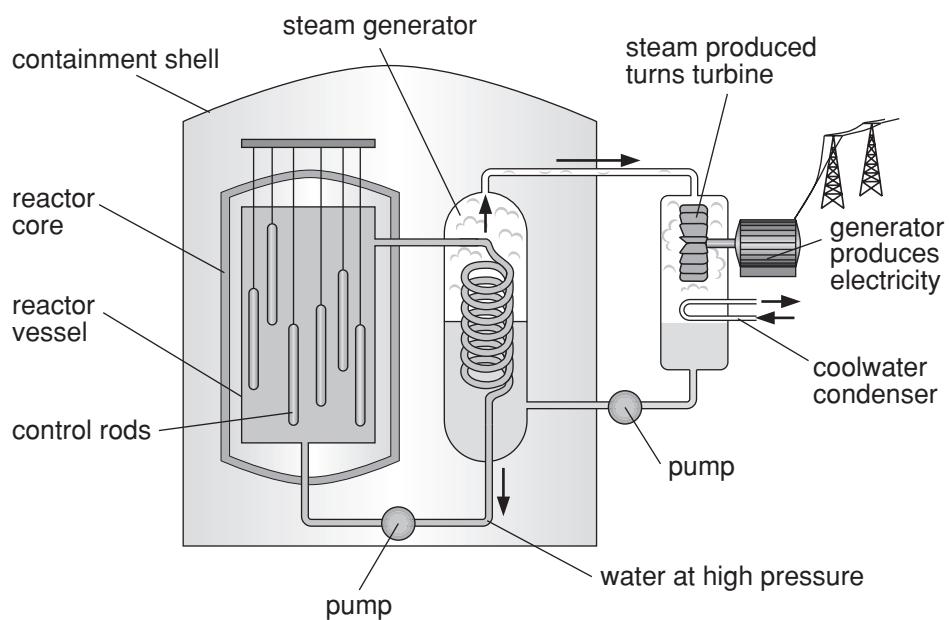
Check your answers.

## Nuclear reactors

Approximately 25% of the world's electrical energy is generated from heat energy released in nuclear reactors by nuclear fission of U-235. Nuclear fission is the division of a heavy nucleus into two unequal masses. This is accompanied by emission of neutrons, gamma rays and a lot of heat energy.

A nuclear reactor is a structure in which nuclear fission can be controlled. The reactor consists of:

- nuclear fuel core
- coolant to cool the core and transfer heat to steam generators
- moderator to moderate the speed of neutrons so they can join U-235 nuclei rather than bounce off
- control rods containing material that absorbs neutrons
- safety devices
- concrete containment shield to absorb neutrons and gamma rays.



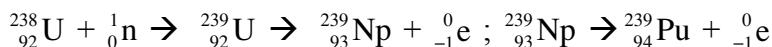
Natural uranium contains 0.7% U-235. Enrichment raises the U-235 concentration to the 3-4% needed to maintain a **chain reaction**. In a chain reaction for every neutron absorbed to cause a U-235 to fission enough neutrons are emitted to cause another U-235 to fission. The fission produces two or three neutrons and at least one of these needs to be absorbed for the chain reaction to be sustained. The two unequal mass nuclei are usually in the mass range 90-100 and 135-145. For example:



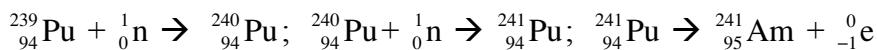
The neutron rich environment inside a reactor core can be used to produce:

- **transuranic elements** with Z = 93, 94 and 95
- commercial radioisotopes for use in industry, medicine and chemical research.

The most abundant uranium isotope U-238 does not undergo fission but can be converted by neutron bombardment to U-239 which undergoes beta decay to neptunium and plutonium:



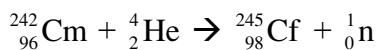
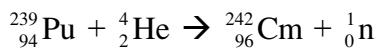
Plutonium-239 is changed to Americium-241 using neutron bombardment. Am-241 is used commercially in house smoke alarms.



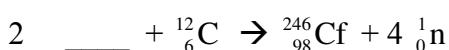
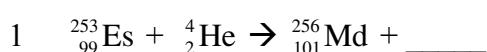
## Production of transuranic elements

The elements with Z = 93, 94 and 95, neptunium, plutonium and americium are produced by neutron bombardment in a nuclear reactor.

Transuranic elements with atomic numbers above 95 are produced using particle accelerators. Small charged atomic particles are accelerated to very high speeds by using electrical attraction and repulsion. The small particles with high kinetic energy then hit a target of large atoms.



Complete these equations for the production of transuranic elements:



Check your answers.

## Production of commercial radioisotopes

Separation of a particular element from the mixtures formed in nuclear fission in a reactor uses differences in chemical properties to separate elements. Used nuclear fuel also contains some unused U-235 which is chemically separated and recycled into new fuel rods.

Because nuclear reactors contain high speed neutrons they are ideal for producing neutron rich isotopes. A neutron rich isotope contains more neutrons in its nucleus than most other atoms of that element.

Cobalt-60, a gamma emitter, and strontium-90, a beta emitter, are neutron rich isotopes because their masses are above the atomic weights for cobalt and strontium of 58.9 and 87.6.

To make neutron deficient radioisotopes a **cyclotron** is used. Cyclotrons use the same acceleration of positive particles as a linear accelerator but have electromagnets so that the charged particles follow a spiral path. This makes the cyclotron compact enough to fit in a hospital basement.



Information about the National Medical Cyclotron at RPA Hospital in Sydney run by the Australian Nuclear Science and Technology Organisation (ANSTO) is available through <http://www.lmpc.edu.au/science>. A diagram illustrating the compactness of this unit is in the *Appendix* of this part.



Knowing that neutron rich radioisotopes are reactor produced and neutron deficient radioisotopes are cyclotron produced you should be able to complete the third column of this table. Use the periodic table on the inside cover of this module to help you decide

Radioisotope	Use	Reactor/cyclotron
technetium-99m	imaging body parts	reactor
iodine-131	treating thyroid disease	
iodine-123	imaging thyroid gland	
phosphorus-32	treating excess red blood cells	
fluorine-18	studying brain function by PET	
gallium-67	imaging tumours	

Check your answer.



Complete Exercise 5.3: *Radioisotopes*.

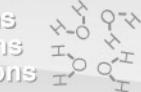
**MACRO**

observe  
infer  
understand



**SYMBOLIC**

$H_2O$  formulas  
equations  
calculations



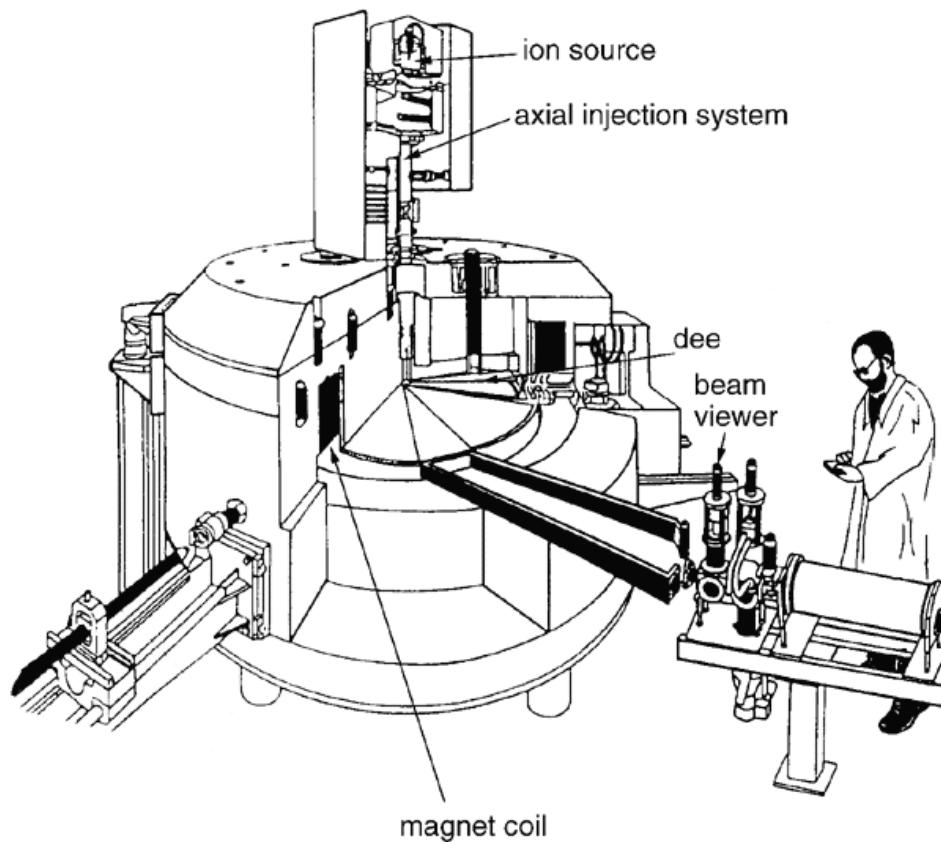
**MICRO**

particles  
energy  
interactions



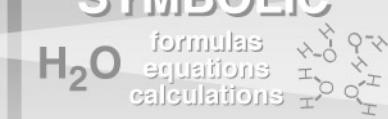
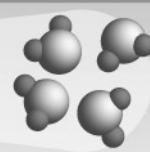
## Appendix

### The national medical cyclotron



Source: Hawkins, G. (Editor). (1992.) *A nuclear source*. Australian Nuclear Science and Technology Organisation. Figure 9.14.

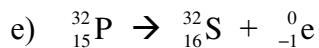
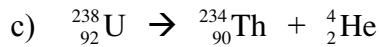
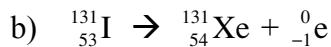
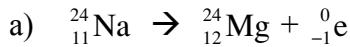


**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions**Suggested answers**

Isotope name	Isotope symbol	Mass no. A (p+n)	Atomic no. Z (p)	A – Z (n)	Radio-activity emitted	half-life d=days y=years
hydrogen-1	${}_1^1H$	1	1	0	–	–
hydrogen-2 or deuterium	${}_1^2H$	2	1	1	–	–
hydrogen-3 or tritium	${}_1^3H$	3	1	2	$\beta$	12.3y
helium-4 or $\alpha$ -particle	${}_2^4He$	4	2	2	–	–
carbon-12	${}_6^{12}C$	12	6	6	–	–
carbon-14	${}_6^{14}C$	14	6	8	$\beta$	5720y
oxygen-16	${}_8^{16}O$	16	8	8	–	–
oxygen-18	${}_8^{18}O$	18	8	10	–	–
cobalt-60	${}_{27}^{60}Co$	60	27	33	$\beta, \gamma$	5.3y
lead-206	${}_{82}^{206}Pb$	206	82	124	–	–
radon-222	${}_{86}^{222}Rn$	222	86	136	$\alpha, \gamma$	3.8d
radium-226	${}_{88}^{226}Ra$	226	88	138	$\alpha, \gamma$	1622y
uranium-235	${}_{92}^{235}U$	235	92	143	$\alpha, \gamma$	$7 \times 10^8$ y
americium-241	${}_{95}^{241}Am$	241	95	146	$\alpha, \gamma$	458y



- 1 Complete the following radioactivity emissions by inserting  ${}^4_2\text{He}$ ,  ${}^0_{-1}\text{e}$  or  $\gamma$ .

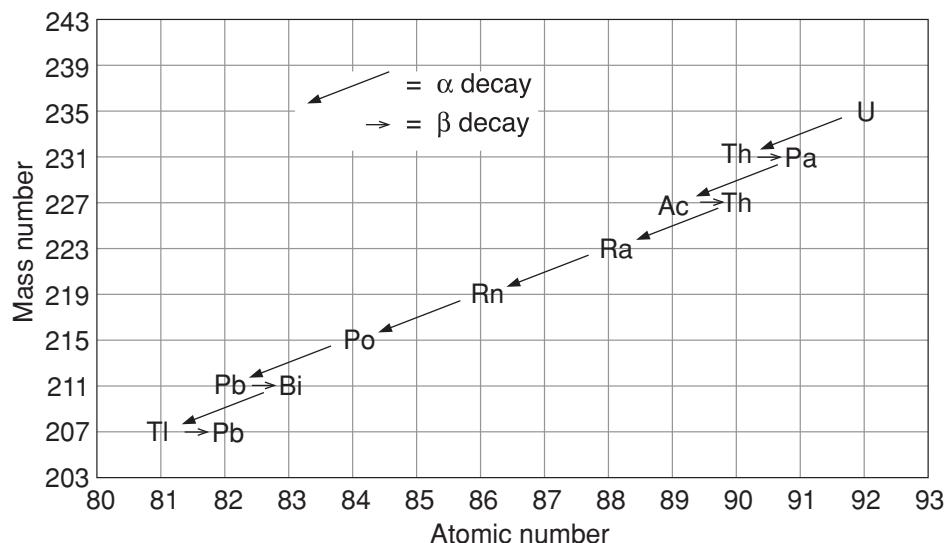


- 2 Complete the following sentences:

When an alpha particle or *beta particle* is emitted the nucleus changes to that of a different element. Emission of a *gamma ray* lowers the energy level but does not produce a new nucleus.

## Uranium decay series

### Uranium-235 decay series



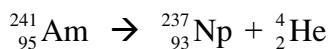
Overall equation is  ${}^{235}_{92}\text{U} \rightarrow {}^{207}_{82}\text{Pb} + 7 {}^4_2\text{He} + 4 {}^0_{-1}\text{e}$

## Applications of radioisotopes

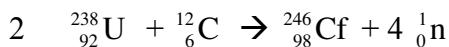


All the iodine element I<sub>2</sub> has come from the iodide ion I<sup>-</sup>, presumably by an oxidation reaction  $2\text{I}^- \rightarrow \text{I}_2 + 2\text{e}^-$

- 2 The O-18 isotope appears in the HOCH<sub>3</sub> but not in RCOOH. The bond between the RCO and OCH<sub>3</sub> must have been broken.



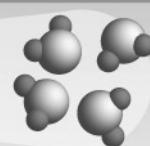
## Production of transuranic elements



## Production of commercial radioisotopes

radioisotope	use	reactor/cyclotron
technetium-99m	imaging body parts	reactor
iodine-131	treating thyroid disease	reactor
iodine-123	imaging thyroid gland	cyclotron
phosphorus-32	treating excess red blood cells	reactor
fluorine-18	studying brain function by PET	cyclotron
gallium-67	imaging tumours	cyclotron



**MACRO**observe  
infer  
understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Exercises – Part 5

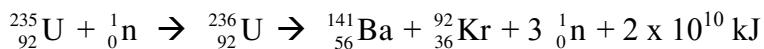
Exercises 5.1 to 5.4

Name: \_\_\_\_\_

## Exercise 5.1 Nuclear fission

Combustion of a fossil fuel typically releases about 50 kJ per gram of fuel.

Nuclear fission of uranium-235 releases much more energy.



As for chemical equations the nuclear equation shows the energy released for mole quantities. One mole of U-235 releases about  $2 \times 10^{10}$  kJ of energy.

Calculate the energy released per gram of U-235 on nuclear fission. Set out your calculation showing working clearly.

Comment on the amount of energy released in a nuclear reaction (eg fission) and the amount of energy released in a chemical reaction (eg combustion).

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## **Exercise 5.2: New elements**



Web sites vary enormously in the quality of the information provided. A chemistry site which has existed since 1993, is regularly updated, and is highly regarded can be found at:

<http://www.webelements.com/index.html>

This web site has a periodic table where you can get extensive information on each element.

Use this web site to describe the recent discovery of two different transuranic elements.

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### **Exercise 5.3: Radioisotopes**

- a) Name a radioisotope used in medicine.
- b) Briefly describe how this radioisotope is used.

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- c) List up to three benefits and problems associated with use of this medical radioisotope. Just use keywords or short phrases:

<b>Benefits</b>	<b>Problems</b>

- d) Name a radioisotope used in industry and identify (name) the industry
- e) Briefly describe how the radioisotope is used in this industry

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- f) List up to three benefits and problems associated with use of this industrial radioisotope. Just use keywords or short phrases:

<b>Benefits</b>	<b>Problems</b>

- f) What you have completed on the previous page could be brief notes written to help answer an extended response question.

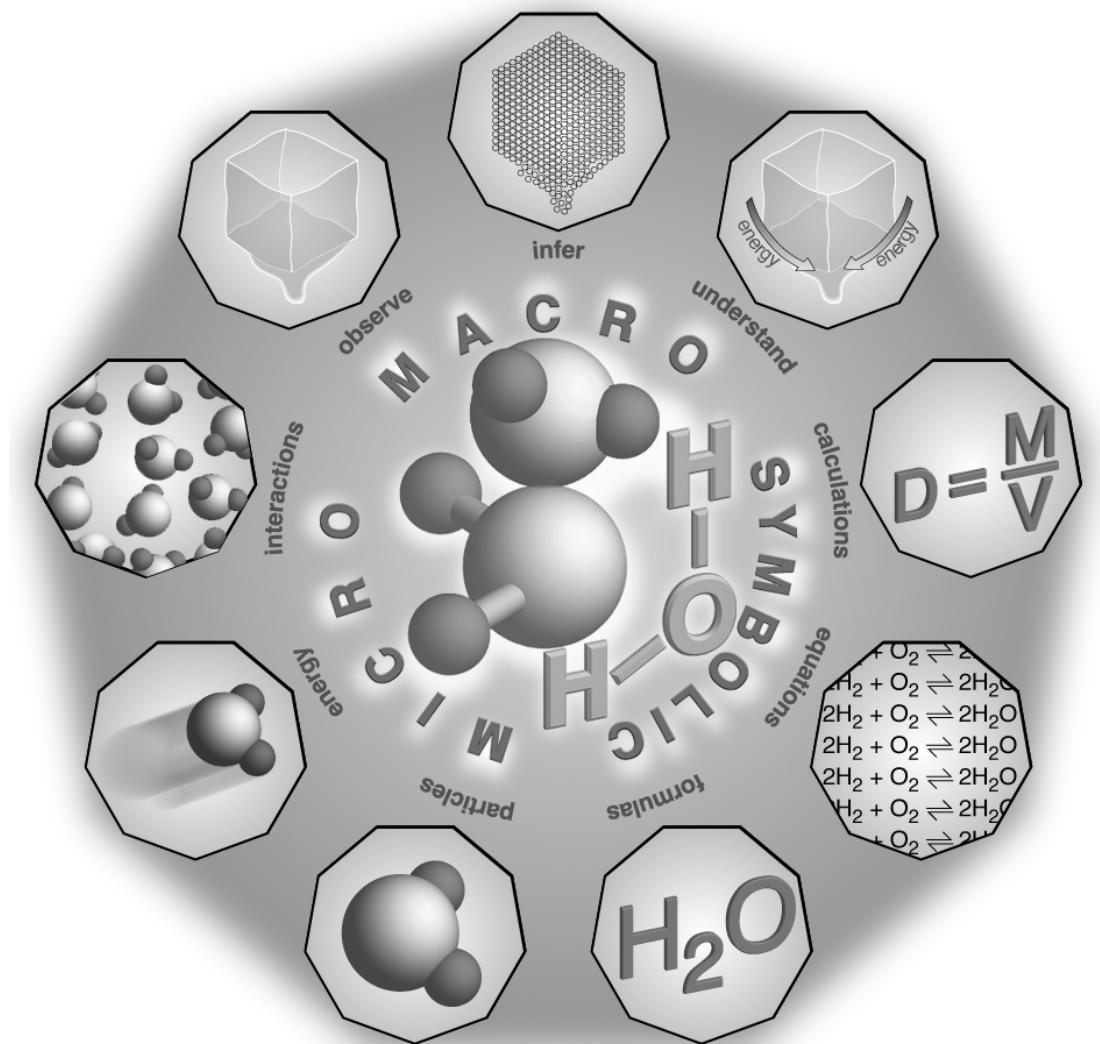
'Analyse the benefits and problems associated with the use of radioactive isotopes. Include at least one medical radioisotope and one industrial radioisotope in your analysis.'

Analyse means 'draw out and relate implications'. Answer this extended response question in the space below. Make sure you include half-life, radioactive waste disposal, security, human exposure to radiation and alternative ways of carrying out the activity in your answer.



# The identification and production of materials

## Part 6: Review, report and outcomes



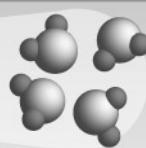
	1 H 1.008 Hydrogen	4 Be 9.01 Beryllium	5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon												
	3 Li 6.94 Lithium	11 Na 22.99 Sodium	19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.39 Zinc	31 Ga 69.72 Gallium	32 Ge 72.61 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
	37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Nb 91.22 Niobium	41 Zr 92.91 Zirconium	42 Tc 95.94 Technetium	43 Mo 95.94 Molybdenum	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon		
	55 Cs 132.9 Cs	56 Ba 137.3 Barium	57-71 LANTHANIDES Actinides	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.8 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po 210.0 Polonium	85 At 210.0 Astatine	86 Rn [222.0] Radium		
	87 Fr [223.0]	88 Ra [226.0] Francium	89-103 ACTINIDES Rutherfordium	104 Rf [261.1] Rutherfordium	105 Db [263.1] Dubnium	106 Sg [264.1] Seaborgium	107 Bh [265.1] Bohrium	108 Mt [268] Meitnerium	109 Hs [269] Hassium	110 Mt [268] Meitnerium	111 Uuu —	112 Uub —	113 Uuo —	114 Uqq —	115 Uuh —	116 Uuh —	117 Uuo —	118 Uuo —	Ununhexium —	
																			Ununquadium —	

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 144.2 Praseodymium	60 Nd 140.9 Neodymium	61 Pm [146.9] Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium
89 Ac [227.0] Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np [237.0] Neptunium	94 Pu [239.1] Plutonium	95 Am [241.1] Americium	96 Cm [244.1] Curium	97 Bk [249.1] Berkelium	98 Cf [252.1] Californium	99 Es [257.1] Einsteinium	100 Fm [258.1] Fermium	101 Md [259.1] Mendelevium	102 No [259.1] Nobelium	103 Lr [262.1] Lawrencium

**MACRO**observe  
infer  
understand**SYMBOLIC**formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Contents

Introduction .....	2
Key ideas .....	4
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equations  
calculations**MICRO**particles  
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interactions

# Introduction

In this part you will review the first five parts of this module, report on your open ended investigation and familiarise yourself with some of the sixteen outcomes designated for the HSC course. The HSC chemistry course outcome are:

A student:

- H1 evaluates how major advances in scientific understanding and technology have changed the direction or nature of scientific thinking
- H2 analyses the ways in which model, theories and laws in chemistry have been tested and validated
- H3 assesses the impact of particular advances in chemistry on the development of technologies
- H4 assesses the impacts of applications of chemistry on society and the environment
- H5 identifies possible future directions of chemical research
- H6 explains reactions between elements and compounds in terms of atomic structures and periodicity
- H7 describes the chemical basis of energy transformations in chemical reactions
- H8 assesses the range of factors which influence the type and rate of chemical reactions
- H9 describes and predicts reactions involving carbon compounds
- H10 analyse stoichiometric relationships
- H11 justifies the appropriateness of a particular investigation plan.
- H12 evaluates ways in which accuracy and reliability could be improved in investigations
- H13 uses terminology and reporting styles appropriately and successfully to communicate information and understanding

- H14 assesses the validity of conclusions from gathered data and information
- H15 explains why an investigation is best undertaken individually or by a team
- H16 justifies positive values about and attitude towards both the living and non-living components of the environment, ethical behaviour and a desire for critical evaluation of the consequences of the applications of science.

Extracts from chemistry Stage 6 Syllabus 1999 © Board of Studies NSW, originally issued 1999. The most up-to-date version can be found on the Board's website at [http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000\\_list.html](http://www.boardofstudies.nsw.edu.au/syllabus99/syllabus2000_list.html)

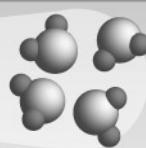
H1 to H5 are Prescribed Focus Area outcomes

H6 to H10 are Knowledge and Understanding outcomes

H11 to H15 are Skills outcomes

H16 is a Values and Altitudes outcome

All outcomes except H16 could be assessed in the HSC Examination.

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calculations**MICRO**particles  
energy  
interactions

# Key ideas

Assess your understanding of this module by answering these true/false statements one part at a time. Write T or F at the end of each statement. Approximately half the statements are true. If you decide the statement is false, rewrite the statement so that it is true.

## Fossil Fuel products

- Most ethene is produced in Australia by steam cracking of ethane from gas fields.
- Catalytic cracking of low value petroleum fractions to higher value petrol produces ethene as a by-product.
- Alkanes and alkenes have high BPs because they are non-polar and have weak dispersion forces between their molecules.
- The double bond in ethene makes it less reactive than ethane.
- Polyethene is a commercially and industrially important addition polymer formed from ethene.
- High density polyethene has more side branching than low density polyethene.
- $\text{--}(\text{CH}_2\text{CH})_n\text{--}$  is polystyrene.  
$$\begin{array}{c} | \\ \text{Cl} \end{array}$$
- most hydrocarbons except ethene are used as fuels.
- most ethene is used as a raw material to make other chemicals.
- addition polymers are formed from monomers with C=C bonds.

## From biomass to polymers

- Cellulose is a condensation polymer and a major constituent of biomass.
- Cellulose contains short chains of carbon atoms.
- Cellulose is a protein biopolymer.

- Cellulase is a glucose based biopolymer.
- The human digestive system contains enzymes to digest cellulose but not starch.
- Sugars in biomass can be converted to ethanol by yeast enzymes.
- Zeolites are used to crack petroleum fractions and to separate ethanol from mixtures of ethanol and water.
- When a biopolymer undergoes hydrolysis to produce glucose water is also produced.
- Starch and cellulose are condensation polymers of glucose with different molecular structures.
- Cellulose produces a colour change with iodine solution but starch does not.

## **Renewable plant resources**

- Ethanol reacts with water to form ethene.
- Ethanol is able to dissolve many substances because it has hydrophilic and hydrophobic parts in its molecule.
- Fermentation of sucrose  $C_{12}H_{22}O_{11}$  to ethanol needs yeast enzymes and water.
- The molar heat of combustion would be higher for methanol  $CH_3OH$  than other alkanols.
- Ethene would be regarded as a renewable resource if made from carbohydrates in plant biomass but as a non-renewable resource if made from hydrocarbons in fossil fuels.
- Combustion of alkanols is normally less polluting than combustion of hydrocarbons.
- $C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_5OH + 2CO_2$
- $C_2H_5OH \rightarrow C_2H_4 + H_2O$
- $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
- $\Delta_cH^\ominus$  is measured in  $kJ\ g^{-1}$ .

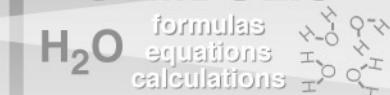
## **Electrochemistry**

- In  $Mg + Sn^{2+} \rightarrow Mg^{2+} + Sn$  the reductant is  $Sn^{2+}$
- An oxidant undergoes reduction.
- The anode is where oxidation occurs in an electric cell.
- The anode of a battery is marked – .

- $\text{F}_2$  is a strong oxidant.
- $\text{F}^-$  is a weak reductant.
- In electroplating the material to be plated is connected to the + battery terminal.
- In the Daniell cell  $\text{Zn} | \text{Zn}^{2+} \parallel \text{Cu}^{2+} | \text{Cu}$  electron flow is from copper to zinc.
- Electrons can flow through metal wires and aqueous electrolyte solutions.
- Photovoltaic devices change electrical energy to light energy.

## Nuclear chemistry

- Isotopes always have the same mass number.
- Radioactive isotopes are stable isotopes.
- Most transuranic elements have been produced using neutrons in nuclear reactors.
- Neutron-deficient radioisotopes can be made in cyclotrons.
- $\alpha$  particles are more penetrating than  $\beta$  particles.
- High energy radioactivity causes ionisation of atoms.
- Low energy radioactivity is detected by scintillation counters.
- ${}_{38}^{90}\text{Sr} \rightarrow {}_{39}^{90}\text{Y}$  is an example of  $\beta$  decay.
- ${}_{43}^{99\text{m}}\text{Tc} \rightarrow {}_{43}^{99}\text{Tc}$  is an example of  $\alpha$  decay.
- ${}_{88}^{226}\text{Ra} \rightarrow {}_{86}^{222}\text{Rn}$  is an example of  $\gamma$  decay.

**MACRO**observe  
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understand**SYMBOLIC** $H_2O$  formulas  
equations  
calculations**MICRO**particles  
energy  
interactions

# Suggested answers

## Fossil Fuel products

- Most ethene is produced in Australia by steam cracking of ethane from gas fields. T
- Catalytic cracking of low value petroleum fractions to higher value petrol produces ethene as a by-product. T
- Alkanes and alkenes have high BPs because they are non-polar and have weak dispersion forces between their molecules. F  
*Alkanes and alkenes have low BPs*
- The double bond in ethene makes it less reactive than ethane. F  
*The electron rich double bond in ethene makes it more reactive than ethane.*
- Polyethene is a commercially and industrially important addition polymer formed from ethene. T
- High density polyethene has more side branching than low density polyethene. F  
*High density polyethene has less side branching so its molecules can fit closer together and so have high density.*
- $-(CH_2CH)_n$  is polystyrene. F    *Structure shown is PVC*  
                        |  
                        Cl
- most hydrocarbons except ethene are used as fuels. T
- most ethene is used as a raw material to make other chemicals. T
- addition polymers are formed from monomers with C=C bonds. T

## From biomass to polymers

- Cellulose is a condensation polymer and a major constituent of biomass. T
- Cellulose contains short chains of carbon atoms. T

- Cellulose is a protein biopolymer. F  
*Cellulose is a glucose based biopolymer.*
- Cellulase is a glucose based biopolymer. F  
*Cellulase is a protein biopolymer.*
- The human digestive system contains enzymes to digest cellulose but not starch. F  
*The human digestive system contains enzymes to digest starch but not cellulose.*
- Sugars in biomass can be converted to ethanol by yeast enzymes. T
- Zeolites are used to crack petroleum fractions and to separate ethanol from mixtures of ethanol and water. T
- When a biopolymer undergoes hydrolysis to produce glucose water is also produced. F  
*When a biopolymer undergoes hydrolysis to produce glucose water is required as a reactant.*
- Starch and cellulose are condensation polymers of glucose with different molecular structures. T
- Cellulose produces a colour change with iodine solution but starch does not. F  
*Starch reacts with iodine solution to produce a blue colour but cellulose does not react with iodine.*

## **Renewable plant resources**

- Ethanol reacts with water to form ethene. F  
*Ethene reacts with water in the presence of catalyst to form ethanol*
- Ethanol is able to dissolve many substances because it has hydrophilic and hydrophobic parts in its molecule. T
- Fermentation of sucrose  $C_{12}H_{22}O_{11}$  to ethanol needs yeast enzymes and water. T
- The molar heat of combustion would be higher for methanol  $CH_3OH$  than other alkanols. F  
*Methanol contains fewer C and H atoms to be changed to  $CO_2$  and  $H_2O$  releasing heat than do the other, larger alkanols.*
- Ethene would be regarded as a renewable resource if made from carbohydrates in plant biomass but as a non-renewable resource if made from hydrocarbons in fossil fuels. T
- Combustion of alkanols is normally less polluting than combustion of hydrocarbons. T

- $C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_5OH + 2CO_2$  F  
 $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- $C_2H_5OH \rightarrow C_2H_4 + H_2O$  T
- $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$  T
- $\Delta_c H^\ominus$  is measured in  $\text{kJ g}^{-1}$ . F  
 $\Delta_c H^\ominus$  is the molar heat of combustion and so is measured in  $\text{kJ mol}^{-1}$

## Electrochemistry

- In  $Mg + Sn^{2+} \rightarrow Mg^{2+} + Sn$  the reductant is  $Sn^{2+}$  F  
*The reductant is Mg.*
- An oxidant undergoes reduction. T
- The anode is where oxidation occurs in an electric cell. T
- The anode of a battery is marked – . T
- $F_2$  is a strong oxidant. T
- $F^-$  is a weak reductant. T
- In electroplating the material to be plated is connected to the + battery terminal. F  
*In electroplating the material to be plated is connected to the – battery terminal so that positive metal ions are attracted to it and reduced to metal atoms on its surface.*
- In the Daniell cell  $Zn | Zn^{2+} \parallel Cu^{2+} | Cu$  electron flow is from copper to zinc. F  
*Electron flow is from the more active Zn to the less active Cu.*
- Electrons can flow through metal wires and aqueous electrolyte solutions. F  
*Electrons can flow through metal wires but not through aqueous electrolyte solutions. Movement of ions allows flow of electricity through aqueous electrolyte solutions.*
- Photovoltaic devices change electrical energy to light energy. F  
*Photovoltaic devices change light energy to electrical energy.*

## Nuclear chemistry

- Isotopes of an element always have the same mass number. F  
*Isotopes of an element always have the same atomic number but different mass numbers.*
- Radioactive isotopes are stable isotopes. F

*Radioactive isotopes are unstable isotopes.*

- Most transuranic elements have been produced using neutrons in nuclear reactors. F

*Transuranic elements with atomic numbers 93, 94 and 95 were made using neutron bombardment in nuclear reactors but the higher transuranic elements (up to atomic number 118) have been produced using acceleration of positive ions in accelerators.*

- Neutron-deficient radioisotopes can be made in cyclotrons. T
- $\alpha$  particles are more penetrating than  $\beta$  particles. F  
 *$\alpha$  particles are less penetrating than  $\beta$  particles although they do cause more ionisation.*
- High energy radioactivity causes ionisation of atoms. T
- Low energy radioactivity is detected by scintillation counters. T
- $^{90}_{38}\text{Sr} \rightarrow ^{90}_{39}\text{Y}$  is an example of  $\beta$  decay. T
- $^{99\text{m}}_{43}\text{Tc} \rightarrow ^{99}_{43}\text{Tc}$  is an example of  $\alpha$  decay. F

*This is  $\gamma$  decay as there is no change in atomic number or mass number.*

- $^{226}_{88}\text{Ra} \rightarrow ^{222}_{86}\text{Rn}$  is an example of  $\gamma$  decay. F

*This is  $\alpha$  decay as the atomic number has decreased by two and the mass number has decreased by four.*



Complete Exercise 6.1: *Report on open ended investigation*, Exercise 6.2: *Skills outcomes* and Exercise 6.3: *Prescribed focus area outcomes*.

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infer  
understand

**SYMBOLIC**

$H_2O$  formulas  
equations  
calculations

**MICRO**

particles  
energy  
interactions



# Exercises – Part 6

Exercises 6.1 to 6.3

Name: \_\_\_\_\_

## Exercise 6.1 Report on the open ended investigation

**Part A:** Use information resources to find the solubility of pure chemicals in ethanol

## **Report on the open ended investigation (continued)**

**Part B:** Use chemicals you have at home and test their solubility in methylated spirits.

## **Exercise 6.2: Skills outcomes**

In exercise 6.1 you were given an opportunity to demonstrate the skill outcome **H13: uses terminology and reporting styles appropriately and successfully to communicate information and understanding.**

In this exercise you will be given an opportunity to demonstrate skill outcomes H11, H12 and H14 by answering questions based on your experiences in completing the open ended investigation.

### **H11: justifies the appropriateness of a particular investigation plan**

- 1 List data sources (information resources) used in Part A

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- 2 Devise a way of showing which data sources gave qualitative data and which sources gave quantitative (measurement) data.
  

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- 3 The independent variable is what you are interested in measuring. Dependent variables are quantities that could affect the value of the independent variable measurement.  
From your activity in Part B give an independent variable and a dependent variable and justify your choices.

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- 4 List a sequence of procedures used in your Part B activity.

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- 5 Give an example of where repetition of procedures is appropriate in Part B.

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- 6 Identify a potential hazard in carrying out Part B.

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- 7 How did you address the potential hazard?

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- 8 What technology did you use or could you have used in Part A or Part B?

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- 9 Was the method you used in Part B destructive or non-destructive testing of a material's solubility? Justify (support your argument or conclusion in) your answer.

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**H12: evaluates ways in which accuracy and reliability could be improved in investigations**

- 1 Describe careful and safe disposal of waste materials produced by the investigation in Part B.

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- 2 Identify a safe work practice used during the investigation.

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**H14: assesses the validity of conclusions from gathered data and information**

- 1 Justify a conclusion from your investigation.

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- 2 Formulate a cause and effect relationship to explain some of your results.

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## **Exercise 6.3 Prescribed Focus Area outcomes**

Complete the following tasks designed to give you familiarity with the Prescribed Focus Area Outcomes.

### **H1: evaluates how major advances in scientific understanding and technology have changed the direction or nature of scientific thinking**

Evaluate means 'determine the value of'. Evaluate the impact of Galvani's and Volta's work on biology, chemistry, physics and technology:

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### **H3: assesses the impact of particular advances in chemistry on the development of technologies**

Assesses means 'makes a judgement of the value of'. Assess the impact of Volta's work on development of technologies.

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**H4: assesses the impacts of applications of chemistry on society and the environment**

Assess the development of stable sources of electricity on society and the environment.

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**H5: identifies possible future directions of chemical research**

Identify possible future directions of chemical research for:

- a) producing fuels from biomass

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- b) developing batteries

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- c) identifying the origin of chemicals in a human fingernail.

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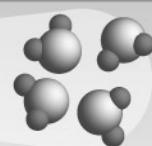
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equations  
calculations**MICRO**particles  
energy  
interactions

## Student evaluation of module

We need your input! Can you please complete this short evaluation to provide us with information about this module. This information will help us to improve the design of these materials for future publications.

1 Name: \_\_\_\_\_

2 Location: \_\_\_\_\_

3 Did you find the information in the module easy to understand?  
\_\_\_\_\_

4 Were the instructions clear? \_\_\_\_\_

5 What did you most like learning about? Why?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6 Which sort of learning activity did you enjoy the most? Why?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7 Did you complete the module within 30 hours? (Please indicate the approximate length of time spent on the module.)  
\_\_\_\_\_  
\_\_\_\_\_

- 8 Do you have access to the appropriate resources? eg a computer, the internet, scientific equipment, chemicals, people that can provide information and help with understanding science

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Please return this information to your teacher, who will pass it along to the materials developers at OTEN – DE.

