Chemistry
Preliminary Course
Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING
TAFE NSW
OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

Energy

Incorporating October 2002 AMENDMENTS

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- Board of Studies NSW. *Chemistry Stage 6 Syllabus*. **Amended October 2002.** The most up-to-date version is to be found at http://www.boardofstudies.nsw.edu.au/syllabus_hsc/index.html
- Messel, H (chair)). (1964.) *Science for high school.* The Foundation for Nuclear Energy. University of Sydney.

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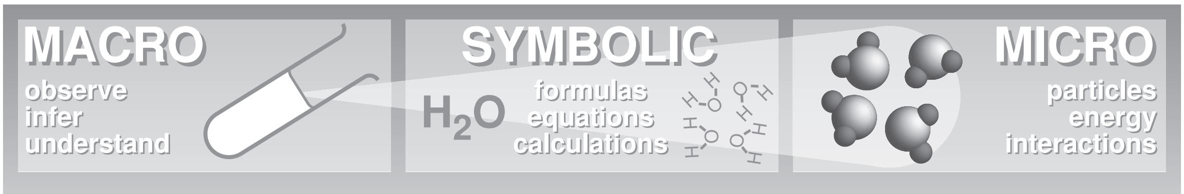
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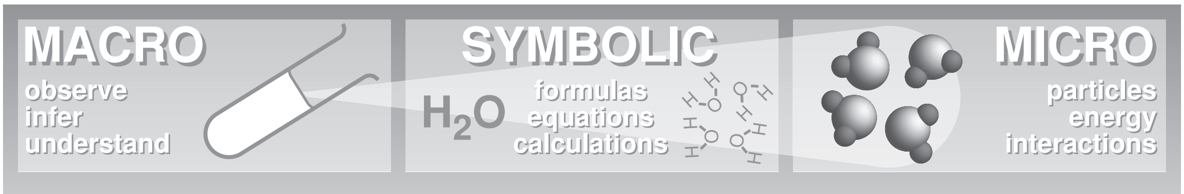

Module overview

Anthropologists and palaeontologists tell us that one of the important cultural achievements of early humans was the discovery of fire and the invention of ways to use fire. Burning is one of the most common and oldest chemical reactions. People meet this in their everyday life in such varied ways as lighting a match, cooking with gas and using fires.

The arrival of the industrial revolution and the increased need for fuels to power machinery means that humans have become increasingly dependant on fuels. Heat is a major product of the burning process. Most burning of fuels in our society is done to produce heat for powering machinery, cooking or providing warmth. The efficiency with which this is done is becoming of increasing concern to society because fossil fuels, which have been the mainstay fuels, are finite and non–renewable.

People are becoming increasingly concerned about the damage done to the Earth's environment by careless and inefficient use of fossil fuels. Strategies for the efficient use of fuels can be assessed in the light of the factors that drive chemical reactions, including combustion. As fossil fuels are carbon compounds an understanding of the structure and properties of simple carbon compounds assists understanding of the issues associated with the use of these fuels.

The emphasis in this module is on Prescribed Focus Areas 3 and 4.

Indicative time

This module is designed to take a minimum of thirty hours. There are a number of practical activities and opportunities to complete an open–ended investigation integrating the skills and knowledge and understanding outcomes. 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 of chemists.

Resources

Materials and equipment you need to carry out activities are listed below. Access to a computer and the Internet are sometimes 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 Part 2 you will require:

- molecular model kit

  or

- packet of maltesers®, toothpicks and a red marker pen.

For Part 3 you will require:

- molecular model kit and/or
- plasticine of two different colours and toothpicks and/or
- Internet access
- 100 mL glycerine (glycerol)
- saucepan and lid
- heat source eg. stove.

For Part 4 you will require:

- steel wool
- candle and knife
- matches
- metal lid

- electronic balance, popsticks, Bunsen burner or
- kitchen scales, large empty steel can, nail and hammer, eucalyptus sticks, solid firestarter

For Part 5 you will require:

- washing soda and spoon
- vinegar
- three 250 mL glass beakers or plastic cups
- access to a refrigerator
- saucepan and hot water
- thermometer
- liquid volume measurer for measuring 10 mL volumes
- green grass
- hydrogen peroxide solution (eg. 100 mL 20 Volume 6%w/v from a pharmacy or supermarket)
- two watch glasses or plates
- fresh potato and knife
- sugar cube, matches and can (sealed or empty opened).

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 a computer for this activity.

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.

Glossary

activation energy	amount of energy required for a chemical reaction to occur
aerobic bacteria	bacteria that use oxygen to obtain energy from high energy compounds
alkyl group	C_nH_{2n+1} group
alkane	general formula, C_nH_{2n+2}
alkene	general formula, C_nH_{2n}
alkyne	general formula, C_nH_{2n-2}
anthracite	jet black, bright lustrous coal containing over 92% carbon that burns producing little smoke
allotrope	different physical forms of an element
anthropologist	scientist who studies human cultural achievements
bituminous coal	black coal
bond energy	energy absorbed when a chemical bond is broken or released when a chemical bond forms; measured in kg/moll
carbohydrates	food group containing the carbon, hydrogen and oxygen; hydrogen/oxygen ratio is 2:1
catalyst	substance which speeds up a chemical reaction and remains unchanged at the end of the reaction
chemical energy	energy stored in chemicals
coal	solid fossil fuel formed from plant remains
combustion	burning; reaction with oxygen releasing heat energy
coalification	process of coal formation
decay	breakdown of chemicals to simpler structures; many small molecules formed at the site of decay escape as gas or liquid

dispersion forces	forces of attraction that occur between all molecules
double bond	covalent bond between two atoms formed by sharing two pairs of electrons
ecosystems	interactions between the living and non–living environment
electromagnetic radiation	waves that range from radio through light to gamma rays that travel at the speed of light
explosive combustion	combustion that occurs so quickly that the products move outwards explosively
fossil fuel	fuel formed from the remains of plants and animals that lived millions of years ago
fraction distillation	distillation of a mixture of liquids into fractions of different boiling point ranges
functional group	distinctive reactive part of an organic molecule
geological maturity	stage of development eg. coal ranges from peat to anthracite with peat being the most geologically immature and anthracite being the most geologically mature
glucose	a water soluble carbohydrate with the formula $C_6H_{12}O_6$
heat of combustion	amount of heat released when a substance burns; can be measured per mole for a pure substance, usually measured per kg or L for fuels
heavy oil	dark petroleum of high density
homologous series	series of chemicals with the same functional group that show a gradual change in properties
hydrocarbon	compound consisting of carbon and hydrogen only
ignite	start burning
ignition temperature	temperature at which a substance in contact with air starts to burn

ionisation energy	energy required to remove the outermost electron from an atom; generally expressed as MJ per mole electrons removed
isomers	molecules with the same molecular formula but different structural formulas
kinetic energy	energy due to movement
knocking	uneven combustion in the cylinder of an internal combustion engine
light oil	light coloured petroleum of lower density
metallurgical coke	coal that has most of its volatile material removed is called coke, and is used to smelt metals
mummified	prevented from decay
natural gas	gas produced underground by anaerobic decay
octane number	measure of the suitability of petrol for high compression engines
palaeontologist	scientist who studies fossils
petroleum	rock oil
photosynthesis	reactions in which low energy carbon dioxide and water are changed into high energy glucose and oxygen
plant debris	leaves, twigs, branches, bark and roots
plant material	remains of plants partly decayed
radioactive decay	radioactive elements break down into other elements
rank	position in the coalification process eg. peat has the lowest rank
reaction rate	rate of reaction measured as change in concentration with time
refining	separation technique that improves the purity of the product

saturated	carbon compound containing only carbon to carbon single bonds; saturated with hydrogen
single bond	covalent bond between two atoms formed by sharing one pair of electrons
sour oil	high sulfur content petroleum
spontaneous combustion	the tendency of a substance to burst into flames without an external spark or heat source
steaming	used to produce steam by boiling water
sublime	change directly from solid to gas
subsided	went down compared to sea level
sweet oil	low sulfur content petroleum
synthetic	made by humans
triple bond	covalent bond between two atoms formed by sharing three pairs of electrons
unsaturated	carbon compound that is not saturated with hydrogen; contains at least one double bond or triple bond between carbon atoms
volatile	easy to turn into a vapour (evaporates easily)
wick	twisted threads that allow movement of liquid upwards into air

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Energy

Part 1: Photosynthesis

Incorporating October 2002
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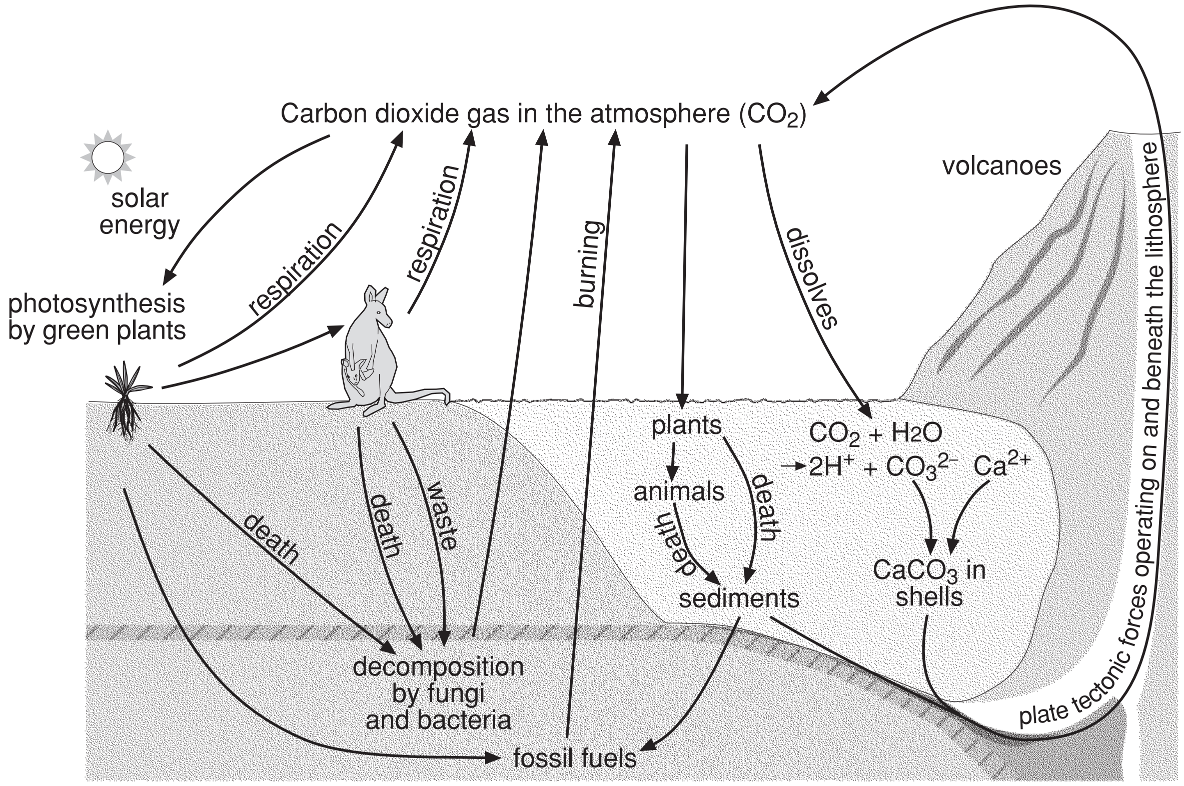
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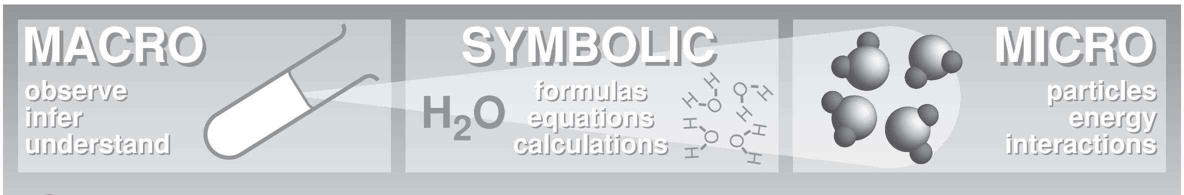
solar energy
photosynthesis by green plants
respiration
respiration
burning
dissolves
volcanoes
death
death
waste
decomposition by fungi and bacteria
fossil fuels
plants
animals
death
death
sediments
$CO_2 + H_2O$
$\rightarrow 2H^+ + CO_3^{2-}$
Ca^{2+}
$CaCO_3$ in shells
plate tectonic forces operating on and beneath the lithosphere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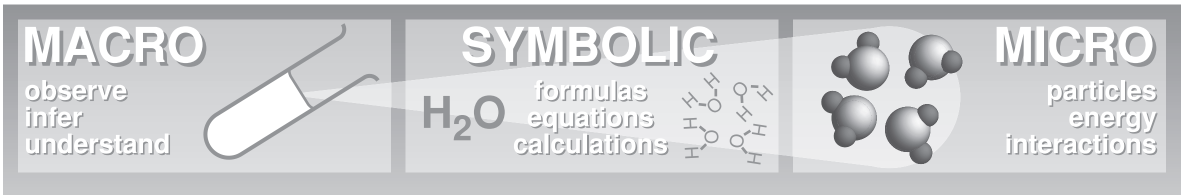


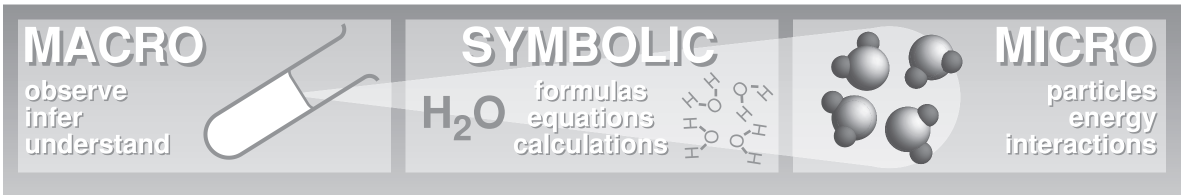
Introduction

In Part 1, where you investigate the process of photosynthesis and associated energy changes, you will be given opportunities to learn to:

- outline the role of photosynthesis in transforming light energy to chemical energy and recall the raw materials for this process
- outline the role of the production of high energy carbohydrates from carbon dioxide as the important step in the stabilisation of the sun's energy in a form that can be used by animals as well as plants
- identify the photosynthetic origins of the chemical energy in coal, petroleum and natural gas

In Part 1, you will be given opportunities to:

- process and present information from secondary sources on the range of compounds found in either coal, petroleum or natural gas and on the location of deposits of the selected fossil fuel in Australia.



Energy and the Earth

The Earth's surface receives energy from two main sources. One is internal and the other is external.

The internal source of energy is heat that is left over from the formation of the Earth. Because of the excellent insulating qualities of rock, this heat is only slowly leaking to the surface. As well, heat is produced by the **radioactive decay** of some elements eg. uranium, within the Earth.

The external source of energy is in the form of **electromagnetic radiation** that reaches the Earth's atmosphere and surface. This travels through space some 150 million kilometres from the Sun and is intercepted by the Earth.

Radiation type	Wavelength (nm)	Atmosphere effects
gamma rays	<0.03	absorbed by upper
X–rays	0.03–3	absorbed by upper
extreme UV, UVc	3–200, 200–280	absorbed by upper
UVb	280–320	mostly absorbed by upper
UVa	320–400	transmitted with scattering
visible	400–700	transmitted with scattering of blue
reflected IR	700–3 000	mostly reflected
thermal IR	3 000–14 000	mostly absorbed
microwave	10^5–10^9	transmitted
radio	$>10^9$	transmitted (some reflection by the ionosphere)

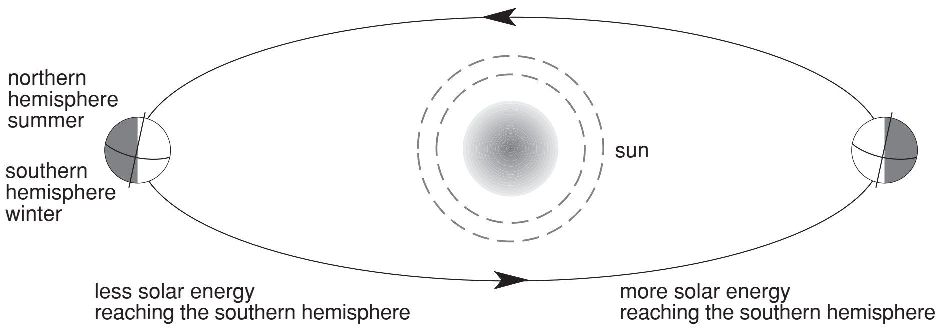
Not all the energy from the Sun is in the form of visible light.

1 Name two other forms of electromagnetic radiation that penetrate the Earth's atmosphere.

2 How much UVb is absorbed by the Earth's atmosphere?

Although the internal energy of the Earth is very important to life on this planet it is not the energy basis for life. That role is the Sun's.

The Sun has been emitting energy at a fairly constant rate for several billion years. Some of this enormous amount of energy falls on the Earth. In fact, in some places in Australia the energy received on the ground can be as high as 20 $MJ/m^2/day$. This, however, varies greatly over the surface of the Earth.

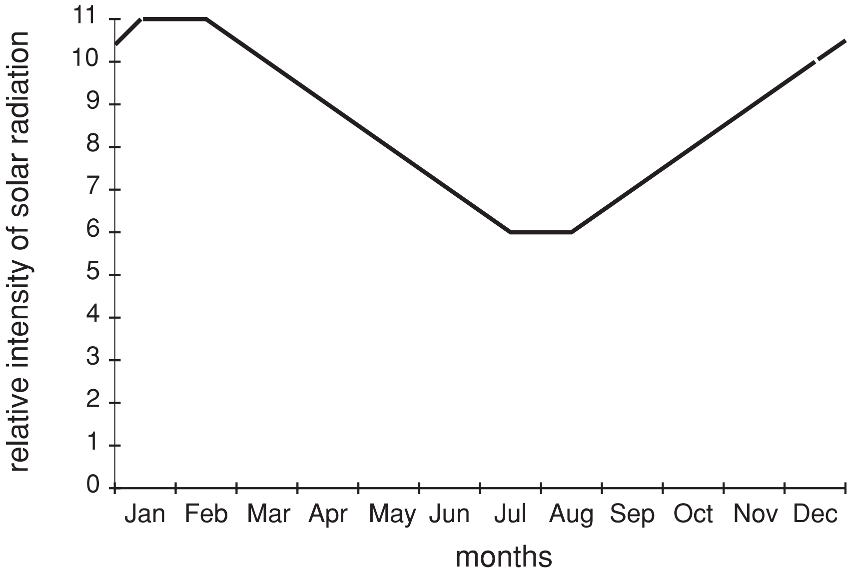


The Earth's rotation around the Sun.

3 Which parts of the Earth receive the most intense solar radiation?

4 Examine the graph that follows.

a) Does the graph represent a location in the Northern or the Southern Hemisphere? Explain your answer.



b) On the graph, draw in a line that would approximately represent a location closer to the equator than the one already drawn.

Check your answers.

The Earth's energy budget

The Earth is constantly receiving energy from the Sun and yet the temperature of the Earth has remained relatively stable throughout the last billion years. This indicates that energy is lost to the Earth at the same rate as it is gained.

energy in = energy out

Using the diagram on the next page, list the ways in which energy from the Sun:

1 is stored by the Earth.

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2 is lost by the Earth.

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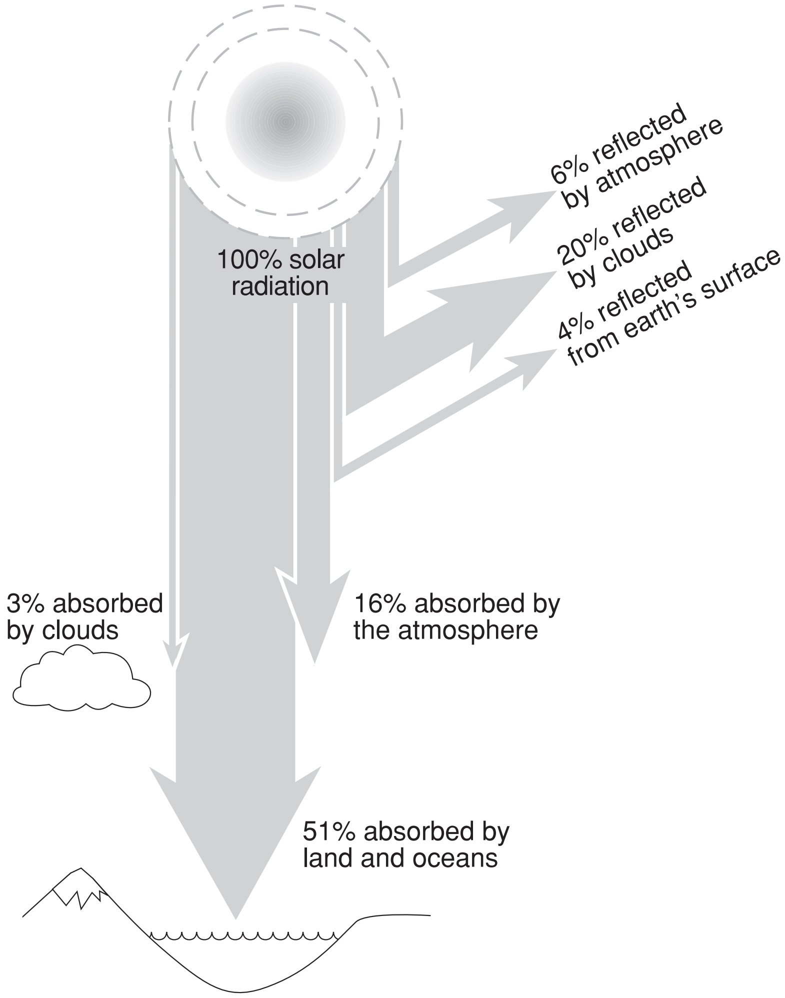
Check your answers.



Some energy from sunlight is absorbed; some is reflected.

Activity 1

Conduct the following simple exercise to see that considerable amounts of solar radiation are reflected back into space, from the Earth.

1 Check your local newspaper, calendar or tide chart to find the date of the next new moon.

2 Identify a clear night three or four days after the new moon. Look into the western sky shortly after sunset on that night.

3 A crescent moon will be visible. The rest of the Moon's disc will be in darkness and so will not be readily visible. However, if you look closely, the rest of the disc should appear very faintly. This is due to light that is reflected back into space from the Earth. On Earth it would be referred to as 'moonlight' so on the Moon it would be referred to as 'earthlight'.

As the Earth is much larger and has a much more reflective surface than the Moon, the Earth would appear very bright when viewed from the surface of the Moon.

In the space below draw an outline of the Moon showing the part illuminated by the Sun and also the part illuminated by light reflected from the Earth.

Check your answer.

Some solar energy can be stored by the solid surface of the Earth to be released some hours later. (This is more noticeable at night.)

Activity 2

Find a brick wall, concrete path, tarred road, large boulder or other solid structure that receives sunlight for the last few hours of the afternoon.

Just after sunset walk on or put your hand on this structure. Compare its temperature with that of some green grass or leaves nearby.

1 What did you notice?

2 Repeat this activity after another hour. Is there any change?

Check your answers.

Some solar energy can be stored by the waters of the oceans in the form of heat. The amount of energy that can be absorbed by the oceans is immense. This is due to several factors.

- Oceans cover some 70% of the Earth's surface.
- Heat is not stored only by the surface layer of the oceans but down through the water column.
- Water has a very high heat capacity. In fact it requires 4.2 joules of energy to raise the temperature of 1 g of water by 1°C. This means that one cubic kilometre of water that increases its temperature by 1°C has absorbed 4.2 x 10^{15} joules. This is approximately equivalent to the energy produced by a large coal fired generator at a power station over a period of three weeks.

This energy is released over a time span ranging from days to several years. If you live near the sea you will notice that the sea has a moderating influence on short term temperatures. That is, days are generally cooler and nights are generally warmer close to the sea compared with only a few kilometres away. The sea can also influence longer term temperatures. The hottest and the coldest parts of the Earth are a long way from the sea.

Activity 3

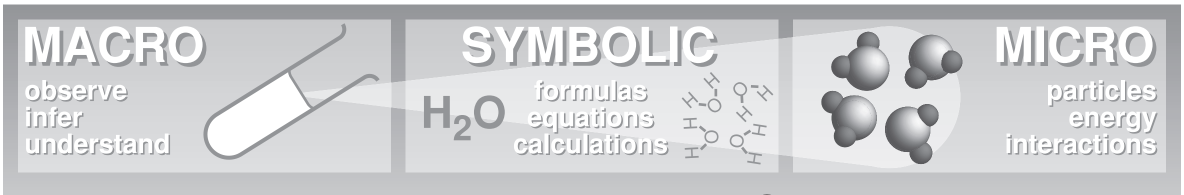
Check your local newspaper, television or radio, weather report and obtain the expected maximum and minimum temperatures for two towns that are close to each other but one on the coast and the other a short distance inland eg. Sydney and Richmond.

	Town	**Expected maximum temperature (°C)**	**Expected minimum temperature (°C)**
Coast			
Inland			

Explain your results.

Check your answers.

Some solar energy can be stored by the biochemical process we call photosynthesis. This energy can be released over a time span of hours stretching through to many millions of years. Photosynthesis and its importance is discussed in detail next.



What is photosynthesis?

Put simply photosynthesis is a chemical process, occurring in green plants and some micro–organisms, that uses light energy from the Sun in the presence of chlorophyll (a green pigment in most plants) to convert carbon dioxide (CO_2) and water (H_2O) into **carbohydrates** with oxygen gas (O_2) as a by product. It can be described by the chemical equation below:

$$6CO_2 + 6H_2O \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + O_2$$

(Balance the above equation by placing coefficients in front of the products.)

Obtain some water plants from a pet shop or creek and place in a container of water. Leave out in sunshine for an hour or two. Bubbles of O_2 should form on the leaves of the plants.

This experiment will also work with algae covered rocks from a stream or algae in a tidal pool on the rock platform.

In the space provided draw a simple diagram showing what you observed.

1 What colour were the bubbles?

____

Optional extension: If you have access to a science laboratory or a test tube and filter funnel you might like to collect some of the oxygen produced. (See diagram on the next page.)

2 What did you notice?

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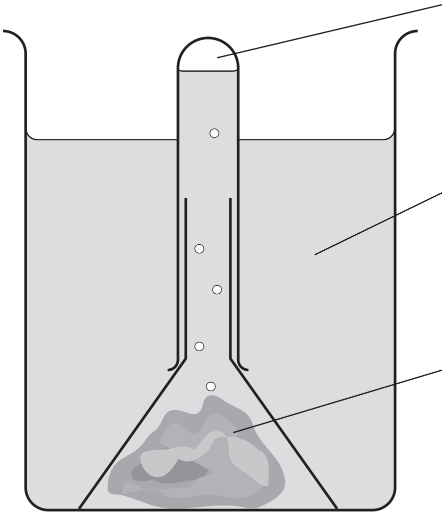
Check your answers.



Set up to collect oxygen from a plant. The oxygen can be tested with a glowing splint.

The importance of photosynthesis

Photosynthesis is vitally important in most **ecosystems** as this process converts inorganic compounds like carbon dioxide and water into energy rich organic compounds called carbohydrates.

Carbohydrates are called 'energy rich' because when they react with oxygen they will produce large amounts of energy. Recall, from the previous module *Water*, that energy is released when chemical bonds are formed and absorbed when chemical bonds are broken.
When carbohydrates react with oxygen: energy released > energy absorbed.

Notice that the statement said 'in most ecosystems'. Until recently it was thought that all ecosystems on Earth depended on the process of photosynthesis to convert low energy, inorganic compounds to high energy, organic compounds that can be used by both plants and animals for their life processes. About 20 years ago it was found that there were ecosystems on the ocean floor that did not depend on energy from the Sun but were in fact powered by chemical energy from within the Earth.

1 What is(are) the source(s) of heat energy for these ecosystems?

____

____

____

To find out about the chemicals used as a source of chemical energy:
http://www.lmpc.edu.au/science

The most valuable product of photosynthesis is the production of a group of compounds called carbohydrates.

Carbohydrates are important because they can be easily transported in plant bodies as small, water soluble molecules such as glucose and can be stored by plants as large, mostly water insoluble molecules such as starch. Later, large storage molecules can be broken down to smaller water soluble **glucose** molecules and easily transported to any part of the plant needing to release energy for living processes.

2 Prepare a list of some of these living processes that would require energy.

Like plants, animals are also dependent on photosynthesis for their energy needs. Animals lack the green pigment chlorophyll and so cannot make carbohydrates from CO_2 and H_2O.

Animals therefore need to eat plants, plant products or other animals to obtain the necessary carbohydrates. Do you remember studying food chains and food webs during your junior science years?

If you don't then maybe you should ask your teacher to refresh your memory or you should do a quick Internet search.

3 Using your knowledge of photosynthesis describe a situation where the stored energy of photosynthesis can be released:

a) after a few hours

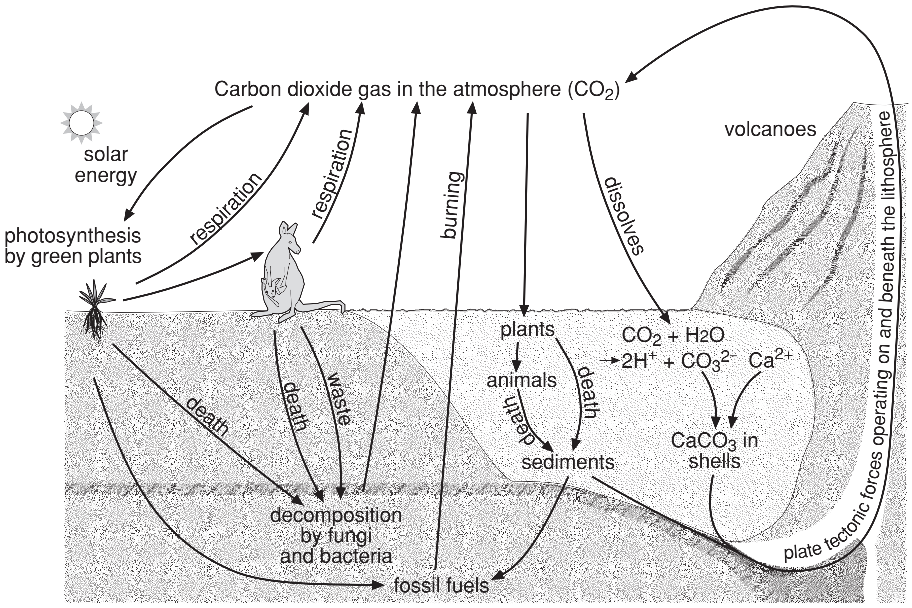
b) after a few months

c) after millions of years

Check your answers.

The source of carbon dioxide

Plants obtain the CO_2, used in photosynthesis, from the Earth's atmosphere. But, as the percentage of CO_2 in air is only about 0.04%, the atmosphere would soon be depleted of CO_2 if it wasn't being continually recycled. The diagram below shows how this recycling occurs.



The carbon cycle in nature.

Using the above diagram as a guide to answer the following questions.

1 List two ways in which humans have influenced the natural recycling of carbon dioxide.

2 Describe one way that allows carbon dioxide to enter the atmosphere that, at *no* stage, requires living processes.

____

____

Check your answers.

Natural processes and the carbon cycle

As plants and animals grow they accumulate energy gained from photosynthesis in the form of carbon (organic) compounds. The larger an organism becomes, the greater the mass of carbon compounds. Therefore, the greater the amount of energy being stored.

When an organism dies and decays this stored energy can be released by bacteria and fungi and the process (if allowed to run its full course) produces carbon dioxide which goes back into the atmosphere to be used again. This process is known as **decay** and is virtually the reverse of photosynthesis.

Write a generalised decay reaction in words.

____

Check your answer.

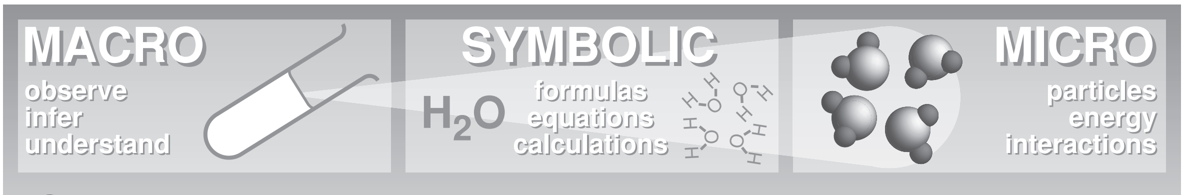
Natural geological processes can also interfere with this natural recycling. This is done by interrupting the process of decay.

The two main natural processes that interrupt the complete decay process are:

- the formation of peat and coal
- the formation of oil and natural gas.

These will be described in the next section.

Do Exercise 1.1 now.



Coal, oil and natural gas

Coal is a sedimentary rock formed from layers of plant material. This vegetable matter is the direct result of the photosynthesis reaction.

Coal comes in a variety of forms depending upon differences in their formation, chemical composition and physical properties.

Australia's oldest deposits of black coal found in NSW and Queensland, were formed between 225 and 180 million years ago. However, younger black coal mined in Queensland, South Australia and Tasmania are between 140 and 180 million years old. Victoria's brown coal deposits are young by comparison, formed less than 45 million years ago.

On the time line below, plot the ages of the coal deposits mentioned above.

300 200 100 present

Millions of years ago

Formation of coal

When plant debris in low lying coastal and river areas subsided under water, the low oxygen environment inhibited the decay process so that plant remains were, in effect, **mummified**. As successive layers of silt and sand forced the matter deeper and increased the pressure and temperature, **coalification** began. The intensity of pressure and temperature and the time the process has taken matches the **geological maturity** of coal.

Rank is measured by the degree of physical and chemical change that has taken place in the coal. The higher its carbon content, for example, the higher the rank. The lower its volatile content, the more mature it is because large volumes of gas (water and sulfur) were produced and dissipated during the coalification process.

The lowest ranking, or most geologically immature product of the coalification process, is peat. It consists of partly decomposed vegetable matter and has a high oxygen and water content (over 75%). Peat commonly has a carbon content of around 10%, **volatile** components of about 15% and an average energy value of 16 MJ/kg.

Brown coals have a high oxygen content (up to 30%), a relatively low carbon content (6–25% on a dry basis), and a high moisture content (30 to 70%). The volatile components are around 15%. Brown coals, found in Australia in Victoria's Latrobe Valley, are used for power generation (energy content of 23 MJ/kg) but generally are uneconomic to transport because of their high moisture content. These coals are also susceptible to **spontaneous combustion**. This can create serious problems in mines and there needs to be adequate provision of sprinkling systems available.

Sub–bituminous coals usually appear dull black and waxy. They have a carbon content of 71% to 77%, volatile components average 32% and the moisture content of up to 10%. They are used for electricity generation or can be converted to liquid or gaseous fuels. The average energy value is 33 MJ/kg. Queensland, New South Wales, Tasmania, South Australia and Western Australia have deposits of sub–bituminous coals.

Bituminous coals are dense black solids, frequently containing bands with a brilliant lustre. The carbon content of these coals ranges from 78% to 91% and the water content from 1.5% to 7% with volatile components of about 32%. The major NSW and Queensland deposits are bituminous and many are suited to the production of **metallurgical coke**. **Steaming coals** are burnt in power stations to produce heat which makes steam used for power generation, cement making and to provide heat and steam in industry. The average energy value is 36 MJ/kg.

The highest ranked coal, **anthracite**, is the most mature. Anthracite is jet–black with a bright lustre and contains more than 92% carbon with very little moisture (around 2%). The amount of volatiles is also small (around 7%). Anthracite is difficult to **ignite** due to its high degree of compaction but has a high heating value, producing on average 35 MJ/kg. It also has a low sulfur content (0.7%). When burnt it produces very little smoke. This fact was put to use in World War I where anthracite was used to power warships.

Complete the table below by referring to the information in the section on the formation of peat and coal.

Rank	Carbon Content (%)	Moisture content (%)	Volatile content (%)	Energy value
peat				
brown coal				
sub–bituminous				
bituminous				
anthracite				

Check your answers.

Formation of oil and natural gas

Oil and natural gas are mixtures of a vast number of compounds (at least 60 000 so far identified) mainly made up of the elements hydrogen and carbon. These compounds are generally known as **hydrocarbons**. They can occur together or separately in the Earth's crust.

The processes involved in the formation of oil and natural gas are not fully understood but we believe that they form from the partial decomposition of marine or aquatic plant and animals. These plants and animals die and their remains are deposited on the bottom of large lakes or seas in an environment that is low in oxygen. This lack of oxygen prevents complete decomposition by **aerobic bacteria** which would result in the production of carbon dioxide and water.

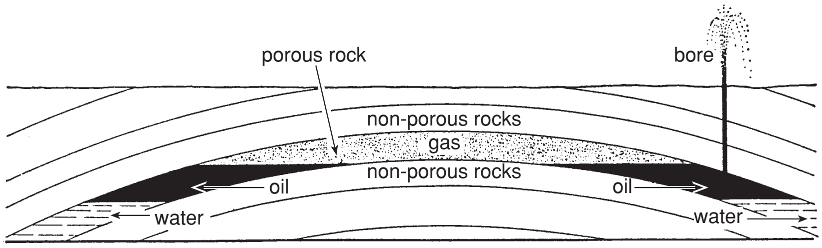
In a low oxygen environment bacteria are only able to partially decompose the material. The partially decomposed material is then buried by sediment and over millions of years is subjected to heat and pressure in the earth's crust. This converts the animal and plant remains into oil and/or gas. (It is thought that the temperature and pressure are critical in determining the ratio of oil to gas.)

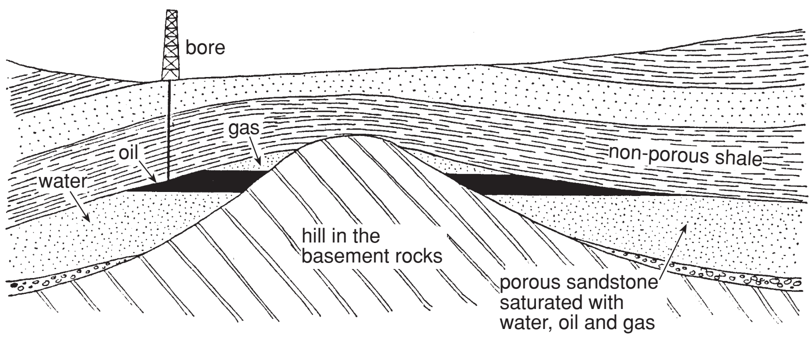
Once the oil and gas has formed in these rocks it either remains where it is, trapped between the grains of sediment or, if the rock is permeable then the oil and gas can migrate through the rock.

Much of the sedimentary rock of the crust contains water and the oil and gas float on this. The oil and gas rise towards the surface and escape into the oceans or the atmosphere unless they are trapped by geological structures and strata. Where oil and gas is trapped by geological structures it accumulates. These accumulations are called reservoirs and can occur at any depth, from a few metres to several kilometres below the Earth's surface. They also are found on land as well as under water due to the fact that the Earth's crust is in constant motion and most of these deposits formed millions of years ago.

Oil and gas is not actually in large caverns or lakes underground but found in spaces between the grains of sedimentary rocks. These spaces known as pores vary amongst rock types but typically are 5–10%.

structural trap eg anticline





Two possible occurrences of petroleum

Source: Messel, H. (chair). (1965.) Science for high school students. The Foundation for Nuclear Energy. University of Sydney.

What comes from oil and gas?

Crude oil and natural gas have very few uses in their natural state. However, as mentioned earlier, they contain in excess of 60 000 compounds. Many of these compounds are useful to humanity and extraction processes have been developed to separate the components of this complex mixture.

The basic procedure for separating this mixture is known as **refining** and the industrial complex is known as an oil refinery. It is in the refinery that fractional distillation techniques are used. (You will recall this technique from the first module: *The chemical Earth* as a means for separating mixtures of liquids having differing boiling points.)

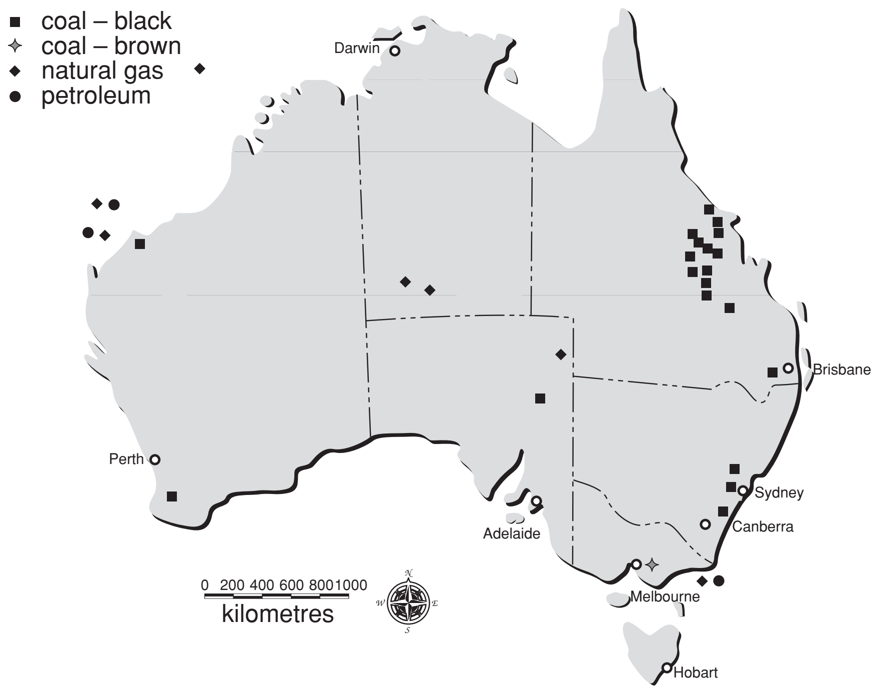
Original source	**Product**	**Uses**	**Comments**
Natural Gas	methane	domestic and industrial heating; compressed it is used as an automotive fuel	produces low level of CO_2 emissions, in 1999 provides about 18% of Australia's energy
Natural Gas and Crude Oil	propane/ butane (LPG)	automotive fuel, domestic and industrial heating in areas not connected to natural gas, barbecues	Available Australia wide, is in liquid form which makes it easy to transport and store, low levels of noxious emissions
Crude Oil	aviation gasoline	high octane fuel for piston driven aircraft	powers most small passenger aircraft
	petrol	automotive fuel	petrol is relatively cheap, safe, easy to store and transport, noxious emissions are a problem
	kerosene (jet fuel)	aviation fuel for jet turbine aircraft	powers most of the world's commercial aircraft, has problems with noxious emissions
	heating oil	domestic and industrial heating	relatively expensive and has high noxious emissions; there are better alternatives
	diesel fuel	automotive fuel, electrical generation in isolated communities	efficient fuel, relatively high noxious emissions, safe, easy to transport
	furnace oil	fuel for ships and large scale industrial heating	safe, easy to transport and store

Some of the products that are produced by the refining process are: petrol, diesel(also known as distillate), lubricating oil, heating or fuel oil, aviation kerosene, waxes and bitumen.

Gases are liberated from the process or from natural gas and include: methane, ethane, propane and butane as well as carbon dioxide, water, oxygen, nitrogen and hydrogen sulfide.

The products of the basic refining process are either used by themselves eg. as fuels; or provide the chemical feed stocks for industries producing millions of useful compounds ranging from livestock feed to plastics and pharmaceuticals. Most **synthetic** organic compounds can be produced from oil or natural gas.

Coal, oil and natural gas in Australia



Energy reserves in Australia.

In terms of total energy reserves Australia is very well off. We have abundant reserves of high quality and easily accessible coal reserves. Some estimates suggest that there are enough proven reserves to last several hundred years at the present rate of consumption.

Much of our coal is also found close to the major population centres on the east coast, which has implications for transport costs.

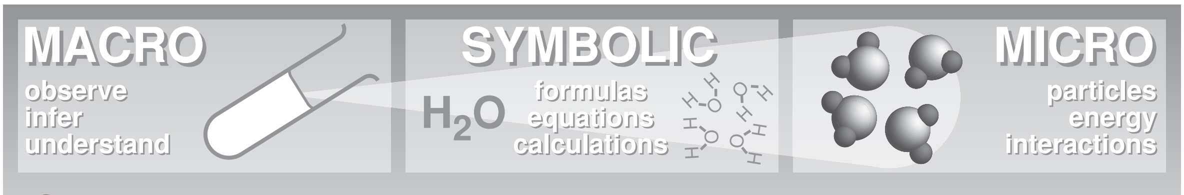
Australia also has abundant reserves of natural gas. Some reserves like those in Bass Strait are very close to markets and cheap to transport.

However, the very large reserves of natural gas situated in the central and northwest Australia are several thousand kilometres from markets. Transport costs here are very high and influence the potential market. Much of this natural gas is exported overseas by tanker or, in the case of Central Australia, carried vast distances by pipelines. Darwin for instance obtains its electricity from the burning of natural gas that is piped, from near Uluru in Palm Valley, a distance of over 1000 km.

Australia's oil reserves are not as extensive as either coal or natural gas. In fact we have less than our fair share of the world's known oil reserves on a per capita basis. Most of the oil fields discovered so far are relatively easily accessible and because of the high value of oil, transport costs are not significant.

If you wish to find out more about our coal, oil and natural gas industry visit this web site: http://www.lmpc.edu.au/science

Do Exercise 1.2 now.



Suggested answers

Energy and the Earth

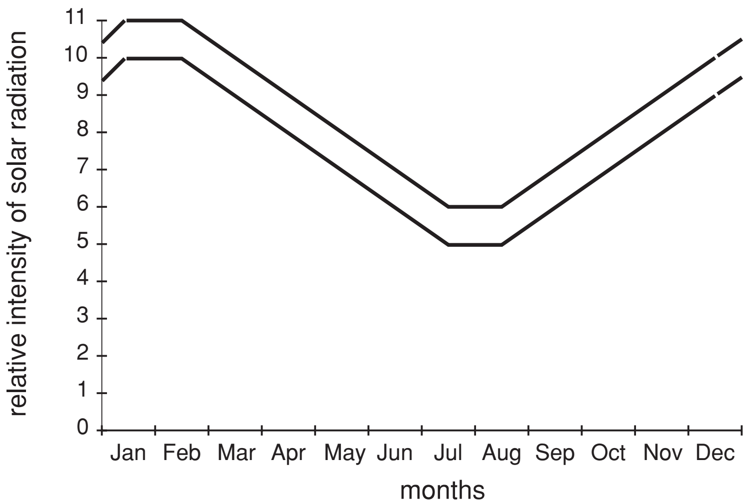
1 Other forms of electromagnetic radiation that penetrate the Earth's atmosphere would include: infra–red, microwaves, radio waves and ultra violet waves.

2 Most UVb is absorbed by the atmosphere.

3 The parts of the Earth receiving the most intense solar radiation would be those areas closest to the equator or high on mountains.

a) Southern Hemisphere. On the graph, the intensity of solar radiation peaks in December, January and February which corresponds to summer in the Southern Hemisphere.

b)

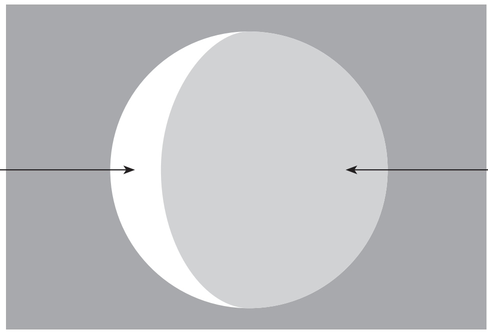


The Earth's energy budget

1 Energy is stored by the Earth in: the atmosphere, clouds, land and oceans.

2 Energy is lost by the Earth by: reflection by the atmosphere, clouds, the Earth's surface; conduction and convection; and infra–red radiation from the surface.

Activity 1



Activity 2

1 You should have noticed that the brick wall, concrete path, road or large boulder would still be warm while the grass or leaves would feel much cooler.

2 After another hour you may notice that the brick wall, concrete path, road or large boulder would have cooled considerably but the grass or leaves may not have changed in temperature noticeably.

Activity 3

Expected maximum and minimum temperatures will vary but generally the maximum will be lower near the coast and the minimum higher near the coast. This is due to the moderating effects of the ocean. The ocean is slower to warm up during the day and slower to cool down at night.

What is photosynthesis?

1 The bubbles of oxygen produced are colourless. A silvery colour seen is light reflected from the interface between gas and water.

2 **Optional** Oxygen ignites a glowing splint. This is a standard test for oxygen.

The importance of photosynthesis

1 The heat originates from within the Earth. It is a combination of: heat left over from the formation of the Earth, heat from the radioactive decay of elements and heat produced by friction as the geological plates move across and below the surface of the Earth.

2 Living processes that could require energy could include: growth and repair, reproduction, respiration, movement.

3 a) Plants may produce carbohydrates during the daylight hours and use those carbohydrates that night in respiration.

b) A potato plant may store carbohydrates in a tuber which is then harvested and eaten by people several months later.

c) Plants may store carbohydrates which are then turned into coal buried in the Earth and then mined millions of years later and burnt.

The source of carbon dioxide

1 Humans have influenced the natural recycling of carbon dioxide by: burning fossil fuels and clearing vegetation to build towns and cities.

2 Volcanic activity would be an example of carbon dioxide release that at no stage requires living processes.

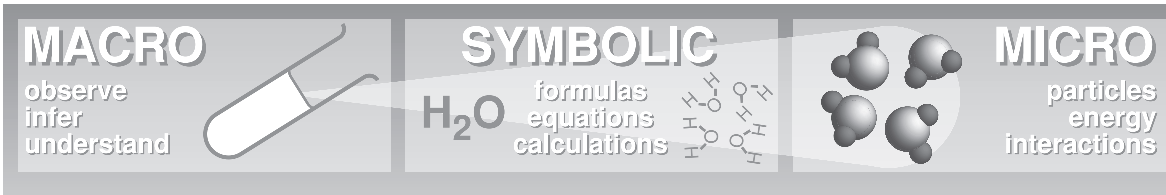
Effects of natural processes on the carbon cycle

1 In the space below write a generalised decay reaction in words.

carbohydrate + oxygen $\rightarrow$ carbon dioxide + water

Formation of coal

Rank	Carbon content (%)	Moisture content (%)	Volatile content (%)	Energy value
peat	10	>75	15	16 MJ/kg
brown coal	6–25	30–70	15	23 MJ/kg
sub–bituminous	71–77	10	32	33 MJ/kg
bituminous	78–91	1.5–7	32	36 MJ/kg
anthracite	92	2	7	35 MJ/kg



Exercises – Part 1

Exercise 1.1 to 1.2 Name: ____________________________________

Exercise 1.1: Photosynthesis

Photosynthesis plays a vital role in almost all ecosystems on Earth.

a) What is photosynthesis?

b) Write a balanced chemical reaction for photosynthesis.

c) Explain why both products of the photosynthesis reaction are important to life on Earth.

d) Carbon dioxide is important in photosynthesis and yet it occupies only a small portion of the Earth's atmosphere.

i) What is its abundance in the atmosphere (expressed as a percentage)?

iii) How do you account for this small percentage?

e) As you have read earlier the temperature of the Earth has remained relatively constant over time.

Remember: energy in = energy out

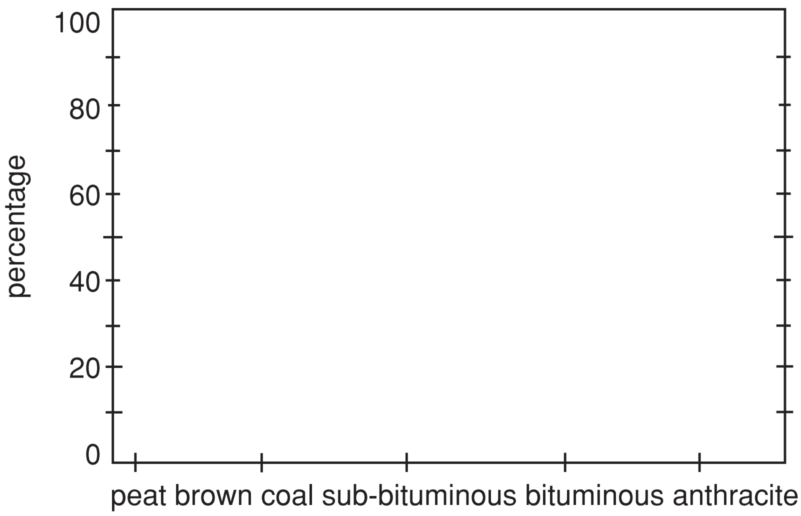
How does the process of photosynthesis affect the energy balance on Earth?

____

____

Exercise 1.2: Coal, oil and natural gas

a) Turn to the table you completed earlier for formation of peat and coal graph carbon content, volatile components and moisture content. Then answer the questions.



i) Coal that has a moisture content of 5% and a carbon content of about 63% would best be classified as:

____

ii) Describe what happens to the volatile components of coal as the rank changes from peat to anthracite.

____

____

iii) Explain why brown coal is not exported overseas as an energy source (Give two reasons: one economic and one safety.)

____

____

____

iv) Anthracite is not widely used in Australia for a number of reasons. One reason is that we do not have large deposits. What is another reason?

____

____

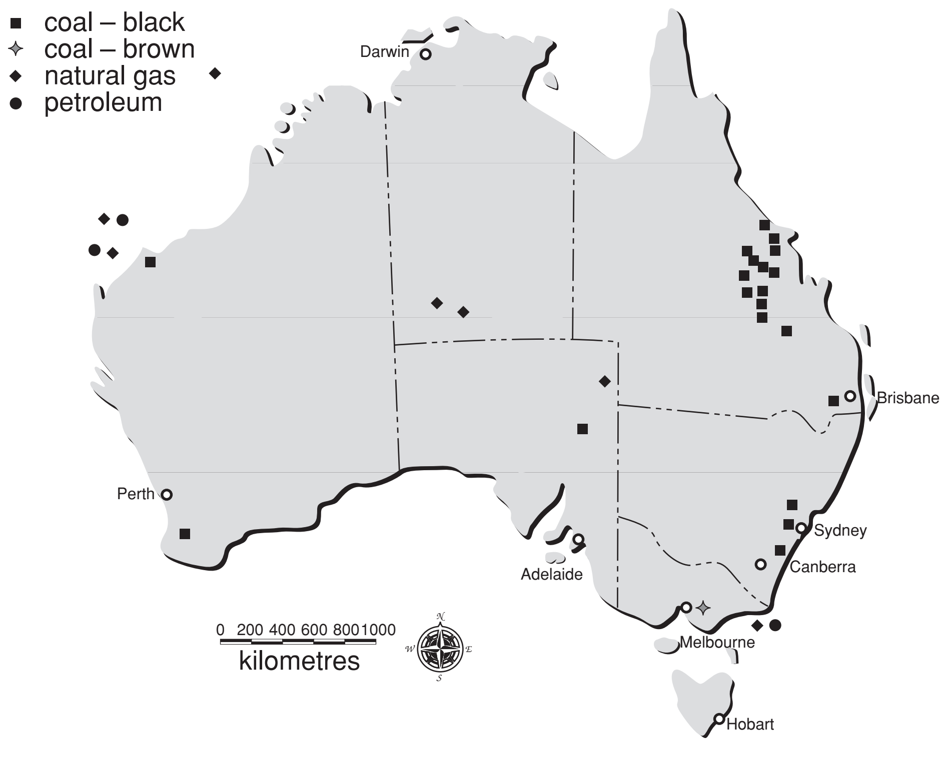
b) Using a chemistry/geology text or the Internet:

i) Find information on the latest theories on the formation of: coal, and oil/natural gas.

Process this information and present it in the form of two simple diagrams that show the sequence of events that, it is believed, led to the formation of coal, oil and natural gas.

Use you own paper.

ii) Find information on the location of coal, oil and natural gas deposits in Australia. Add any locations, that you have found, to the map of Australia below.



iii) Find and list the range of compounds found in coal, oil and natural gas. You may wish to present this information in the form of a table. use your own paper.

Attach your information to this page for your teacher.

Chemistry

Preliminary Course

Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING

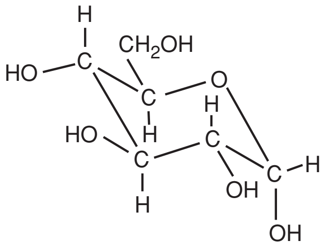
TAFE NSW

OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

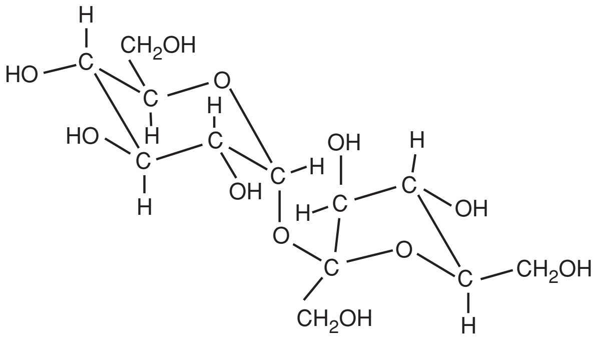
Energy

Part 2: Carbon and its compounds

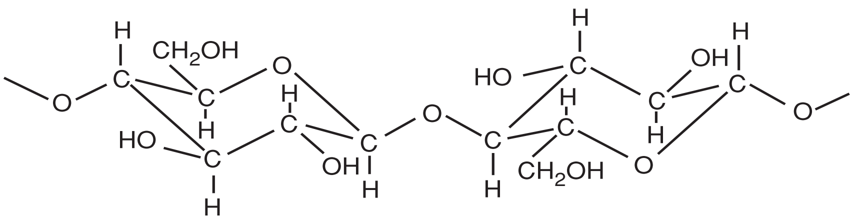
Incorporating October 2002 AMENDMENTS



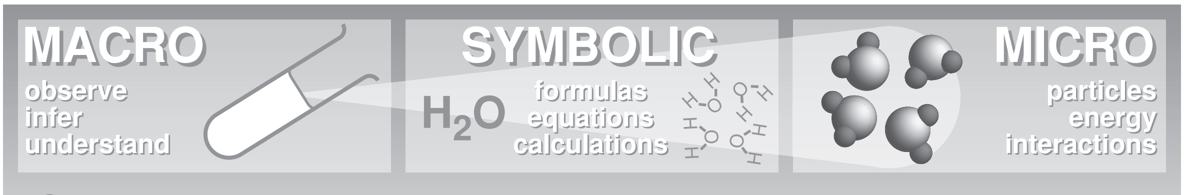
glucose



sucrose



cellulose


MACRO
observe
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SYMBOLIC
H_2O
formulas
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MICRO
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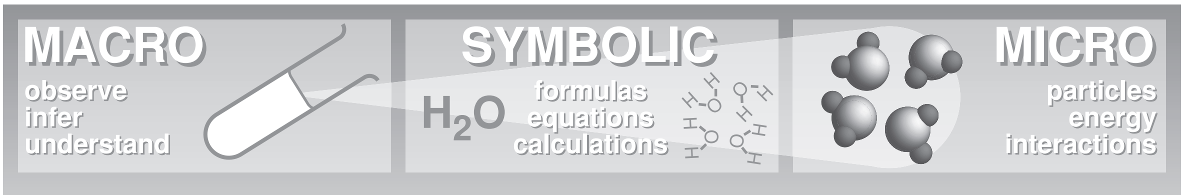
interactions

Contents



Introduction

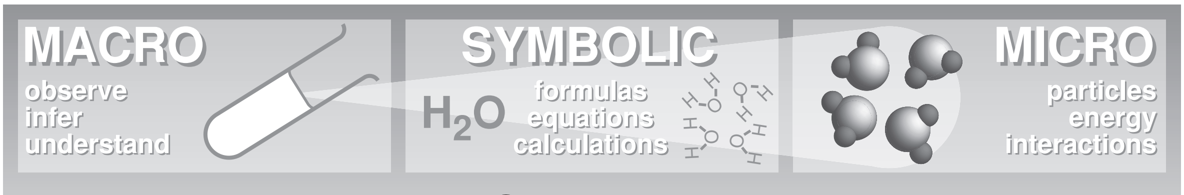
In Part 2, where you investigate the element carbon and its compounds, you will be given opportunities to:

- identify the position of carbon in the Periodic Table and describe its electronic configuration
- describe the structure of the diamond and graphite allotropes and account for their physical properties in terms of bonding
- identify that carbon can form single, double or triple covalent bonds with other carbon atoms
- explain the relationship between carbon's combining power and ability to form a variety of bonds and the existence of a large number of carbon compounds.

In Part 2, you will be given opportunities to:

- perform a first–hand investigation, analyse and use available evidence to model the differences in atomic arrangement of diamond, graphite and fullerenes
- process and present information from secondary sources on the uses of diamond and graphite and relate their uses to their physical properties
- identify data, and choose resources from secondary sources such as molecular model kits, digital technologies or computer simulations to model the formation of single, double and triple bonds in simple carbon compounds.

Extracts from *Chemistry Stage 6 Syllabus* © Board of Studies NSW, November 2002. The most up–to–date version is to be found at http://www.boardofstudies.nsw.edu.au/syllabus_hsc/index.html



What is carbon?

Carbon is a naturally occurring chemical element. The element carbon has been known for thousands of years. Its name comes from the Latin word for coal. (Remember that coal is mostly made up of carbon.)

Carbon – its vital statistics

Carbon melts at about 3970°C. It is, however, difficult to get carbon to melt because at about 3930°C it begins to **sublime.**

1 a) Use a text or the internet to define the term ‘sublimation’.

____

____

b) Explain how sublimation would make it difficult to obtain liquid carbon.

____

____

2 Using your knowledge of the periodic table of elements, and carbon’s position in the table, complete the following list.

Element: carbon

Atomic number: ____________

Metal/non–metal: __________

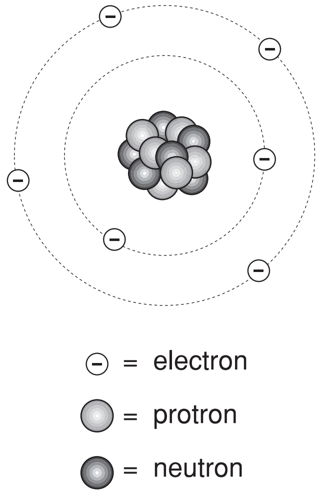
Number of protons: ___________

Number of electrons: ________

Number of electrons (first shell): _________

Number of electrons (second shell): _________

Check your answers.



The atomic structure of carbon.

The atomic mass of carbon is usually listed as close to 12.01 in most periodic tables. This indicates that most carbon atoms have six neutrons in the nucleus, as well as six protons, giving a mass of 12.

Isotopes of carbon

Remember that atomic mass can be calculated by adding the number of protons and neutrons (each with a mass of 1). Carbon does, however, exist as a number of other isotopes.

For revision of isotopes read *Metals Part 3, Atomic Structure*.

The most common isotope is carbon–12 (C^{12}). In this isotope, which accounts for nearly all carbon atoms, the nucleus contains the mandatory 6 protons and 6 neutrons. This, when added together, gives an atomic mass of 12. Carbon–12 is a stable isotope meaning that it is not radioactive. It has a natural abundance of 98.893%.

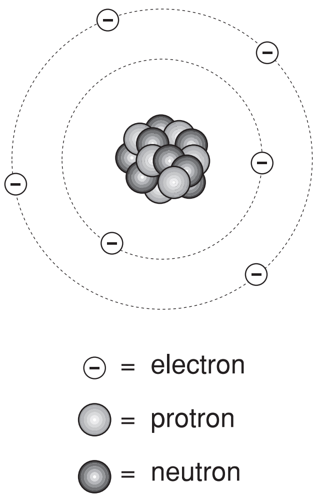
Another stable isotope of carbon is carbon–13 (C^{13}) which has a natural abundance of 1.107%. The average atomic mass of carbon is:

$$\frac{98.893}{100} \times 12 + \frac{1.107}{100} \times 13 = 12.01$$

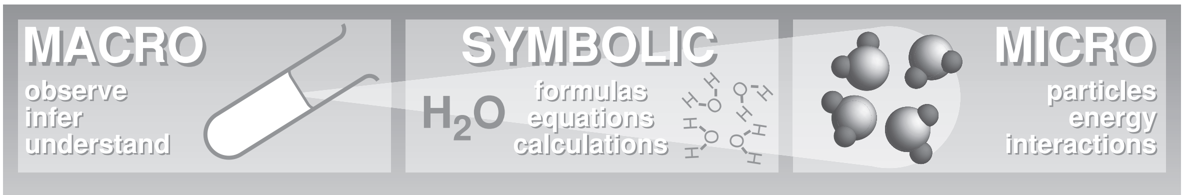
This is the value given for carbon in the periodic table.

There are also several unstable (radioactive) isotopes of carbon. They are carbon–10 (C^{10}), carbon–11 (C^{11}), carbon–14 (C^{14}), carbon–15 (C^{15}) and carbon–16 (C^{16}).

You have probably heard of carbon 14 before. It is a radioactive isotope that is commonly used by scientists to date objects containing carbon that are up to 50 000 years old.



To find out more about carbon dating visit the following web site: http://www.lmpc.edu.au/science



Allotropes of carbon

In the solid state, carbon is covalently bonded to other carbon atoms. These covalent bonds are very strong and require large amounts of energy to break. This is reflected in carbon's very high melting point.

There are a number of ways that the covalent bonds of carbon can be arranged. This results in different physical forms of carbon.

Different physical forms of an element are known as **allotropes**.

Carbon has three known forms or allotropes. They are:

- graphite
- diamond
- fullerenes (such as buckminsterfullerene also known as buckyball).

For information on the structure of the allotropes of carbon visit:

http://www.lmpc.edu.au/science

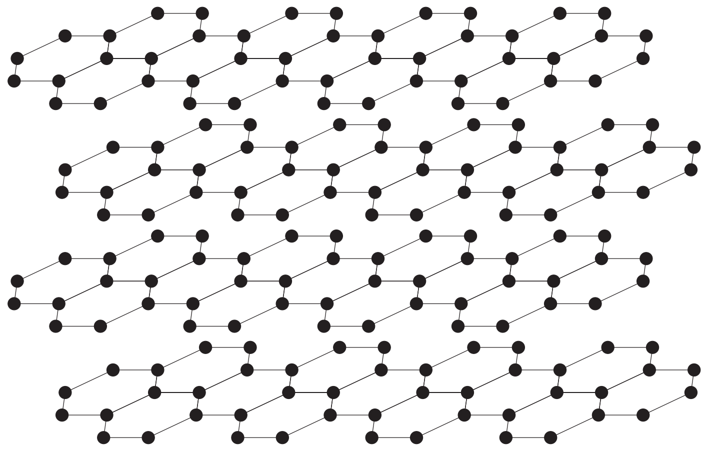
How are allotropes different? There are two ways of looking at the allotropes of carbon.

Looking at the micro (atomic) level.

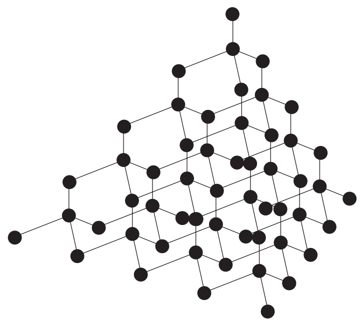
- All allotropes of carbon contain **only** carbon atoms.
- Allotropes differ in the way in which the carbon atoms are bonded to each other.

Looking at the macro level:

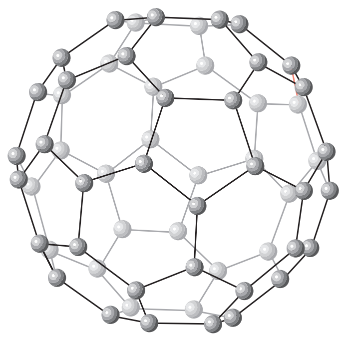
- The different arrangements of atoms, produced by differences in bonding, result in different physical properties. For example, the allotropes of carbon have different densities, colour, hardness, electrical conductivity and crystal shape.



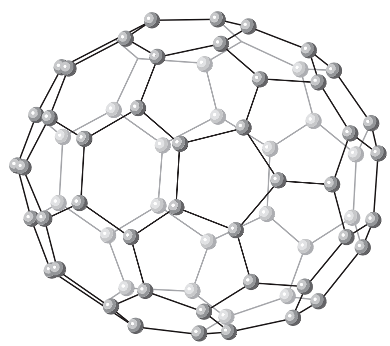
graphite C



diamond C



buckminsterfullerene C_{60} (buckyball)



fullerene C_{70}

Use your molecular model kit (if you have one) or Maltesers™ and toothpicks to produce models of a small portion of the crystal lattice of diamond, graphite and a fullerene. (Use the diagrams above to help you.)

Draw or photograph your models and include them with your send–in pages as part of Exercise 2.1: *Allotropes*.

The table below lists some of the properties of the allotropes of carbon. Match the property with the bonding and/or structure information on the right hand side of the table.

Property	**Bonding and/or Structure**
Hardest naturally occurring substance	Presence of free electrons between layers
Soft greasy feel	Covalent bonds in an infinite array
High melting point	Carbon atoms strongly bonded in layers but with weak dispersion forces between them
Good electrical conductivity	Open geodesic structure
Very low density	Carbon atoms strongly bonded in a tetrahedral arrangement

Check your answers.

Graphite

Most of you will be familiar with graphite. It is the main ingredient in 'lead' pencils (it is mixed with clay to harden it.)

The word 'graphite' comes from the Greek word 'to write'.

Lead pencils are available in a variety of types. Each one differing in hardness and blackness. For example: 3H, 2H, H, HB, B, 2B, 3B. 'H' is an indication of the hardness of the lead and 'B' is an indication of the blackness.

Graphite is a soft, black naturally occurring mineral that has a greasy feel. It is very soft and can be easily scratched with your fingernail. Graphite has a density of 2.26 gcm^{-3}.

The carbon atoms in graphite are arranged in rings of six atoms. These rings are arranged in layers. The bonds between the atoms of these rings are covalent and very strong. However, the bonds between the layers are weak **dispersion forces**. These weak forces allow the layers to slide over each other and this gives graphite its soft, greasy feel.

There are free electrons that can move along between the layers and this makes graphite a good conductor of electricity.

Diamond

As its price suggests, diamond is a relatively rare form of carbon.

Diamonds are transparent and very hard solids. These properties make them valuable for industrial purposes. In fact diamonds are the hardest naturally occurring substances, rating 10 on the 1–10 Moh's scale of hardness. On this scale a steel knife blade rates a hardness of about 6. Diamonds have a density of 3.52 g cm^{-3}.

The carbon atoms in diamond are arranged tetrahedrally where each carbon atom is covalently bonded to four other carbon atoms.

There are no free electrons so diamonds do not conduct electricity.

Diamonds will burn in the presence of oxygen to form carbon dioxide but if heated strongly in the absence of oxygen will turn into graphite.

Diamonds can be cleaved to produce smooth reflective surfaces. This process is used when large diamonds are broken up to produce smaller polished gems.

Fullerenes

These allotropes of carbon has only recently been discovered (1989). Research indicates that in the future they may be useful in superconductors, metal coatings, catalysts, polymers, medicines, lubricants, tools, building materials, new fuels and more efficient combustion techniques.

The original allotrope consists of 60 carbon atoms arranged in an array similar to geodesic structures designed by the architect Buckminster Fuller. This has been called **buckminsterfullerene**.

Buckminsterfullerene is solid at room temperature and has a low density.

Since this initial discovery, more fullerenes containing different numbers of carbon atoms have been discovered. Fullerenes were first made in the laboratory but have since been found in nature. Those containing 70 carbon atoms are red in colour. It appears that fullerenes are more common than was initially thought.

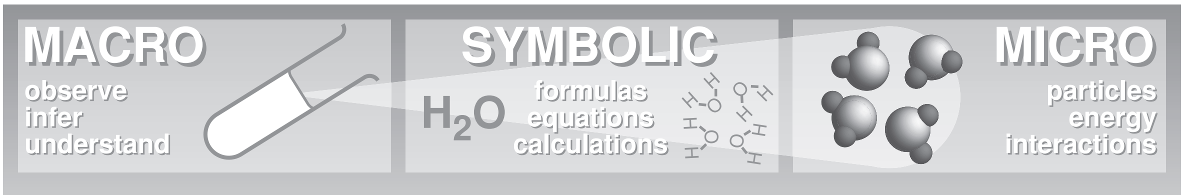
The main source of fullerenes seems to be cosmic. They have recently been discovered at meteorite impact sites around the world and one very interesting discovery was made when a micro meteorite impact crater on an American satellite was examined and found to contain fullerenes. It is not known whether these were produced by the impact or are normally present in some meteorites.

The discovery of fullerenes and related carbon structures has opened up a whole new field of chemistry.

For more information on fullerenes visit:

http://www.lmpc.edu.au/science

Complete Exercise 2.1: *Allotropes* now.



Electronic structure and reactivity

When an atom reacts, it does so in order to achieve an outer shell of eight electrons. This is referred to as a noble gas structure. Carbon could lose four electrons or it could gain four electrons. Losing four electrons produces an outer shell (first shell) of two electrons while gaining four electrons produces an outer shell (second shell) of eight electrons. However, in chemical reactions, carbon does neither.

Carbon's chemical nature

Carbon occupies a unique position in the periodic table. It is only a relatively small atom that has six protons in its nucleus. There are four electrons in its outer shell which is halfway to being complete. Successive ionisation energies for carbon are shown below.

Electrons removed	1st	2nd	3rd	4th
Ionisation energy (MJ/mol electrons)	1.1	2.4	4.6	6.2

How does the energy required to remove successive electrons from an atom of carbon vary?

Check your answer.

The reason for this is quite simple. Adding and/or removing electrons involves energy. The result of this is that more energy is required to remove the second electron than the first. By the time the fourth electron is removed, the energy required is so great that it is beyond the energy available in most chemical reactions. This energy is known as **ionisation energy**. Therefore, carbon does not generally form positive ions.

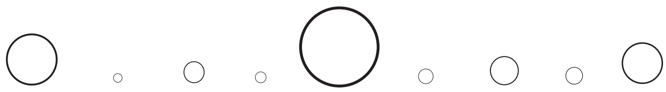
Each time an electron is removed from an atom, the remaining electrons are held much closer to the nucleus. This is because there is one less electron in the layer and so there are less electrons repelling each other (remember that like charges repel). This reduces the overall size of the atom.

The reverse applies in adding electrons to the atom. The first electron added encounters repulsion from the four other electrons already present in that layer. This increase in size of the atom increases the difficulty of adding more electrons to form ions with a charge of –2 and –3.
This increases as more electrons are added and so it becomes virtually impossible to add the four electrons that are needed to fill the outer shell.

1 The spheres drawn below represent the four negative and the four positive ions of carbon as well as a neutral carbon atom. Arrange the spheres to match the ions.

Ion	–4	–3	–2	–1	0	+1	+2	+3	+4

Sphere



2 Explain why, in most chemical reactions, carbon does *not* form ions.

Check your answers.

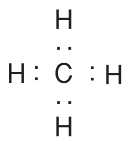
OK, so how does carbon react?

As you have seen, it requires huge amounts of energy to ionise carbon atoms. Therefore, carbon does not enter into ionic bonds. It does instead readily form covalent bonds. Put simply, a covalent bond is known as a sharing bond. In it, an atom is able to share one or more of its electrons with another atom or atoms. It is a little like leasing as opposed to buying when referring to real estate!

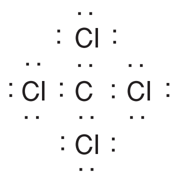
In the case of carbon there are four electrons to share. Carbon then shares four electrons from other atoms. This effectively gives carbon eight electrons which fills its outer shell.

Carbon is not particularly selective about which atoms it shares with and commonly shares electrons with other carbon atoms. Because of this ability to share with other carbon atoms, and its ability to share with up to four other atoms at the one time, carbon can therefore form a huge range of compounds.

Some of the other elements that carbon commonly shares electrons with are: hydrogen, oxygen, fluorine, chlorine, bromine, iodine, sulfur and nitrogen. The Lewis diagrams below show sharing of electrons.



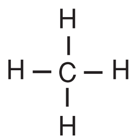
methane



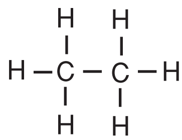
tetrachloromethane

carbon dioxide

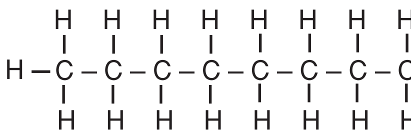
When carbon shares electrons it can form compounds where only one carbon atom is involved eg. CH_4 (methane); or two carbon atoms eg. C_2H_6 (ethane) or many carbon atoms. Each shared pair of electrons or covalent bond is shown by a line – drawn between two atoms.



methane

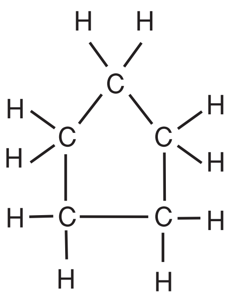


ethane

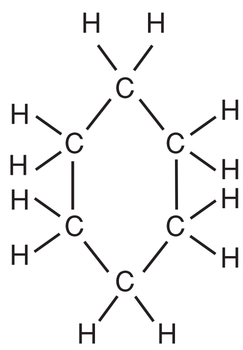


octane

Carbon is able to join to carbon to form chains and even rings. This allows for an endless number of possible compounds.



cyclopentane

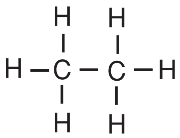


cyclohexane

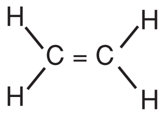
When carbon joins to carbon to form chains or rings the covalent bonds can be: single, double or triple.

Single covalent bonds involve only one pair of electrons; double bonds involve two pair of electrons; and you guessed it, triple bonds involve three pairs of electrons.

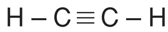
A single covalent bond is represented diagrammatically by a single line (–), a double covalent bond by double lines (=) and a triple covalent bond by triple lines (≡).



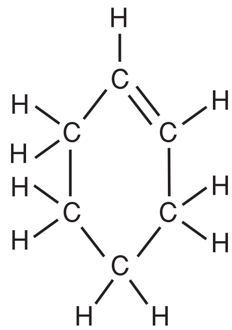
ethane



ethene



ethyne



cyclohexene

Significance of single, double and triple bonds

Single, double and triple carbon–carbon covalent bonds affect, both the shape and physical behaviour of a molecule, as well as its reactivity.

Single bonds are relatively unreactive and allow rotation round the bond making the molecule three–dimensional (3D).

Double bonds are reactive and lock the adjoining carbon atoms in a two–dimensional (2D) planar shape.

Triple bonds are more reactive than double bonds and lock the carbon atoms either side into a one–dimensional linear shape.

Molecules containing only single carbon–carbon covalent bonds are said to be ‘**saturated**’. The term ‘saturated’ means that there are no spaces to add hydrogen atoms to the chain.

Molecules with double or triple carbon–carbon covalent bonds are said to be ‘**unsaturated**’. Unsaturated means that it is possible to add hydrogen atoms to the chain by reducing the double and triple bonds to single bonds.

Activity 1

Many margarines and edible oils contain both saturated and unsaturated molecules. Survey your refrigerator and kitchen pantry cupboard for foodstuffs containing edible oils and fats (margarine and cooking oils). The oil or fat content of the food will be written on the side or bottom of the container. The type of oil or fat will be indicated as well as the percentage. Those that are unsaturated will be written as either mono–unsaturated or polyunsaturated.

Complete the following table.

Food	**Fat/oil type**	**Percentage of each type (saturated or unsaturated)**

Activity 2

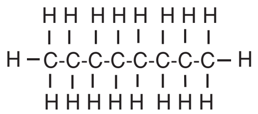
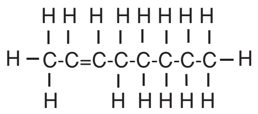
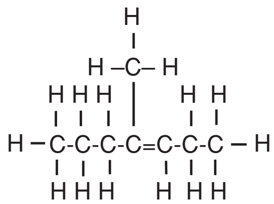
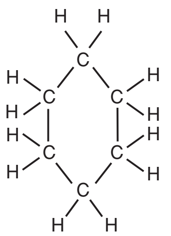
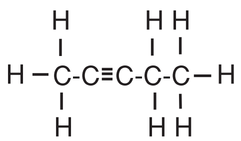
Use an Internet site that allows you to model compounds. One can be found by visiting http://www.lmpc.edu.au/science or use a molecular model kit or use:

- a packet of maltesers™ to represent C atoms
- toothpicks to represent the bonds
- a red marker pen to mark the bonds that have a H atom attached.

Select five, six, seven or eight carbon atoms (in a molecular model kit they are generally black). Arrange these carbon atoms to make as many structures, containing these carbon atoms, as you can. Use a variety of single, double and triple bonds.

Do not limit yourself to straight chains. You may have branches, and even rings, or any other combination.

Some examples are shown in the table to get you started.

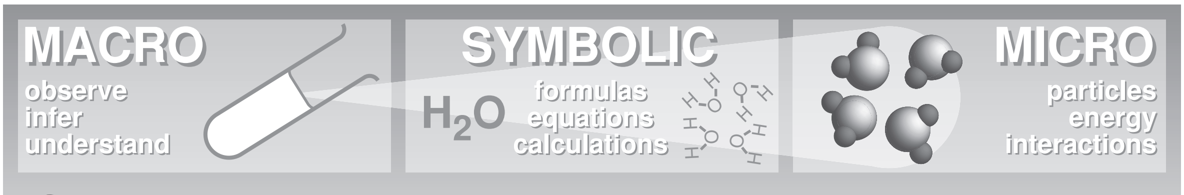
Structural formula	**Systematic name**	**Notes on naming**
	octane	oct = 8 carbons, ane = only single C to C bonds
	2–octene	ene = double C=C bond, 2= double bond between second and third carbon atoms
	4–methyl–3–heptene	CH_3 (methyl group) on the 4th carbon atom, C=C double bond between the third and fourth carbon atoms
	cyclohexane	cyclo = ring
	2–pentyne	yne = triple carbon to carbon bond

Draw or photograph five of the structures that you have made, not including the examples already given.

Name the compounds you made.

Use the naming rules for *Naming carbon compounds* in *The chemical Earth*, Part 6 and notes in the above table.

Include the names you have worked out as part of Exercise 2.2: *Compounds of carbon*.



Carbon compounds in living things

Starting with relatively simple compounds, such as carbon dioxide and water, living cells are able to synthesise a huge array of complex organic compounds. Most biologically important compounds are very complex and involve many hundreds of atoms eg. deoxyribose nucleic acid (DNA). Not all molecules, however, are as large and complex as DNA.

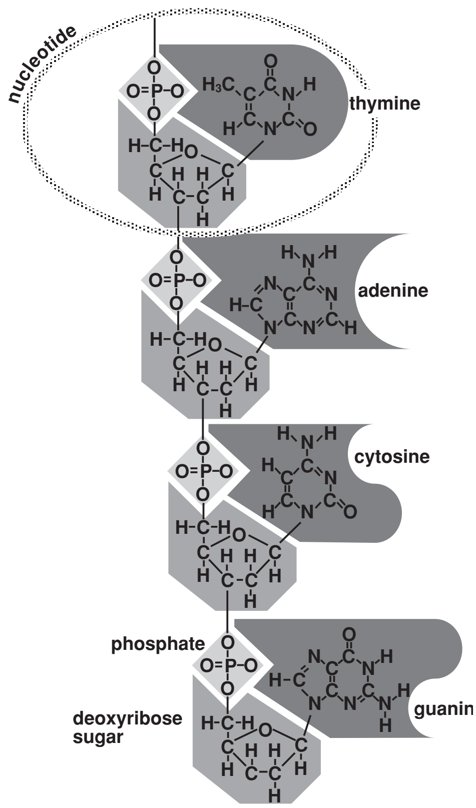
You have probably seen DNA represented as a double helix, like a spiral staircase.

Each spiralling strand consists of a deoxyribose sugar and phosphate backbone with attached bases (thymine, adenine, cytosine and guanine.)

The thymine on one strand can form hydrogen bonds with the adenine on the other strand, while cytosine hydrogen bonds with guanine on the other strand.

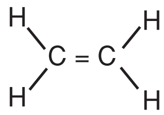
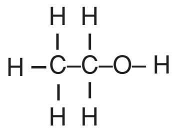
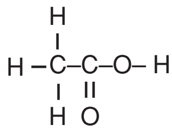
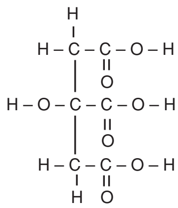
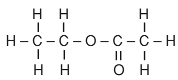
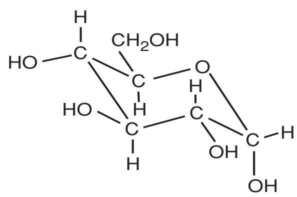
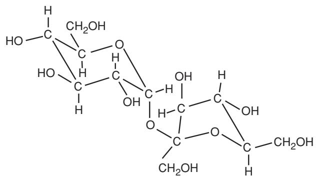
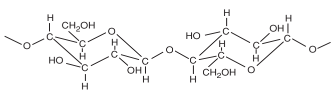
Most of the mass of the bases and deoxyribose sugar is due to carbon atoms. While phosphorus, oxygen, nitrogen and hydrogen are important parts of this structure carbon is the only atom that links to the same sort of atom to form stable structures.

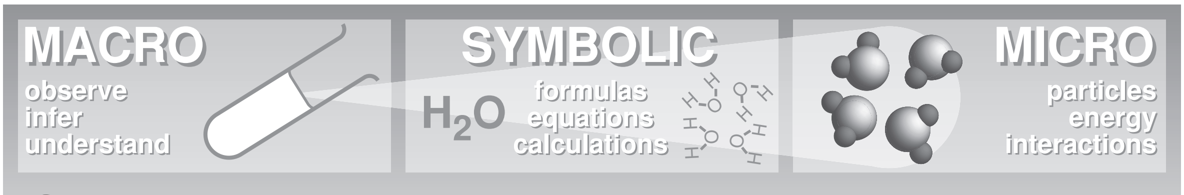
In DNA the P, O, N and H atoms are always bonded to a different atom to form stable structures.



Structure of DNA.

Commonly encountered organic compounds associated with living things are shown in the table following.

Compound	Molecular formula	Structure	Comments
ethene	C_2H_4		produced naturally by ripening bananas
ethyne	C_2H_2	$H-C\equiv C-H$	used to produce high temperature flames for metal working
ethanol	C_2H_5OH		industrial solvent; alcoholic beverages; produced naturally by fermentation
ethanoic acid	CH_3COOH		is the main ingredient of vinegar besides water; produced naturally by fermentation; important industrially
2–hydroxy–1,2 ,3–propane tricarboxylic acid	$C_6H_8O_7$		involved with the release of energy by living cells (Krebs/tricarboxylic acid[TCA]/citric acid Cycle)
ethylethanoate	$C_2H_5OOCCH_3$		used as an industrial solvent; has fruity sweet smelling flavour
glucose	$C_6H_{12}O_6$		product of photosynthesis; sweet tasting carbohydrate used as additive in confectionery
sucrose	$C_{12}H_{22}O_{11}$		cane sugar; used as a sweetener
cellulose	$(C_6H_{10}O_5)_n$		constituent of plant cell walls; insoluble carbohydrate



Suggested answers

Carbon – its vital statistics

1 a) Sublimation is the tendency of some substances to turn directly from a solid to a gas without passing through the liquid state.

b) Because solid carbon begins to sublime (form a gas) at 3930°C, then it would be difficult to produce liquid carbon as the melting point is higher (3974°C). Therefore, carbon would sublime before it melts.

2 Element: carbon

Atomic number: 6

Metal/non–metal: non–metal

Number protons: 6

Number of electrons: 6

Number of electrons (first shell): 2

Number of electrons (second shell): 4

Allotropes of carbon

Property	Bonding and/or Structure
Hardest naturally occurring substance	Covalent bonds in an infinite array
Soft greasy feel	Carbon atoms strongly bonded in layers but with weak dispersion forces between them
High melting point	Carbon atoms strongly bonded in a tetrahedral arrangement
Good electrical conductivity	Presence of free electrons between layers
Very low density	Open geodesic structure

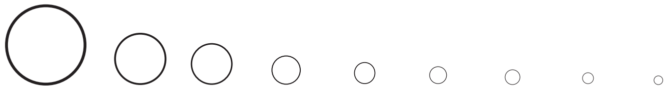
Carbon’s chemical nature

The energy required to remove electrons increases with each successive electron.

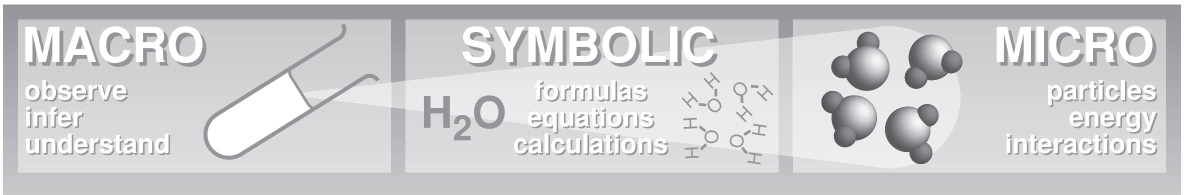
1

Ion –4 –3 –2 –1 0 +1 +2 +3 +4

Sphere



2 The energy required to form positive ions (by removing electrons) is not generally available in a chemical reaction. The increase in the size of the negatively charged ion (as electrons are gained) and the increase in repulsion makes it extremely difficult for carbon to form cations.



Exercises – Part 2

Exercise 2.1 to 2.2 Name: ___________________________________

Exercise 2.1: Allotropes of carbon

a) i) Complete the following table to summarise the properties and uses of three allotropes of carbon.

	Graphite	Diamond	Buckminster-fullerene
Colour			
Density			
Hardness			
Atomic arrangement			
Electrical conductivity			
Uses			

ii) Relate the structure of each allotrope to its different properties.

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iii) Having identified specific uses of each allotrope explain why graphite is used in a different way to that of diamond. Consider the atomic structure of the allotrope in your explanation.

b) The number of neutrons in the nucleus of:

carbon 10 ______

carbon 11 ______

carbon 13 ______

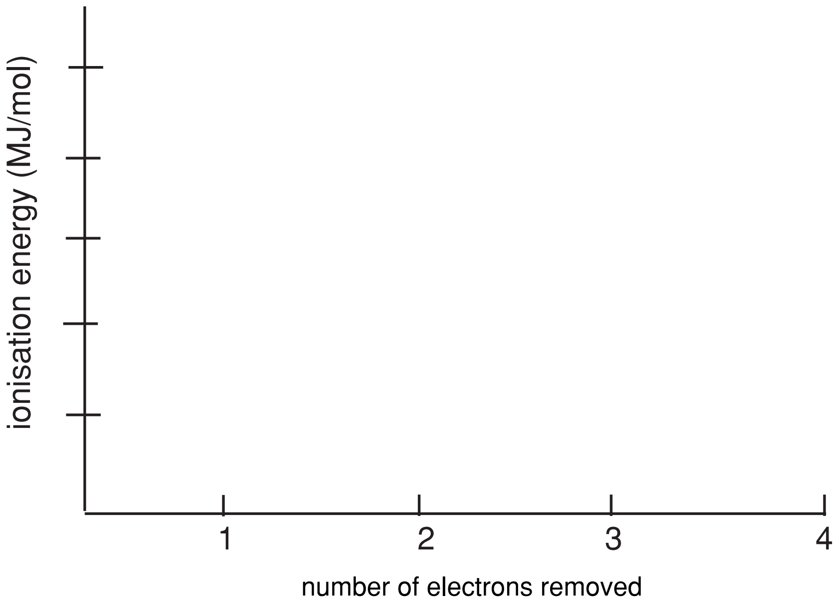
carbon 14 ______

carbon 15 ______

c) Insert drawings or photographs of the models you made of diamond and graphite and a fullerene.

Exercise 2.2: Compounds of carbon

a) i) Graph the successive ionisation energies of carbon.



ii) Explain why the ionisation energy increases with each electron removed.

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____

b) The names for the five structures you made in activity 2 are:

i)___________________________________

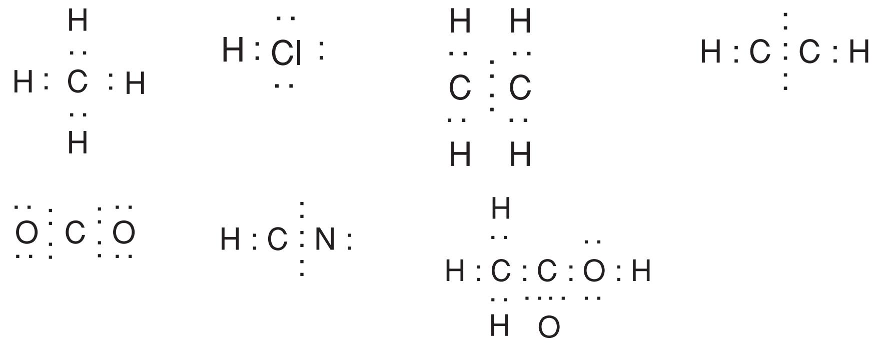
ii)__________________________________

iii)_________________________________

iv)__________________________________

v)___________________________________

c) Mark all the covalent bonds on the molecules in the diagrams as single(s), double(d) or triple(t).



d) Most compounds of the 20 million compounds known to humans are carbon compounds. What is it about the way carbon combines with itself and other elements that leads to such a high number of carbon compounds?

____

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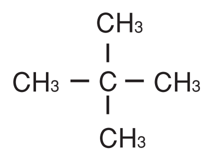
e) Make a model of pentane $CH_3CH_2CH_2CH_2CH_3$ and 2,2–dimethylpropane $CH_3C(CH_3)(CH_3)CH_3$ which can be also drawn as:



Both molecules are non–polar, contain the same number of carbons and hydrogens and have the same molecular mass and number of electrons.

However, pentane has a boiling point of 36^{o}C and 2,2–dimethylpropane a boiling point of only 9^{o}C.

Explain why the dispersion forces are stronger between pentane molecules than between 2,2–dimethylpropane molecules.

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Chemistry

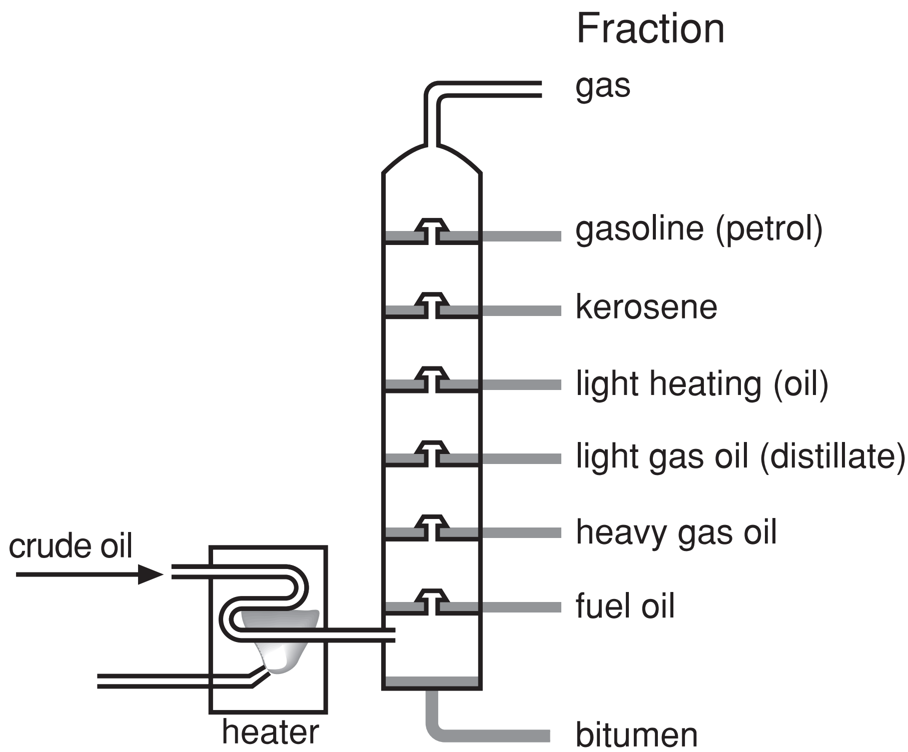
Preliminary Course
Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING
TAFE NSW
OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

Energy

Part 3: Hydrocarbons

Incorporating October 2002
AMENDMENTS


Fraction
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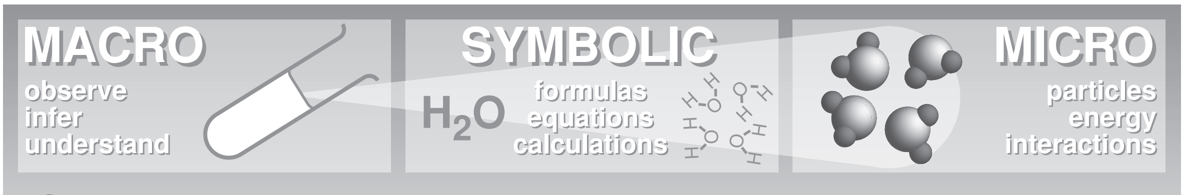
gasoline (petrol)
kerosene
light heating (oil)
light gas oil (distillate)
heavy gas oil
fuel oil
bitumen
crude oil
heater


MACRO
observe
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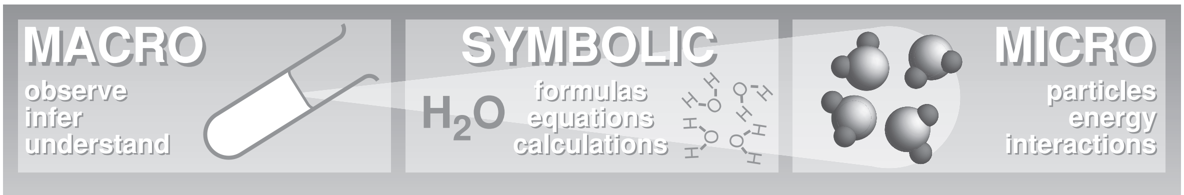
SYMBOLIC
H_2O
formulas
equations
calculations
MICRO
particles
energy
interactions

Contents



Introduction

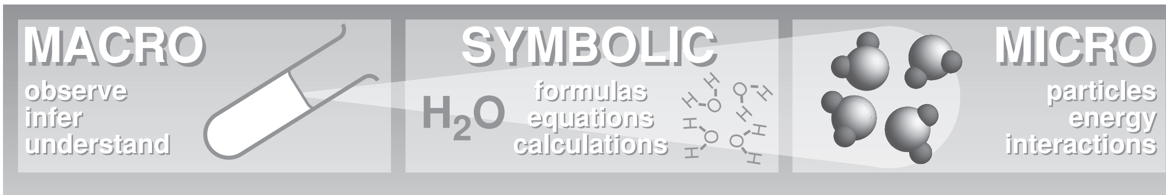
In Part 3, where you investigate the nature, extraction and uses of carbon compounds, you will be given opportunities to:

- describe the use of fractional distillation to separate the components and identify the uses of each fraction obtained
- identify and use the IUPAC nomenclature for describing straight–chained alkanes and alkenes from C1 to C8
- compare and contrast the properties of alkanes and alkenes C1 to C8 and use the term 'homologous series' to describe a series with the same functional group
- explain the relationship between the melting point, boiling point and volatility of the above hydrocarbons, and their non–polar nature and intermolecular forces (dispersion forces)
- assess the safety issues associated with the storage of alkanes C1 to C8 in view of their weak intermolecular forces (dispersion forces).

In Part 3 you will be given opportunities to:

- perform a first–hand investigation and gather first–hand information using the process of fractional distillation to separate the compounds of a mixture such as ethanol and water
- plan, identify and gather data from secondary sources to model the structure of alkanes and alkenes C1 to C8
- process and present information from secondary sources and use available evidence to identify safety issues associated with the storage of alkanes.

Extracts from *Chemistry Stage 6 Syllabus* © Board of Studies NSW, November 2002. The most up–to–date version is to be found at http://www.boardofstudies.nsw.edu.au/syllabus_hsc/index.html



Hydrocarbon nomenclature

Many organic compounds have been known and used for hundreds, if not thousands of years. During that time these compounds have acquired common or semi–scientific names. This did not create much of a problem while the number of compounds remained relatively small. However, as scientific knowledge increased rapidly in the late 1800s and early 1900s it became obvious to scientists around the world that a new organisation and naming system for compounds was needed. Rules for the naming of organic compounds were first established in 1892.

The International Union of Pure and Applied Chemistry (IUPAC) met in 1921 in Geneva, Switzerland and set up a committee to evaluate these rules. This resulted in a uniform system for the naming of organic compounds. This system is now known as the IUPAC system and is the system that we use today. It is constantly evaluated and updated to keep it up to date with the huge number of organic compounds made or discovered each year.

What’s in a name?

Have you ever gone to a fish market? If you have then you may have noticed that a particular fish may have several different common names eg. a fillet of shark is rarely sold as shark but is often called flake and morwong is generally sold as deep sea bream. Flake sounds better than shark and bream are known to be tasty.

This lack of a consistent naming system can often create confusion. Scientists need a system that prevents errors. In the case of fish the system we use is that of Latin names. These are standard around the world so there is no confusion amongst scientists.

Why do scientists need to have a uniform naming system when naming organic compounds?

____

____

Check your answer.

How do we name hydrocarbons?

Hydrocarbons are the simplest organic compounds and contain only the elements hydrogen and carbon. Can you see where the name hydrocarbon originates?

The simplest hydrocarbon would contain only one carbon atom, the next simplest would contain two and so on.

Rule: The only rule so far is that when naming you must only count the carbons that form a continuous chain. Examples follow.

– C –	one carbon atom
– C – C –	two carbon atoms
– C – C – C –	three carbon atoms
– C – C – C – | C	three carbon atoms

You can see that in the fourth example there are in fact four carbon atoms in the molecule but the longest continuous chain has only three. Therefore for naming purposes, this compound is considered to have three carbon atoms. You will learn how to name the side chain containing one carbon later.

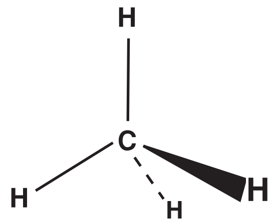
A prefix is used to indicate the number of carbon atoms in a continuous chain. These prefixes are listed below.

meth: one carbon atom	hex: six carbon atoms
eth: two carbon atoms	hept: seven carbon atoms
prop: three carbon atoms	oct: eight carbon atoms
but: four carbon atoms	non: nine carbon atoms
pent: five carbon atoms	dec: ten carbon atoms

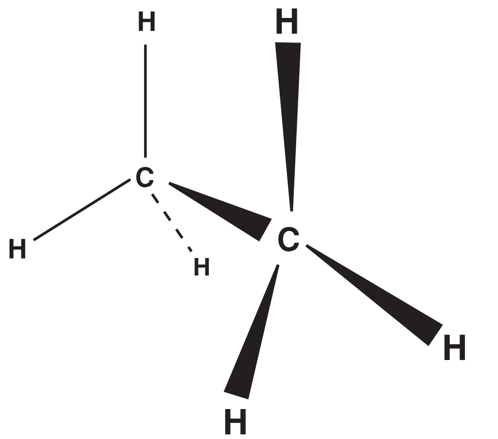
Note: You only need to know the prefixes for compounds with up to eight carbon atoms. The others have been added for interest as you could encounter them. It is very important that you learn the first eight. Carbon chemistry is very difficult if you need to consult your notes every time you need a prefix. Make up a list and pin it to the back of the toilet door or some other place where you will see it every day!

Now you know the prefixes, the next step is to name some compounds. The simplest family of hydrocarbons contains only **single covalent bonds**. They are known as the **alkanes**.

The first member of this alkane family or series has one carbon atom and four hydrogen atoms. It is a gas known as methane. Methane is the main component of natural gas and is sometimes known as 'swamp' or 'marsh' gas as it is often formed by decaying plant material. Methane's molecular formula is CH_4.



The second member of this family has two carbon atoms, joined by a single covalent bond, and six hydrogen atoms.



1 Suggest a IUPAC name for this compound using the list of prefixes that you have learnt.

____

2 What is its molecular formula?

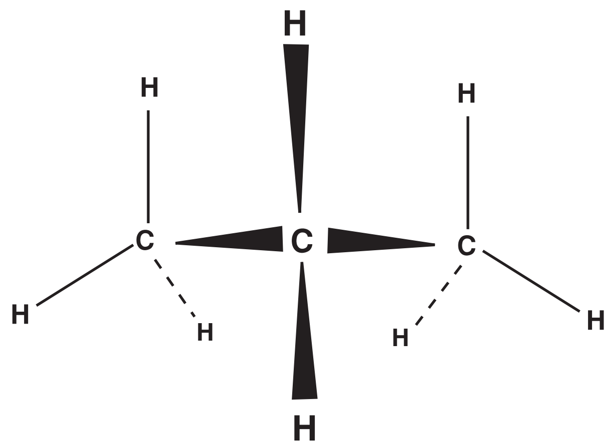
____

Check your answers.

The alkanes are known as an **homologous series**. This means that they form a series of ever longer carbon chains sharing very similar structures. This structure (single carbon–carbon covalent bond) makes the alkanes all behave chemically in a similar fashion and is known as a ‘functional group’.

They all have the same general formula (C_nH_{2n+2}). Here the letter ‘n’ refers to the number of carbon atoms in the molecule. Alkanes are sometimes called saturated hydrocarbons. Their functional feature is that they are saturated with hydrogen – no more hydrogen atoms can be added to a structure containing C to C single bonds only.

The third member of the alkanes is known as propane and its molecular formula is C_3H_8. Its structure is shown below.



Notice that only the end or terminal carbon atoms are attached to three hydrogen atoms. The internal or middle carbon atoms have only two hydrogen atoms.

Why? (Hint: what is the valency of carbon?)

____

____

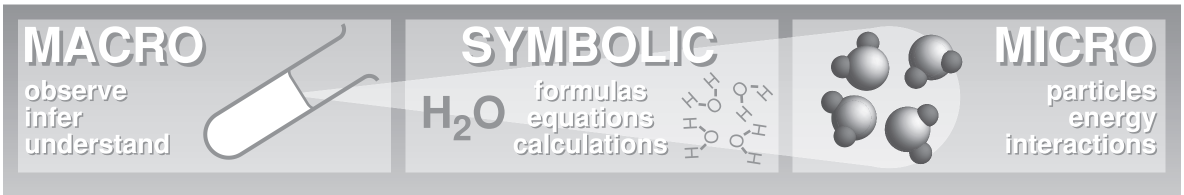
____

____

Check your answer.

On your own paper, give the structural formula, name and molecular formula of the straight chained alkanes from four up to eight carbon atoms.

To find out more information about the naming of organic compounds try: http://www.lmpc.edu.au/science



Properties of hydrocarbons

Alkanes

1 Complete the table below by calculating the molecular mass of each alkane.

Alkane	MP (°C)	BP (°C)	Density (gcm^{-3} at 25°C)	Molecular Mass
methane	–183	–162	N/A	16
ethane	–183	–89	N/A	
propane	–188	–42	N/A	
butane	–138	–1	0.601	
pentane	–130	36	0.621	
hexane	–95		0.655	
heptane	–91	98	0.680	
octane	–57	126	0.698	
nonane	–54	151	0.714	
decane	–30	174	0.726	

(Source: SI Chemical Data)

2 Suggest a reason why a value for the density of methane, ethane and propane is not included in the table.

____

____

3 The molecular masses of consecutive members of the alkane homologous series differ by 14. Can you explain why the difference is 14?

Check your answers.

Alkenes

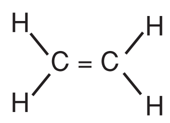
In some hydrocarbons the carbon to carbon bond may be double instead of single. As you have learned earlier a **double bond** is written as = .

Hydrocarbons containing one double bond are known as the **alkenes**. The functional group in the alkenes is in fact the double bond.
The double bond determines the way in which the molecule reacts chemically.

The simplest alkene contains two carbon atoms.

1 Suggest a reason why an alkene cannot have one carbon atom.

Alkenes are named in exactly the same way as alkanes except that their names end in –ene rather than –ane. The simplest alkene is drawn below and has the formula C_2H_4. Its IUPAC name is ethene. However, in industry it is called ethylene.



In going from the alkanes to the alkenes, a single carbon to carbon single bond is lost. A carbon to carbon double bond is gained. In doing so, two hydrogen atoms are also lost. This gives a new general formula.

2 What is the general formula for the alkenes?

3 a) In the margin draw the alkene that has three carbon atoms.

b) What is its name?

Check your answers.

Now that we think we are going great let's complicate matters a little.

Try drawing an alkene that has four carbon atoms in the chain.
Use the margin.

Did you notice that there is more than one possibility? If not then have another look at your drawing.

You should have noticed that the double bond could go between the first and second carbon atoms. It could also go between the second and the third carbon atoms. This creates a problem! There are two compounds with the same molecular formula (C_4H_8). Each of these compounds have different physical and chemical properties.

To avoid confusion a naming system needs to be adopted that takes this problem into account.

Rules for naming alkenes

1 Count the number of carbon atoms in the longest carbon chain.

2 Always count from the end closest to the double bond. It doesn't matter whether you count right to left or left to right.

For example: C–C=C–C–C is the same as C–C–C=C–C

3 Name the compound by indicating which carbon atom is attached to the beginning of the double bond. The number here needs to be kept as small as possible which is why you should always count from the end closest to the double bond.

In the example above the double bond is attached to the second carbon atom. Thus we name this compound, 2–pentene.

The number 2 indicates that the **functional group** is attached to the second carbon atom. The name pentene indicates that there are five carbon atoms in the molecule and the functional group is a double bond (an alkene.)

Alkynes

There is also an homologous series that contains a carbon to carbon **triple bond**. This series is known as the **alkynes**.

The rules for naming the alkynes are exactly the same as those for naming the alkenes, except that their name ends in –yne.

Alkynes have the general formula ______________.

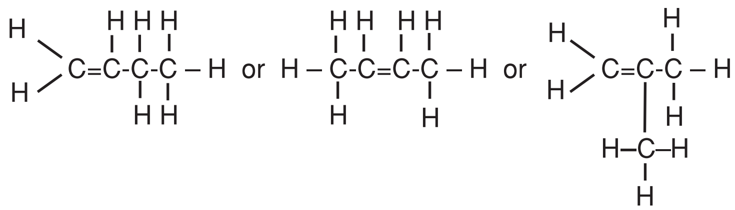
Check your answers.

Isomers

Isomers are compounds that have the same molecular formula but a different structure from each other.

For example: C_4H_8

There are three possible alkenes with this formula.



These three isomers have different physical and chemical properties.
For this reason we need to be able to tell them apart.

We tell them apart by naming the first one 1–butene, the second one 2–butene and the third one is methylpropene. You will learn how to name branched chain hydrocarbons like methylpropene shortly.

We use the numbers 1 and 2 to denote which carbon atom is followed by the functional group (in this case the double bond.)

Because a number of compounds share the same molecular formula the IUPAC name, in some ways, is more important than the formula.

Properties

The alkanes, alkenes and alkynes all show similar trends with regard to their melting point, boiling point and volatility.

Melting point and boiling point increase as the length of the carbon chain increases. However, melting points and boiling points are relatively low due to the fact that the main intermolecular forces are dispersion forces.

You will recall, from an earlier unit, that dispersion forces are due to the fact that the electron clouds in a molecule are constantly moving.
This means that at one instant in time more electrons may be on one side of the molecule than the other. This creates a temporary electrical imbalance making one part of the molecule slightly negative while another part will be slightly positive. This induces or creates temporary dipoles on nearby molecules which helps to hold them together.
The larger the molecule, the larger the dispersion force.

For more information on properties of alkanes try:

http://www.lmpc.edu.au/science

Name the alkanes, in the table *Properties of the alkanes*, that would be liquids at room temperature (normally taken as 25°C).
State each boiling point.

Check your answer.

Substances with weak intermolecular forces, such as alkanes, alkenes and alkynes, have a boiling point close to room temperature. They are known as volatile liquids. (Recall volatility from *The chemical earth.*)

The rate at which a substance evaporates (volatility) increases as the temperature of the liquid approaches the boiling point of that liquid.

For example, pentane (BP 36°C) evaporates faster on a hot day than on a cold day. If the temperature rose to 36°C then pentane would boil.

Safety issues associated with volatility

Many short chained hydrocarbons are used as fuels. Before a fuel can burn, it must first turn into a vapour. Volatile hydrocarbons turn into vapour very easily and so make excellent fuels. This ability to readily vaporise, however, has some disadvantages. When a fuel vaporises into the air it may form a mixture with the air that when ignited, with a spark or flame, burns almost instantly. This mixture is known as an explosive mixture.

The percentage of fuel vapour in the air that forms an explosive mixture varies greatly from one hydrocarbon to another.

For sample chemical safety cards and more information on safety issues try:
http://www.lmpc.edu.au/science

Some examples of explosive mixtures are listed in the table below.

Gas	Molecular mass	Relative vapour density (air = 1)	Lower explosive limit (% vapour by volume)	Upper explosive limit (% vapour by volume)
methane	16	0.6	5	15
ethene	28	0.98	2.7	36
ethyne	26	0.906	2.5	100
propyne	40	1.4	2.4	11.7
1–butene	56	1.9	1.6	10.0
butane	58	2.1	1.8	8.4
methylpropane	58	2.1	1.8	8.5

All the compounds listed are gases at room temperature and so have already vaporised. Many fuels are liquids at room temperature eg. petrol, methanol and ethanol. In many ways these are a greater risk for explosion than the gases. Why?

One of the properties of gases is that they always completely fill their containers. So even when the container is ‘empty’ it will still be filled with the gas at the same pressure as the outside air. This makes it difficult for outside oxygen to enter the container and so an explosive mixture is unlikely to form. However, liquids do not completely fill their containers at all times. This means that as a container of petrol, for example, empties, air can enter to replace the petrol used and some of the petrol left in the container will vaporise. This can often lead to the formation of an explosive mixture which can be ignited with a spark.

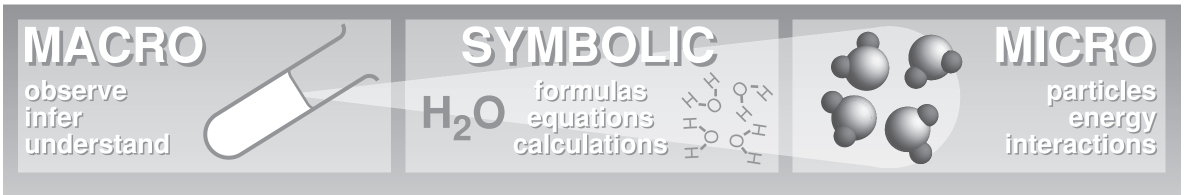
One of the most common accidents that can occur with welding or metal cutting is an explosion of an ‘empty’ fuel drum. Even though a fuel drum may have been ‘empty’ for some time there may have been a few drops in the bottom and this has vaporised and formed an explosive mixture which has been ignited with a spark from a welder or cutter.

Another common accident occurs where fuel leaks into an enclosed or poorly ventilated space eg. inside the engine room of a boat. How often do you see a report, on the nightly news, of a fire or explosion in a boat?

Most boats are equipped with spark arresting devices on the starter motor and alternator in an effort to reduce ignition of explosive mixtures.

Another safety device is the installation of blowers in the engine room. These blow outside air in and flush out any fuel vapour that may have collected rather than draw out the air /fuel mixture already present. They do this because the blowers are electrical and may produce sparks and ignite the mixture flowing through them.

Do Exercise 3.1: *Straight chained hydrocarbons* now.



Fractional distillation

As you learnt, in *The chemical earth* Part 1, distillation is separation of a liquid mixture into its parts by using differences in boiling point.

Fractional distillation is a special kind of distillation that involves the separation of a mixture into fractions that have different BP ranges.

Fractional distillation is used in a number of industries eg. the oil industry, separation of air into its elements, alcohol production and the production of perfumes and cosmetics. You will now consider fractional distillation within the oil industry in detail.

What is crude oil?

Crude oil is a mixture and its composition varies from place to place. In fact, no two oil wells produce exactly the same oil. The oil industry uses terms such as ‘light’, ‘heavy’, ‘sweet’, and ‘sour’.

Light oil contains high concentrations of short chained hydrocarbons such as gas and petrol.

Heavy oil contains high concentrations of long chained hydrocarbons such as lubricating and fuel oil.

Sweet oil contains low concentrations of sulfur compounds which when burnt produces sulfur dioxide an acidic gas.

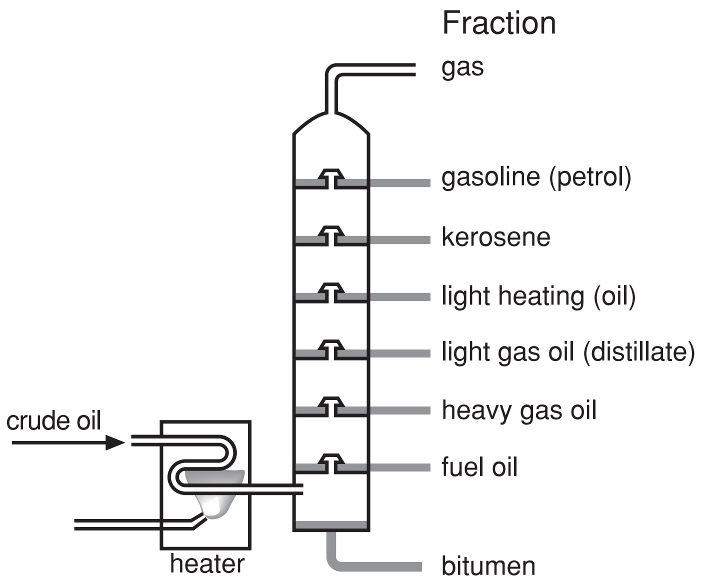
Sour oil contains high concentrations of sulfur compounds.

Because of the varying nature of crude oil, refineries either blend their crude oil or have differently designed fractionating columns for each oil type.

You may have noticed in the newspaper or on television that the price of crude oil is quoted in the finance/business section. It is generally quoted for ‘light sweet Texas crude’. This is the standard upon which other types of crude oil are rated.

Most of the crude oil produced in Australia falls into the light sweet category. This is the most valuable type but has a major drawback. We cannot produce the heavier fractions such as lubricating oil, so Australia has to import some heavier crude oil.

Oil refining



Fractional distillation of crude oil.

Crude oil contains an enormous number of hydrocarbons. Many of these hydrocarbons have similar boiling points but many also have differing boiling points. It is possible, using fractional distillation, to separate these hydrocarbons into groups of compounds with similar boiling points.

Fractional distillation, using a column similar to that above operates at normal atmospheric pressure. The process is known as atmospheric distillation. It produces a range of products. (See the table following.)

Sometimes the residue at the bottom of the fractionating column contains large amounts of heavy distillates. These can be drawn off and piped to another distillation column that operates under a partial vacuum. This is known as vacuum distillation. Operating under a partial vacuum depresses the boiling points of the materials. This allows distillates to be produced at lower temperatures.

The advantage of operating at lower temperatures is that this prevents some of the longer molecules from producing unwanted residues such as coke and gas.

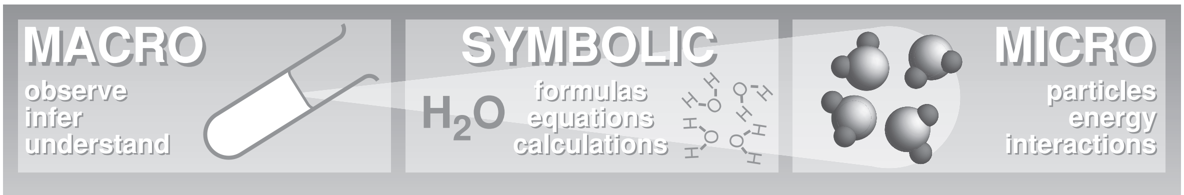
Product	**Approximate number of carbon atoms**	**Approximate boiling point range (°C)**	**Main end products or uses**
gas	C_1–C_4	–164 to +10	fuel, LPG
light petroleum	C_5–C_7	20–200	solvent, dry cleaning, refrigerant
petrol	C_5–C_{12}	40–205	motor fuel, aviation fuel
kerosene	C_{12}–C_{16}	150–300	jet fuels
diesel oil	C_{15}–C_{18}	190–370	diesel engines
lubricating oil	C_{16}–C_{40}	360–500	lubrication
heavy fuel oil	C_{20} up	210 up	furnace oil, ships' boilers
paraffin wax	C_{20} up	melts 51–55	candles, waterproofing fabrics
bitumen	——	residue	road making
petroleum coke	——	residue	carbon electrodes

Products of fractional distillation of crude oil. (from 'Science for High School Students' Table 48.1).

For more information on the refining of crude oil try:

http://www.lmpc.edu.au/science

Now do Exercise 3.2: *Fractional distillation of glycerol*.



Branched chain hydrocarbons

So far you have only dealt with straight chained hydrocarbons.
The majority of hydrocarbons found in crude oil are what are termed 'branched chain hydrocarbons'.

Consider a hydrocarbon with the formula C_6H_{14}. This formula can describe a number of compounds.

```
                         C-C-C-C-C
                           I
C–C–C–C–C–C  hexane        C          2–methylpentane
```

```
                             C-C-C-C-C
                             I
Note: hexane can be drawn this way C        but it is still hexane, not
methylpentane.
```

You will recall from earlier that compounds with the same molecular formula but different structures are called isomers.

Naming

The group CH_3 that was placed in the middle of the chain is called a methyl group. It is in effect methane that is minus a hydrogen atom.
It can be placed anywhere in the carbon chain, except at the end.

Alkanes that are minus a hydrogen atom can be placed in many carbon chains and are known as **alkyl** groups. Thus, ethane minus a hydrogen is known as ethyl and so on.

Name the other alkyl groups (with up to 8 carbon atoms).

____

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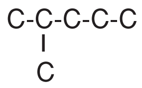
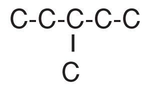
Check your answers.

Position, position, position

When attaching an alkyl group to a carbon chain it is important to accurately describe its position. For example, when attaching a methyl group to pentane there are a number of places it could fit.

a)  or b) 

Both of these compounds could be named as a methylpentane. As they both have different properties and potential uses, industrially, we need to be able to differentiate between them.

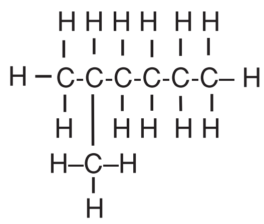
In the example, (a) becomes 2–methylpentane and (b) becomes 3–methylpentane.

The main rule here is: always count from the end that will give you the smallest number.

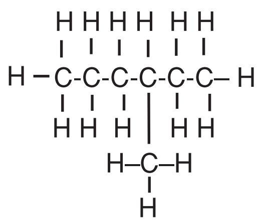
In example (a) the carbon atoms were counted from the left but they could also be counted from the right. However, if counted from the right, the name would have been 4–methypentane. Obviously 4 is a larger number than 2 so using the main rule the compound is named as 2–methylpentane, not 4–methylpentane.

In the example, (b) is 3–methylpentane. It would make no difference which end the carbons were counted from!

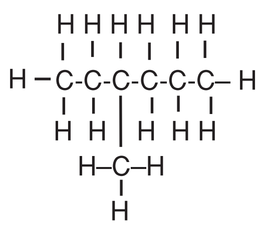
1 Name the following branched chain hydrocarbons.



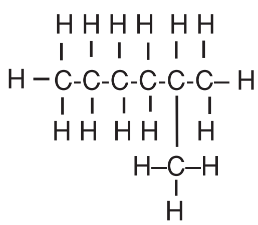
Name: ______________________



Name: ______________________



Name: ______________________



Name: ______________________

2 Has the same name appeared more than once? (If so what does this tell you?)

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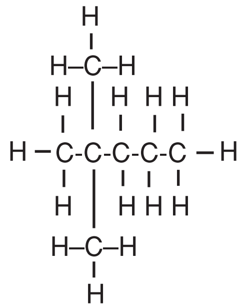
Often a hydrocarbon will have more than one alkyl group attached.

For example, an isomer of C_7H_{16}, (shown below) has the name 2,2–dimethylpentane.

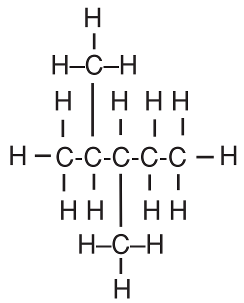


Notice here that where there are a number of alkyl groups, a prefix is used to indicate the number of identical alkyl groups.

The prefixes used are:

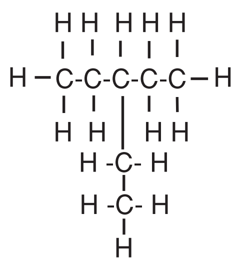
- di – 2 groups
- tri – 3 groups
- tetra – 4 groups
- penta – 5 groups.

Another isomer of C_7H_{16} two methyl groups is 2,3–dimethylpentane. This is shown below.



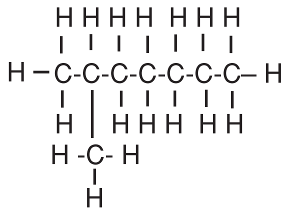
Draw and name two more isomers of C_7H_{16} with two methyl groups on your own paper.

Instead of methyl groups it is possible to have ethyl groups. For example, the compound shown below is 3–ethylpentane.



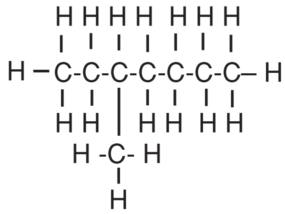
3 Name the following compounds.

i)



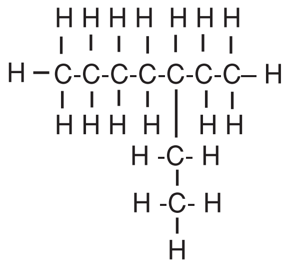
Name: ____________________

ii)



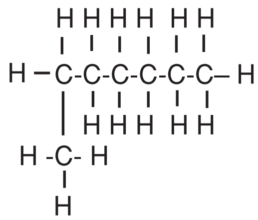
Name: ____________________

iii)



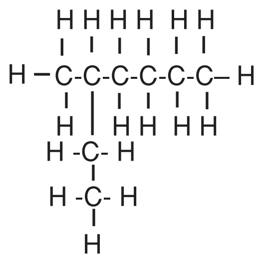
Name: ____________________

iv)



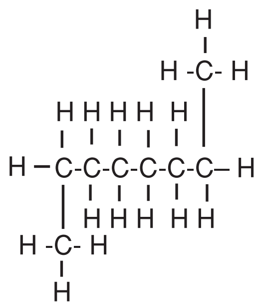
Name: ____________________

v)



Name: ____________________

vi)

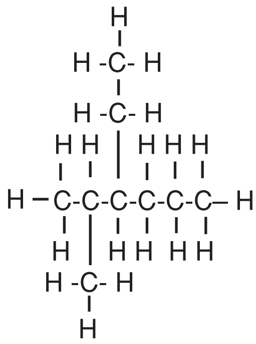


Name: ____________________

Check your answers.

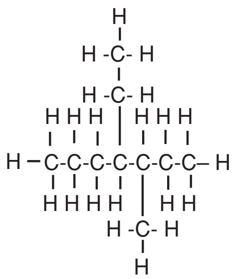
Compounds with different alkyl groups

Often a compound will have two different alkyl groups attached.
The correct name of this compound is 3–ethyl–2–methylhexane.
Note: the alkyl groups are arranged alphabetically.



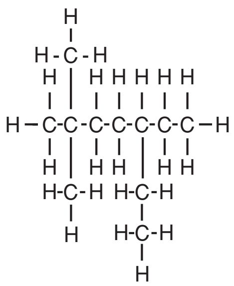
Name the following compounds.

i)



Name: ______________________

ii)



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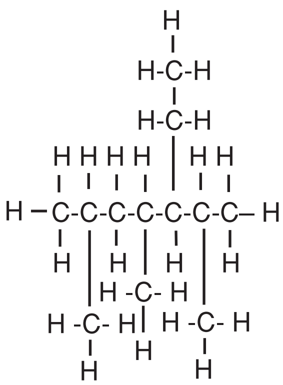
iii)



Name: ______________________

Check your answers.

Now do Exercise 3.3: *Models*.

Branched chains and octane rating

In a straight–out distillation of crude oil, only about 20% of the crude oil appears in the petrol fraction (depending on the type of crude). To meet the requirements of the world's automobiles and planes without producing excess quantities of other petroleum products, a much higher yield is necessary. Moreover, the products of such a distillation cause knocking in engines.

The compression ratio of an internal combustion engine is the ratio of the volume of the cylinder with the piston at the end of the outstroke, to the volume of the cylinder with the piston at the end of the instroke.
For most efficient operation this should be as high as possible.
If increased beyond a certain limit, however, the heat of compression is sufficient to explode the fuel unevenly and produce a violent jarring against the cylinder wall and the piston, causing loss of efficiency and possible damage to these parts. The engine is then said to be **knocking**.

The composition of fuel is of great importance in the prevention of knocking. Hydrocarbons which have their carbon atoms arranged in a straight chain cause more knocking than those whose chains are branched. One **isomer** of octane (iso–octane) has excellent anti–knock properties and is given an **octane number** of 100. Straight chain heptane causes bad knocking and is given an octane number of 0. The octane number of any petrol is equal to the percentage of iso–octane in a mixture of iso–octane and heptane which would produce, under standard conditions, the same amount of knocking as the petrol being tested.

Branched chain hydrocarbons can be made from hydrocarbons with larger molecules by a process known as catalytic 'cracking' or 'cat cracking'. The process takes place at temperatures from 400°C to 510°C and a pressure of from between one and two atmospheres. The chemical reaction which occur during cracking are complex but the branched chain products formed give higher octane ratings to the fuel.

Uses of oil, natural gas and coal

In the space below compile a list of the main uses of crude oil. (Use the information contained in the preceding pages as your reference.)

Natural gas commonly consists of the gases methane, ethane, propane and butane. These gases have the following uses.

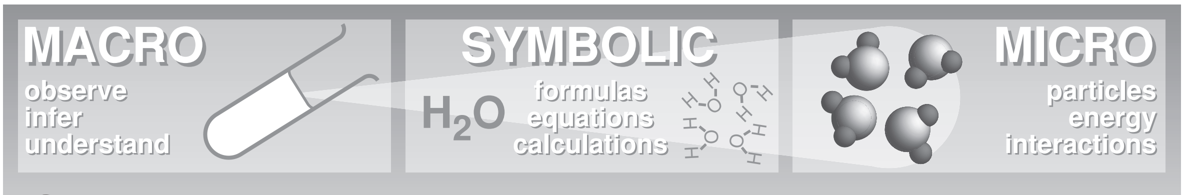
- Methane – fuel gas.
- Ethane – feed stock for the chemical industry. Ethane is used for making chemicals for plastics.
- Propane/butane – marketed as LPG (liquid petroleum gas) to be burnt as a fuel.

For more information on the products obtained from natural gas try:

http://www.lmpc.edu.au/science

Most coal is used as a fuel for power generation and the production of steam for use in industry. Some coal is heated out of contact with air to produce 'coke' for use in the metal extraction industry.

A number of by–products result from the distillation of coal. They are: methane, hydrogen, carbon monoxide, all of which can be burnt as a fuel; ammonia; hydrogen sulfide, which can be oxidised to produce sulfur or sulfuric acid; benzene, toluene, and xylene which are important solvents and chemical feed stocks; and tars. The tars produced are further refined to produce a large array of dyes and pharmaceuticals.



Suggested answers

What's in a name?

As there are a great many very similar organic compounds a uniform naming system would avoid confusion.

How do we name hydrocarbons?

1 ethane

2 The molecular formula is C_2H_6

3 Carbon has a valency of four which means it can form four single covalent bonds. A carbon atom that is attached to two other carbon atoms has already used up two of its bonds. It only has two spaces for hydrogen atoms left.

Properties of the alkanes

Alkane	MP	BP(°C)	Density (gcm^{-3} at 25°C)	Molecular Mass
methane	–183	–162	N/A	16
ethane	–183	–89	N/A	30
propane	–188	–42	N/A	44
butane	–138	–1	0.601	58
pentane	–130	36	0.621	72
hexane	–95		0.655	86
heptane	–91	98	0.680	100
octane	–57	126	0.698	114
nonane	–54	151	0.714	128
decane	–30	174	0.726	142

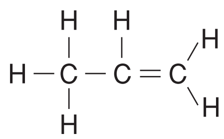
2 Alkanes are gases at room temperature and their densities would be much less than the other alkanes which are liquids. It would not be meaningful to include them.

3 Consecutive members of the series differ by CH_2 which was a mass of 14.

Alkenes

1 All alkenes have a double carbon to carbon covalent bond. This requires at least two carbon atoms.

2 The general formula for the alkenes is C_nH_{2n}

3 a) 

b) propene

Alkynes

Alkynes have the general formula: C_nH_{2n-2}

Properties

1

pentane	36
hexane	
heptane	98
octane	126
nonane	151
decane	174

Naming

Other alkyl groups include propyl, butyl, pentyl, hexyl, heptyl and octyl.

Position, position, position

1 i) Name: 2–methylhexane

ii) Name: 3–methylhexane

iii) Name: 3–methylhexane

iv) Name: 2–methylhexane

2 Yes. It means that different looking diagrams can represent the same molecules. When different looking diagrams are named systematically and give the same name they represent the same substance.

3 i) Name: 2–methylheptane

ii) Name: 3–methylheptane

iii) Name: 3–ethylheptane

iv) Name: heptane

v) Name: 3–methylheptane

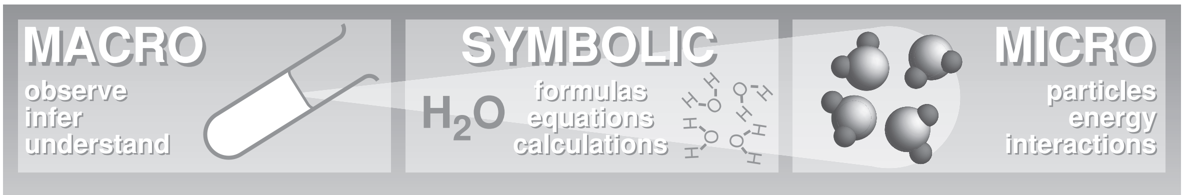
vi) Name: octane

Compounds with different alkyl groups

i) Name: 4–ethyl–3–methylheptane

ii) Name: 5–ethyl–2,2–dimethylheptane

iii) Name: 3–ethyl–2,4,6–trimethylheptane



Exercises – Part 3

Exercises 3.1 to 3.3 Name: ________________________________

Exercise 3.1: Straight chained hydrocarbons

a) i) Using the graph paper in the *Appendix*, graph the boiling point and density of the alkanes (methane to decane) vs molecular mass. (Draw two separate graphs.)

Attach your graphs to this page.

ii) From one of the graphs you have drawn predict the boiling point of hexane.

____

b) In the space provided draw and name all the possible straight chained alkenes having eight carbon atoms.

c) i) Ethyne is commonly called acetylene which is used for thermal cutting and welding and is a very dangerous gas. It is so dangerous that it is dissolved in acetone (a liquid) rather than a gas in cylinders. After looking at the table on explosive mixtures suggest one reason why ethyne is so dangerous.

____

____

ii) Use the information contained in the table of explosive mixtures to identify the most dangerous gas (from an explosive mixture perspective).

____

iii) Methane (natural gas) and butane (LPG) are two of the most commonly used fuels in a domestic setting.

What are the explosive mixture ranges for :

methane ___________________

butane_____________________

iv) There is a greater risk of explosion when using butane, even though methane has a larger explosive mixture range. Using the information contained in column three of the table to suggest a reason.

____

____

v) Samples of air were obtained from a coal mine over a seven day period. Upon analysis the following results were measured for methane content.

methane/air percentage

Day 1	2.35
Day 2	4.76
Day 3	6.87
Day 4	18.9
Day 5	12.57
Day 6	1.35
Day 7	9.54

On what day(s) was there a danger of an explosion in the mine?

____

Exercise 3.2: Fractional distillation of glycerol

Before attempting this activity you will need to obtain some glycerol. Glycerol is a high boiling point alcohol commonly called glycerine. It is non–toxic with a sweet taste. It is often used as an additive to foods and is formed as a by–product in the manufacture of soap. Glycerol may be purchased from a supermarket or chemist. You will only need a small amount (about 100 mL) for this activity.

The objective of this activity is to investigate the process of fractional distillation. Fractional distillation is a technique that is used to:

____

____

Here our aim is to remove water from a mixture of glycerol and water.

Method:

1 Place about 200 mL of water with 100 mL of glycerol in a saucepan or other heat resistant container.

2 Taste a small amount of the mixture.

3 Heat the mixture on a stove or other heat source until gentle boiling commences.

4 Place a cool metal lid or heat resistant plate over the container *for a few seconds.*

5 Remove the lid or plate and see if any vapour has condensed on its undersurface. If so then taste the condensate.

Results:

1 Describe the appearance of the undersurface of the lid or plate.

____

____

2 How did the taste of the condensate compare to the taste of the original mixture?

____

____

____

Exercise 3.3: Models

Using the molecular model kit provided or plasticine and toothpicks construct eight molecular models of hydrocarbons you have so far encountered.

Use IUPAC nomenclature to name each model. Photograph your models and attach to the send–in pages. If you do not have access to a camera you may draw the models.

If you have internet access you may use a site linked to: http://www.lmpc.edu.au/science to model some molecules.

Appendix

Chemistry
Preliminary Course
Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING
TAFE NSW
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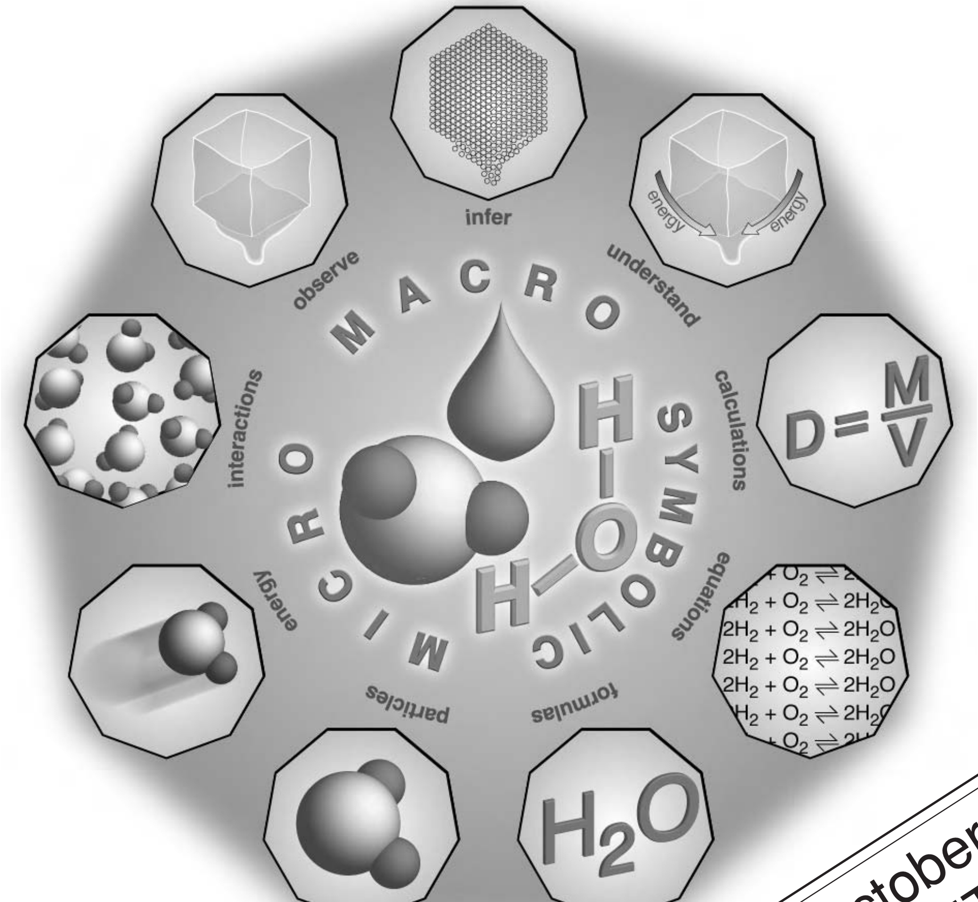
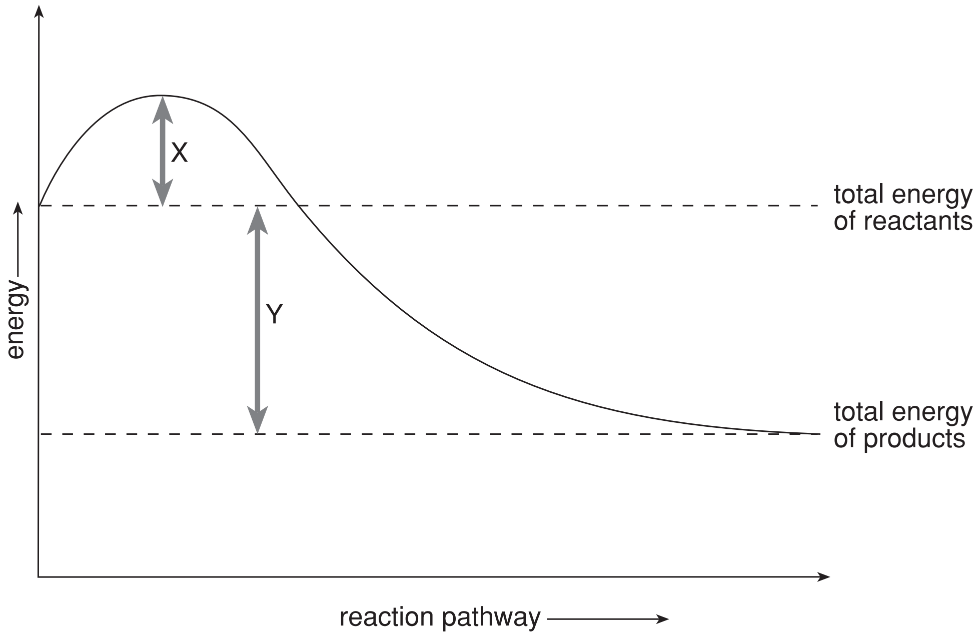
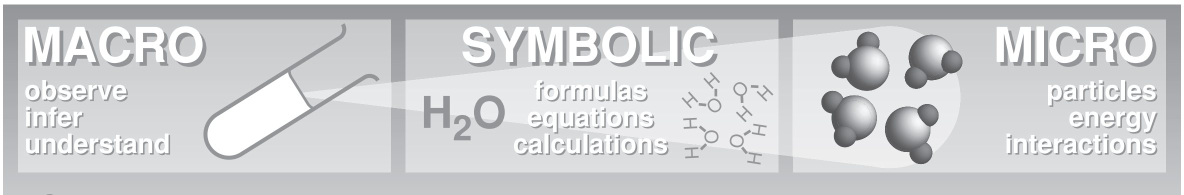
Energy

Part 4: Chemical reactions – combustion



Incorporating October 2002 AMENDMENTS


X
Y
total energy
of reactants
total energy
of products
energy
reaction pathway


MACRO
observe
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H2O
formulas
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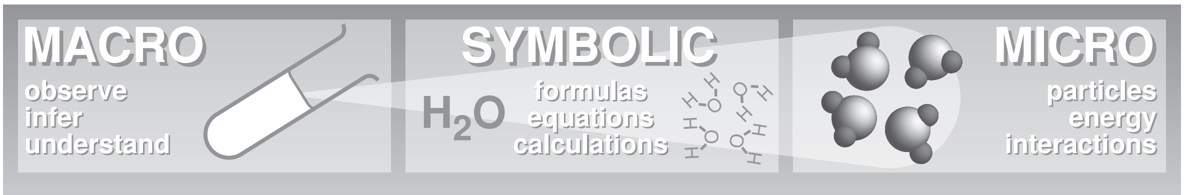
MICRO
particles
energy
interactions

Contents



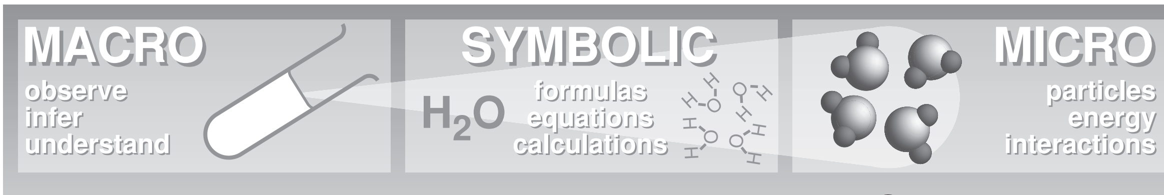
Introduction

In Part 4, where you investigate chemical reactions, in particular combustion, you will be given opportunities to:

- describe the indicators of chemical reactions
- identify combustion as an exothermic chemical reaction
- outline the changes in molecules during chemical reactions in terms of bond breaking and bond making
- explain that energy is required to break bonds and energy is released when bonds are formed
- describe the energy needed to begin a chemical reaction as activation energy
- describe the energy profile diagram for both endothermic and exothermic reactions
- explain the relationship between ignition temperature and activation energy
- identify the sources of pollution which accompany the combustion of organic compounds and explain how these can be avoided
- describe chemical reactions by using full balanced equations to summarise examples of complete and incomplete combustion.

In Part 4 you will be given opportunities to:

- solve problems and perform a first–hand investigation to measure the change in mass when a mixture such as wood is burnt in an open container
- identify the changes of state involved in combustion of a burning candle
- perform first–hand investigations to observe, and describe examples of endothermic and exothermic chemical reactions.



What is a chemical reaction?

At the micro level a chemical reaction is the rearrangement of atoms or ions so that new substances are formed.

For example: $AB + CD \rightarrow AC + BD$

Here substance AB has combined with substance CD to produce two new substances AC and BD.

It is obvious that the particles (atoms or ions) A, B, C, and D have rearranged themselves. It is not possible to see the particles rearranging themselves as they are too small to be seen by the naked eye or even with most microscopes.

Has a chemical reaction occurred?

While it is not possible to see the individual particles rearranging themselves, there are a number of indications that a chemical reaction is occurring. Indicators include:

- difficult to reverse change in colour
- change in temperature
- production of a gas
- production of a precipitate
- emission of light.

Change in colour

A change in colour is a common and easily recognisable indicator of a chemical reaction.

For example, a piece of meat cooking on a barbeque undergoes changes. The meat gradually changes colour from pink or white to brown and eventually to black. The changes in colour indicate a chemical reaction.

Activity 1

1 Take a small piece of steel wool.

2 Describe its colour ______________________________

3 Wet the steel wool with water leave it outside overnight describe its colour the next day ______________________________

4 Has a chemical reaction occurred? ____________________

5 Explain ______________________________

____

Check your answers.

Change in temperature

Many chemical reactions are accompanied by a change in temperature. In fact the temperature change may be the reason for using the reaction.

For example, burning gas in a Bunsen burner produces a rise in temperature that is used for experiments.

Some reactions result in a drop in temperature. You will learn about these later in this module.

Production of a gas

Many reactions produce a gas as one of the products. One such reaction is photosynthesis, which you learnt about in Part 1.

1 What gas was produced in photosynthesis?

____

____

2 Describe another chemical reaction that produces a gas

____

____

Check your answers.

Production of a precipitate

Sometimes when two solutions are mixed the result is a precipitate. For example, when silver nitrate solution is mixed with sodium chloride solution the result is a precipitate of silver chloride.

Emission of light

Some reactions produce energy in the form of visible light. For example, a burning match or candle both produce light.

Light emitting reactions sometimes also produce ultra–violet radiation. For example, burning magnesium.

It is important to note that more than one indicator of a chemical reaction may occur together.

Give an example of a chemical reaction that produces:

1 light and change in temperature

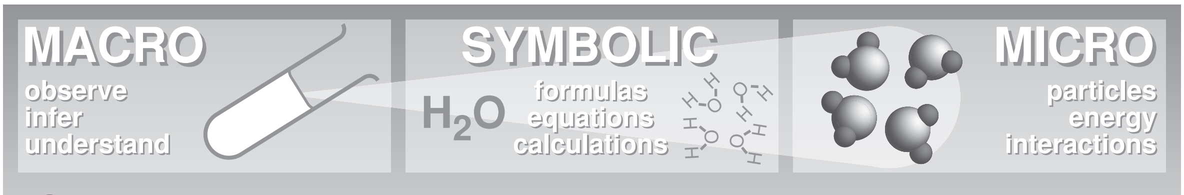
____

2 a change in colour as well as produces a gas

____

Check your answers.

Do Exercise 4.1: *Chemical reactions*.



Combustion

Combustion is the name given to the rapid reaction between oxygen and another element, compound or a mixture. Combustion always produces heat and may also produce light and a flame. It is commonly called burning.

Not all substances are capable of reacting with oxygen eg. gold, salt (NaCl).

The products of combustion are a group of compounds called oxides.

Examples of combustion include burning:

- wood
- sulfur
- propane
- ethanol
- gunpowder
- sodium
- petrol
- kerosene
- methane
- magnesium.

Classify each of the above examples of combustion as involving, elements, compounds or mixtures.

Elements	**Compounds**	**Mixtures**

Check your answers.

Combustion at the macro level

Have you ever noticed that some substances burn very easily while others are much more difficult?

1 Rank the following substances on the basis of how easy you think they are to ignite (start burning) with a lighted match. You must not attempt to burn any of these substances. This is a 'thought experiment'.

wood, wax candle, natural gas, oil, petrol, methylated spirits, coal, iron nail, LP gas

easy to ignite	difficult to ignite

2 What do the substances, that you think are easy to ignite, have in common?

____

____

Check your answers.

Before a substance can burn, some of its particles need to be heated enough for them to vaporise (turn into a gas). It is only when they have vaporised that they have enough energy to combine chemically with oxygen and undergo combustion. The temperature at which this will occur is known as the **ignition temperature.** The amount of energy required by the reactants for ignition is known as the **activation energy**. Measurements of ignition temperature are made on a mixture of fuel and air. The larger the activation energy required for fuel and air to react, the higher the ignition temperature.

Substances that are already gases are easily ignited, substances that are solids are much more difficult to ignite. Ease of ignition is directly related to volatility.

A way of igniting a substance with low volatility is to only vaporise small amounts of the substance. When this small amount starts burning the heat released vaporises more of the substance and the combustion continues. The most easily seen example of this is with a candle.

As you have seen in *The chemical earth*, Part 4; page 6 a candle is composed of wax which could have an average chemical composition of $C_{40}H_{82}$. This wax is a solid at room temperature and so has a low volatility.

Activity 2

Take a candle and scrape some of the solid wax into a metal lid from a jar. Try igniting the wax with a match.

What did you notice?

Cut a piece of the wick out of the candle and stand it in the wax. Now try igniting the wax by igniting the wick.

Describe what happened.

Using the diagram on page 6, Part 4: *The chemical earth* as a guide, and evidence from the above activity, explain the significance of a wick in igniting low volatility substances.

Instead of candle wax repeat the above experiment using cooking oil.

Describe your results.

When substances containing mostly carbon and hydrogen are burnt in oxygen, the most common products are gases such as carbon dioxide and steam (water). When combustion occurs in an open container these gases escape to the surrounding atmosphere. This will result in a change in mass.

Activity 3

In this activity you will investigate the change in mass that occurs when wood is burnt in an open container.

There are a number of ways that this activity can be performed.

Method A:

If you have access to a science laboratory with an electronic balance simply take one or two clean dry popsticks.

1 Weigh them and record the mass.

2 Ignite them over a Bunsen burner.

Collect the ash when combustion ceases and then weigh the ash.

Results:

1 Mass of sticks ____

2 Mass of ash ____

3 Calculate the loss in mass

____

____

4 What percentage of the mass of the wood was lost?

____

____

Method B:

If you do not have access to an electronic balance then the amount of wood needed will be much greater, as a kitchen balance is not as sensitive as an electronic balance.

1 Take a large empty steel can (a dog food can is ideal). With a large nail and hammer, make a series of holes in the sides of the can towards the bottom. About ten or twelve should be enough.

2 Measure and record the mass of the can with kitchen scales.

3 Collect some hardwood sticks. (Enough to fill the can). Take care not to use painted or treated wood as burning these may cause poisonous gases to be produced. Dry eucalyptus sticks are best and can easily be collected from beneath most gum trees.

4 Weigh the sticks. Record the mass.

5 Place the can on a solid surface, such as a brick, outside away from any flammable substances. Place a solid firestarter in the can and ignite it with a match. Put the sticks in the can and wait until all combustion has ceased and the can has cooled.

6 Weigh the can and ash.

Results:

1 Mass of can = ____

2 Mass of sticks = ____

3 Mass of can and ash = ______________________________________

4 Calculate the mass of ash.

____

____

5 Calculate the loss in mass.

____

____

6 What percentage of the mass of the wood was lost?

____

____

Complete Exercise 4.3: *Combustion of wood.*

Combustion at the atomic level

You will recall that a chemical reaction involves the rearrangement of atoms or ions. To achieve this rearrangement is necessary to break the chemical bonds that hold atoms together and ions together. As new substances form new chemical bonds are formed. This breaking and forming of chemical bonds involves energy.

Whenever chemical bonds are broken energy is required.
Whenever chemical bonds are formed energy is released. The amount of energy involved is the same whether a bond is broken or formed.

For example, the energy in a carbon – carbon (C–C) single bond is 346 kJ/mole of bonds. This means that 346 kJ is needed to break one mole of carbon – carbon single bonds and conversely 346 kJ is released when one mole of carbon–carbon single bonds are produced.

Some examples of bond energies are listed in the table below.

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

Bond energy can be used to calculate the amount of energy that is produced when substances are burnt.

For example, methane burns in oxygen.

$$CH_{4(g)} \;+\; 2O_{2(g)} \;\rightarrow\; CO_{2(g)} \;+\; 2H_2O_{(g)} \;+\; \text{energy}$$

The bonds present are:

```
      H
      |
H —  C  — H      + O=O + O=O  →  O=C=O  +  H–O–H  +  H–O–H
      |
      H
```

Bonds broken	**Bonds formed**
4 x C–H	2 x C=O
2 x O=O	4 x H–O

Energy in	Energy out
(4 x 414) + (2 x 498) = 2652	(2 x 804) + (4 x 463) = 3460

Clearly ‘energy out’ is greater than ‘energy in’, the difference being 808 kJ. This means that when one mole of methane is burnt it releases 808 kJ of energy.

1 Using the same format as the above example, calculate the energy produced when one mole of each of the following gaseous substances are burnt to produce carbon dioxide and water.

a) ethane

b) propane

c) butane

d) ethene

e) ethyne

Note: It is important to realise that the above calculations will give an answer that is expressed per mole. Many questions require the answer to be expressed per gram.

2 Calculate the amount of energy released in the above examples per gram.

a) ______________________________

b) ______________________________

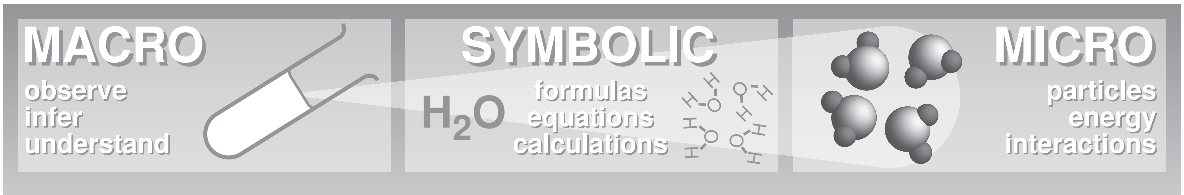
c) ______________________________

d) ______________________________

e) ______________________________

Check your answers.

Complete Exercise 4.4: *Bond energies*.



Energy profiles

While it is not easy to measure the amount of energy in substances (see enthalpy in the *Glossary*), it is possible to investigate the changes in this energy that occur when substances react.

The diagram below shows energy and energy changes in a chemical reaction.

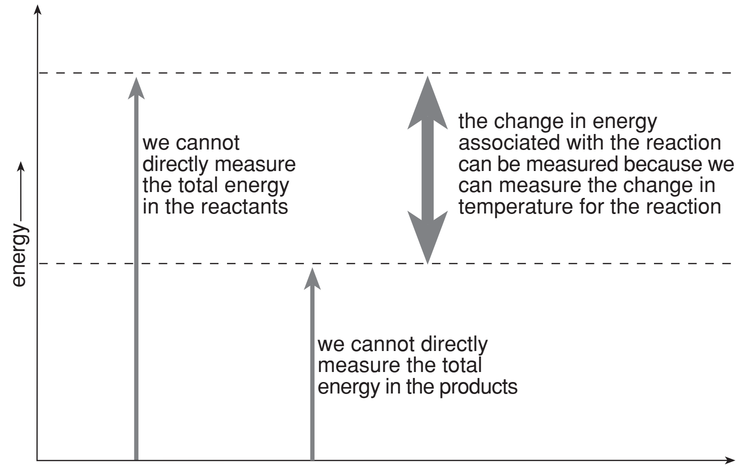


Figure A

1 In the above diagram do the products have more or less energy than the reactants?

____

2 What has happened to this energy?

____

____

____

3 Is the reaction exothermic or endothermic?

____

Check your answers.

Energy profiles and activation energy

All chemical reactions need some energy to start them off.
Every chemical reaction will require a different amount of energy.
This energy is called the activation energy. In the case of combustion, the energy can be provided by a spark, a burning match or even by compression of gases such as in a diesel engine.

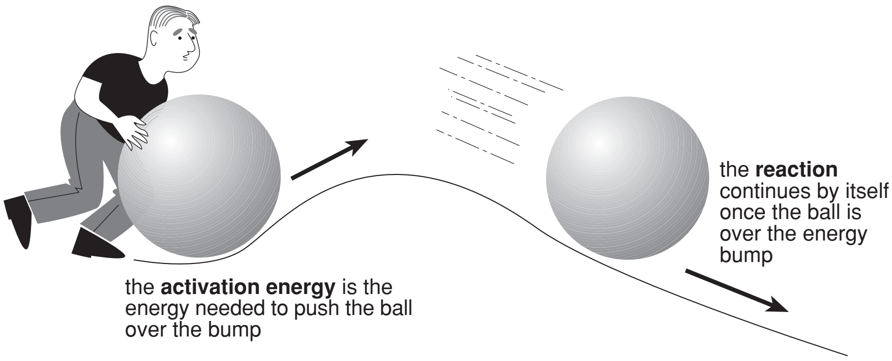


Figure B

Figure A and Figure B can be combined to form an energy profile diagram. A typical example is shown in Figure C.

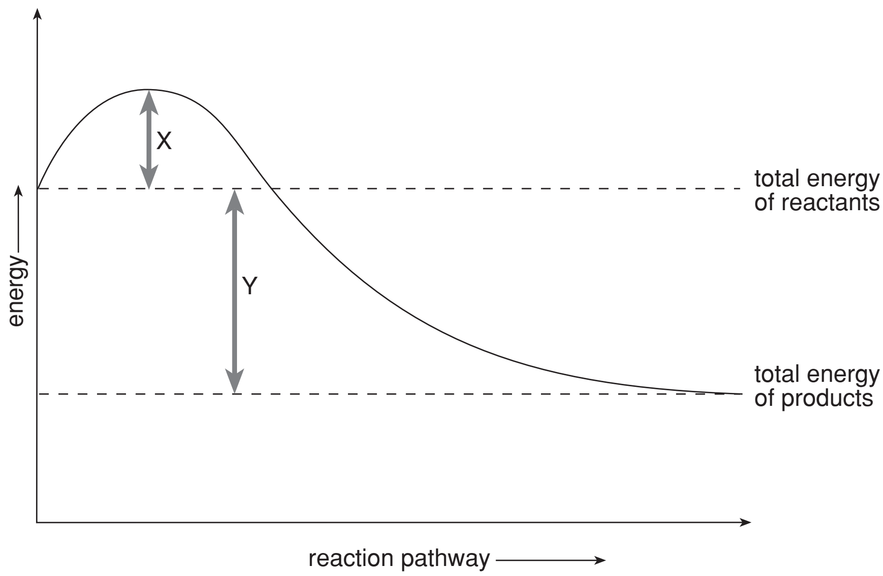


Figure C

1 The hump on the energy profile graph is marked X. What does X represent?

___

___

___

2 In this graph which is greater: energy of reactants or energy of products?

___

3 Does the graph represent an exothermic reaction or an endothermic reaction? Explain

___

___

___

4

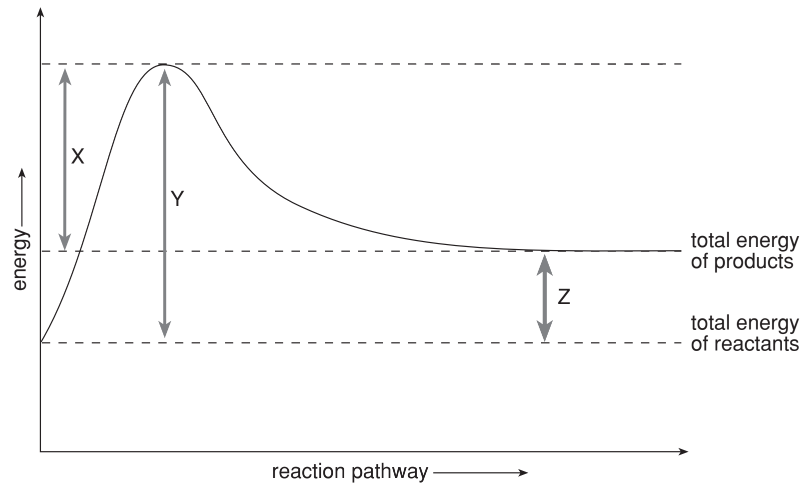


Figure D

Is this reaction exothermic or endothermic? How did you decide?

___

___

___

5 Which letter: X, Y, or Z represents the activation energy?

___

Check your answers.

The higher the activation energy for a reaction the higher the ignition temperature. As temperature is increased more energy is provided to the reactants. At a certain temperature (the ignition temperature) the reactants will have sufficient energy (the activation energy) to begin chemical reaction.

Complete Exercise 4.5: *Energy profiles*.

Combustion and pollution

Complete combustion

When organic compounds are burnt in a plentiful supply of oxygen the most common substances produced are: carbon dioxide and water. These two substances are not generally considered as forms of pollution. Carbon dioxide emissions are causing concern, worldwide, as a major contributor to the enhanced greenhouse effect (many scientists think that this is changing the world's climate). However, at the local level, carbon dioxide is not normally considered a pollutant.

As well as carbon dioxide and water, other substances may be produced when organic substances are completely burnt in air. These substances may be formed from additives or impurities in the fuel or gas naturally present in the air such as nitrogen. Some of these are listed below.

Pollutant	Source	Problem	Solution
sulfur	contaminant in coal and oil	burns to produce sulfur dioxide which dissolves in water to produce an acid	use of low sulfur fuel, use scrubbers in power stations to remove sulfur dioxide from the exhaust
tetraethyl lead	additive to petrol to raise the octane rating	burns to produce lead which is an environmental poison	use of other substances to improve octane rating
nitrogen	component of air	burnt at high temperature and pressure to produce oxides (N_2O, NO, NO_2, N_2O_4); these damage living tissue as well as contribute to the formation of smog	lower the compression ratio in engines

Incomplete combustion

When organic compounds are burnt with insufficient oxygen for complete combustion to occur the main products are carbon dioxide and unburnt hydrocarbons.

Carbon monoxide (CO) is a poisonous gas. It is colourless and odourless and prevents oxygen from being absorbed by the blood. High levels of carbon monoxide can be prevented by increasing the amount of oxygen in the fuel/air mixture and also limiting the amount of time an engine is left to idle.

Unburnt hydrocarbons are often present in vehicle exhausts and contribute to photochemical smog. They can be reduced by having properly adjusted engines and by the fitting of catalytic convertors.

Combustion reactions

1 When a substance such as octane(C_8H_{18}) is completely burnt in air the only products are carbon dioxide and water.

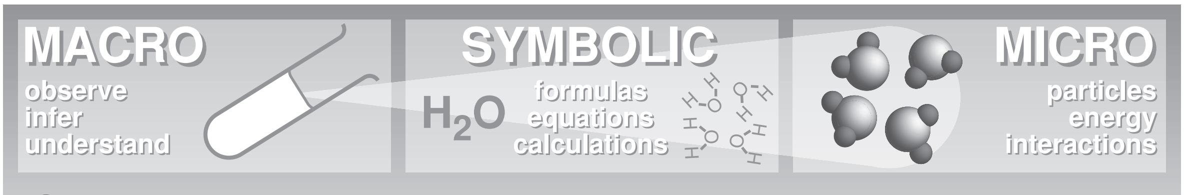
Write a balanced chemical reaction for the complete combustion of octane.

2 When octane is incompletely burnt in air the main products are water and carbon monoxide. Notice that water is always produced.

Write a balanced equation for the incomplete combustion of octane.

Check your answers.

Complete Exercise 4.6: *Pollution*.



Suggested answers

Change in colour

1 Its colour is grey.

2 The colour the next day is reddish–brown.

3 Yes, a chemical reaction occurred.

4 An indicator of a chemical reaction is a change in colour and as the steel wool has changed from grey to reddish–brown we can conclude that a chemical reaction has occurred.

Production of a gas

1 The gas produced in photosynthesis was oxygen.

2 Another chemical reaction that produces a gas is magnesium and dilute sulfuric acid to produce hydrogen gas.

Emission of light

1 Burning magnesium produces light and a change in temperature.

2 Burning wood produces change in colour as well as a gas.

Combustion

Elements	Compounds	Mixtures
sulfur	propane	wood
sodium	ethanol	gunpowder
magnesium	methane	petrol
		kerosene

Combustion at the macro level

1 natural gas, LP gas, petrol, methylated spirits, oil, wax candle, wood, coal, iron nail

easy to ignite → difficult to ignite

2 The substances that are easy to ignite are gases or are easily vaporised.

Combustion at the atomic level

1 a) ethane $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Bonds broken	Bonds formed
12 x C–H 2 x C–C 7 x O=O	8 x C=O 12 x H–O

Energy in	Energy out
(12 x 414) + (2 x 346) + (7 x 498) = 4968 + 692 + 3486 = 9146	(8 x 804) + (12 x 463) = 6432 + 5556 = 11988

Energy released = 11988 – 9146 = 2842 kJ for 2 moles ethane.

When one mole of ethane is burnt it releases 1421 kJ of energy.

b) propane $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Bonds broken	Bonds formed
8 x C–H 2 x C–C 5 x O=O	6 x C=O 8 x H–O

Energy in	Energy out
(8 x 414) + (2 x 346) + (5 x 498) = 3312 + 692 + 2490 = 6494	(6 x 804) + (8 x 463) = 4824 + 3704 = 8528

Energy released = 8528 – 6494 = 2034 kJ mol^{-1} of propane.

c) butane $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Bonds broken	Bonds formed
20 x C–H 6 x C–C 13 x O=O	16 x C=O 20 x H–O

Energy in	Energy out
(20 x 414) + (6 x 346) + (13 x 498) = 8280 + 2076 + 6474 = 16830	(16 x 804) + (20 x 463) = 12864 + 9260 = 22124

Energy released = 22124 – 16830 = 5294 kJ for 2 moles butane.

When one mole of butane is burnt it releases 2647 kJ of energy

d) ethene $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$

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

Energy in	Energy out
(4 x 414) + 614 + (3 x 498) = 1656 + 614 + 1494 = 3764	(4 x 804) + (4 x 463) = 3216 + 1852 = 5068

Energy released = 5068 – 3764 = 1304 kJ mol^{-1} of ethene.

e) ethyne $2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$

Bonds broken	Bonds formed
4 x C–H 2 x C to C triple bond 5x O=O	8 x C=O 4 x H–O

Energy in	Energy out
(4 x 414) + (2 x 839) + (5 x 498) = 1656 + 1678 + 2490 = 5824	(8 x 804) + (4 x 463) = 6432 + 1852 = 8284

Energy released = 8284 – 5824 = 2460 for two moles of ethyne.

When one mole of ethyne is burnt it releases 1230 kJ mol^{-1} of ethyne.

2 a) ethane 1421 kJ/30.07 g = 47.26 kJ/g

b) propane 2034 kJ/44.09 g = 46.13 kJ/g

c) butane 2647 kJ/58.12 g = 45.54 kJ/g

d) ethene 1304 kJ/28.05 g = 46.49 kJ/g

e) ethyne 1230 kJ/26.03g = 47.25 kJ/g

Energy profiles

1 In this diagram products have less energy than reactants.

2 Energy has been released to the surroundings in going from reactants to products.

3 Reaction is exothermic.

Energy profiles and activation energy

1 X represents the energy needed by the reactants to react.

2 Energy of reactants is greater than energy of products.

3 The reaction is exothermic because the products contain less total energy than the reactants.

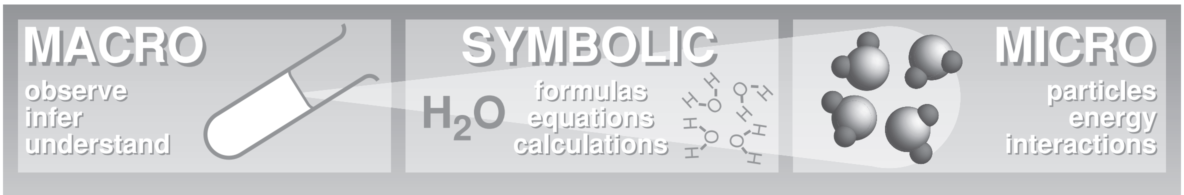
4 This reaction is endothermic. The total energy of products is greater than the total energy of reactants. Energy has been absorbed by the reactants.

5 Y represents the activation energy.

Combustion reactions

1 $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

2 $2C_8H_{18} + 17O_2 \rightarrow 16CO + 18H_2O$



Exercises – Part 4

Exercises 4.1 to 4.6 Name: ______________________________

Exercise 4.1: Chemical reactions

Name a chemical reaction that involves:

a) a change in colour

____

b) a change in temperature

____

c) production of a gas

____

d) production of a precipitate

____

e) emission of light

____

Exercise 4.2: Combustion reactions

a) Select words from the list to complete the following combustion reaction.

ethane, products, heat, carbon dioxide, reactants, oxygen, water

_________ + _________ → _______ + ________ + ______

____________ ____________________

b) i) What part does the wick play in a burning candle?

____

____

____

ii) How does the wick allow low volatility substances to burn?

____

____

____

c) Using information in earlier parts of this module and/or a chemistry textbook and/or a relevant internet site, such as one listed at: www.lmpc.edu.au/science, identify and describe practical applications of five hydrocarbons that you have dealt with.

Hydrocarbon	**Practical applications**

Exercise 4.3: Combustion of wood

In activity 3 you were asked to perform an experiment to measure the mass change when a substance such as wood was burnt in an open container.

a) Which method (A or B) did you use? Why?

____

____

____

b) Transfer your results from the activity into the spaces below.

Results:

Mass of sticks ____________________

Mass of ash ______________________

Calculate the loss in mass

____

____

What percentage of the mass of the wood was lost?

____

____

Account for the loss in mass.

____

____

Exercise 4.4: Bond energies

A student was asked by their chemistry teacher to calculate, using bond energies, the amount of energy that should be released when one mole of methylpropane is burnt.

The student's answer was 780 kJ.

Is this answer correct? (Use the table of bond energies on page 12 and show all the bonds broken and bonds formed.)

____

____

____

____

____

____

____

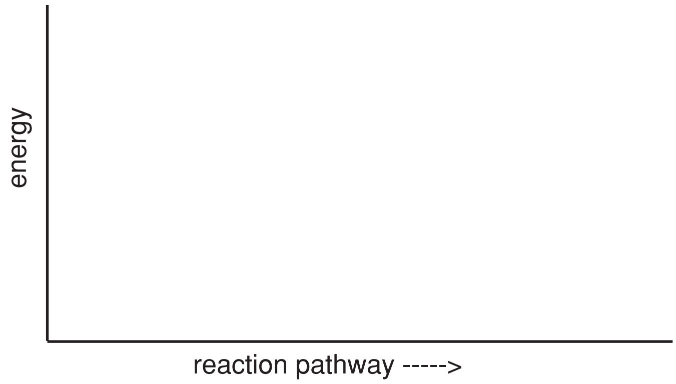
____

____

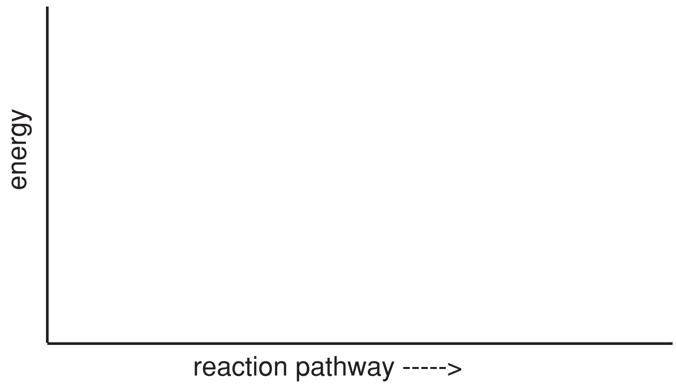
Exercise 4.5: Energy profiles

a) On the reaction coordinates below, draw an energy profile for:

i) an exothermic reaction



ii) an endothermic reaction



iii) On each graph clearly label: activation energy, energy of the reactants, and energy of the products.

b) Each of your graphs has an activation energy.

i) What is activation energy?

____

____

ii) Ignition temperature is the temperature to which reactants need to be raised to achieve activation energy. True/False

c) Using information from this and earlier modules describe two chemical reactions that are exothermic and two chemical reactions that are endothermic.

Exothermic

____

____

____

____

Endothermic

____

____

____

____

Exercise 4.6: Pollution

a) Complete the following table for solutions to combustion pollution problems.

Name	Source	Solution
	additive to fuel	
	contaminant of fuel	
	forms when nitrogen is burnt unintentionally	
	forms when carbon is burnt with restricted oxygen	
	results from incomplete combustion in a car engine	

b) A component of petrol, burnt in car engines, is 3–methylhexane (C_7H_{16}).

i) Write a fully balanced chemical equation to show the complete combustion of 3–methylhexane.

ii) Write a fully balanced chemical equation to show incomplete combustion of 3–methylhexane in a poorly tuned engine.

Chemistry

Preliminary Course

Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING

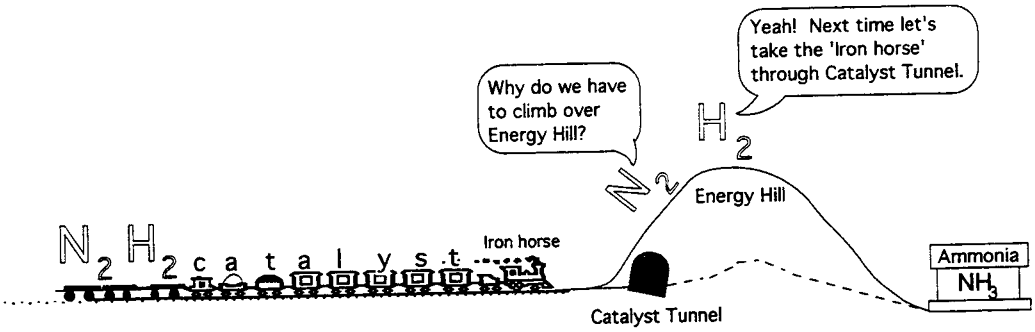
TAFE NSW

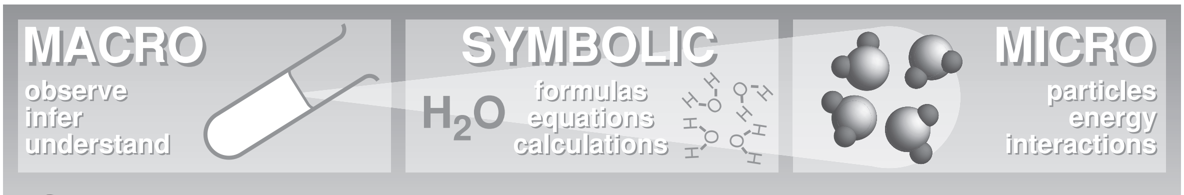
OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

Energy

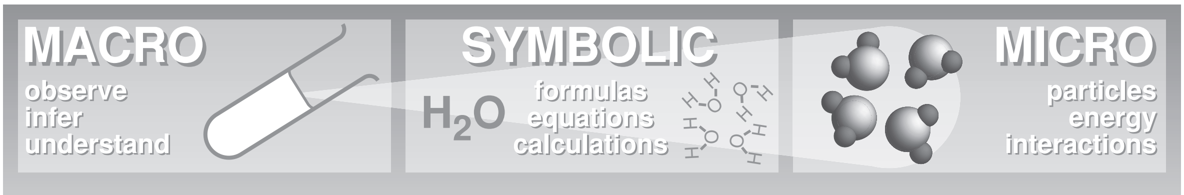
Part 5: The extent and rate of energy release

Incorporating October 2002 AMENDMENTS


Why do we have to climb over Energy Hill?
Yeah! Next time let's take the 'Iron horse' through Catalyst Tunnel.
H2
N2
Energy Hill
N2 H2 c a t a l y s t
Iron horse
Catalyst Tunnel
Ammonia
NH3


MACRO
observe
infer
understand
SYMBOLIC
H2O
formulas
equations
calculations
MICRO
particles
energy
interactions

Contents



Introduction

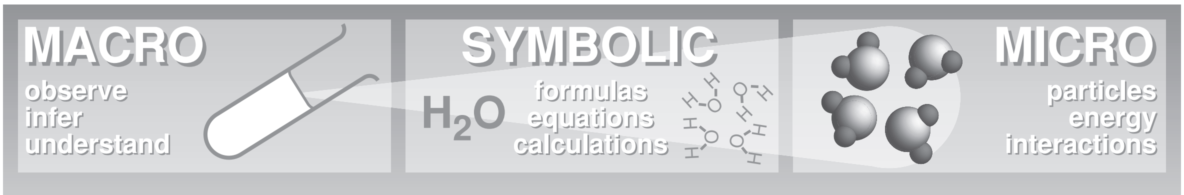
In Part 5, where you investigate the extent and rate of energy release in chemical reactions, you will be given opportunities to learn to:

- describe combustion in terms of slow, spontaneous and explosive reactions and explain the conditions under which these occur
- explain the importance of collisions between reacting particles as a criterion for determining reaction rates
- explain the relationship between temperature and the kinetic energy of particles
- describe the role of catalysts in chemical reactions, using a named industrial catalyst as an example
- explain the role of catalysts in changing the activation energy and hence the rate of chemical reaction.

In Part 5 you will be given opportunities to:

- solve problems, identify data, perform first–hand investigations and gather first–hand data where appropriate, to observe the impact on reaction rates of:
  - changing temperature
  - changing concentration
  - size of solid particles

    adding catalysts
- process information from secondary sources to investigate the conditions under which explosions occur and relate these to the importance of collisions between reacting particles
- analyse information and use the available evidence to relate the conditions under which explosions occur to the need for safety in work environments where fine particles mix with air
- analyse information from secondary sources to develop models to simulate the role of catalysts in changing the rate of chemical reactions.



Temperature and kinetic energy

Temperature is a measure of the average kinetic energy of particles. This means that at a given temperature particles of different chemicals will have the same average kinetic energy.

The **kinetic energy** of a particle is described by the equation:

$KE = \frac{1}{2}mv^2$ where m is mass and v is velocity.

You can see from this equation that the velocity of the particles is very important in determining the kinetic energy (and thus temperature) of the particles.

For a given set of particles, the higher the temperature the faster their average velocity.

1 Consider the following model. You are one of 100 people on a dance floor. Everyone is blindfolded and moving randomly about the room at walking pace. Assuming that no one speaks, how often would you bump into another person? (Underline your choice.)

every half second, every second, every five seconds, once a minute, every hour, never

2 Now imagine that instead of walking everyone runs as fast as they can.

a) What has happened to the average kinetic energy of the people?

____

a) What do you think would happen to the number of collisions?

____

b) Explain your answer.

____

____

Check your answers.

Reaction rates

Chemical reactions can only occur when the reactants can get together (collide with each other). This means that the greater the rate of collisions, the greater the rate of the reaction.

Why does a car engine run better when it ‘has warmed up’?

If you use a vehicle with a diesel engine, have you ever noticed how much harder it is to start in the winter? What time of the year are bushfires most likely and most dangerous? Why are reptiles slower in cool weather?

The answers to these questions all have one thing in common. They all have something to do with ______________.

Check your answer.

Temperature and reaction rate

The rate or speed of a chemical reaction is dependent on a number of factors. One of these factors is temperature.

Activity 1:

Does temperature affect **reaction rate**?

For this activity you will need to have access to washing soda ($Na_2CO_3.10H_2O$) and vinegar (a mixture of water and ethanoic acid CH_3COOH). If you don’t have these items at home both can be purchased at a supermarket.

Method:

1 Place about 100 mL of vinegar into a 250 mL beaker or plastic cup. Add one or two washing soda crystals (about the size of a pea) to the vinegar.

Is a reaction occurring? ____________________________________

How can you tell?

____

____

____

2 Watch the reaction until it ceases.

How can you tell that the reaction has stopped?

Check your answers.

Once you are satisfied that you have an understanding of the reaction between sodium carbonate (washing soda) and vinegar then continue with the rest of the method.

3 In each of three 250 mL beakers place about 100 mL of vinegar. If you do not have access to beakers plastic cups could be used instead. Label the containers A, B and C.

4 Place container A in the refrigerator for about an hour. Leave container B at room temperature and place container C in a saucepan containing hot water from the hot water tap for about ten minutes.

5 Select three roughly equal sized crystals of washing soda (pea sized is good).

6 If you have a thermometer measure the temperature of containers A, B and C. Record these results.

7 Place one of the washing soda crystals into each container and measure the length of time for the reaction to be completed. Record these times.

Results:

	A **refrigerator**	**B** **room**	**C** **saucepan**
Temperature (°C)			
Reaction time (s)			

Conclusion:

1 Is there any relationship between temperature and the rate of this chemical reaction? If there is, explain.

2 Using the model described in this section to explain how temperature affects the rate of the reaction between washing soda and vinegar.

____

____

____

____

Check your answers.

Reaction rates and concentration

Another factor that can affect the rate of a chemical reaction is the **concentration** of the reactants.

Using the model of people on a dance floor it is possible to predict the consequence, on reaction rate, of increasing the concentration of the reactants.

If the number of people was doubled from 100 to 200 on the same dance floor, you would expect the number of collisions to: (circle one answer)

increase decrease remain the same

You now have the chance to test your model with the following activity.

Activity 2:

Do changes in concentration, of one or more reactants, change the rate of a chemical reaction?

For this activity you will need access to washing soda and vinegar.

Method:

1 Place 100 mL of vinegar into a 250 mL beaker or plastic cup. Add a single pea sized crystal of washing soda. Measure the time taken for complete reaction to occur. Record this time.

2 Repeat using 90 mL vinegar and 10 mL water.

3 Repeat using 80 mL vinegar and 20 mL water.

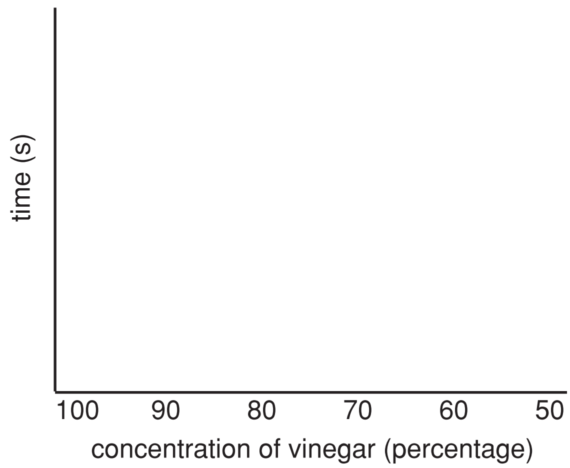
4 Repeat using 70 mL vinegar and 30 mL water.

5 Continue until the mixture of vinegar and water is 50% vinegar.

Results:

Concentration of vinegar (vinegar/water) as a %	100	90	80	70	60	50
Time for complete reaction (s)						

Graph your results on the axes below.



Conclusion:

Using your results as a guide comment on the role concentration plays in the rate of chemical reactions.

____

____

____

____

____

Check your answer.

Reaction rate and surface area

Rates of chemical reactions can also be affected by a change in the size of the particles of any solid reactant.

Before completing the next activity, consider the following model.

1 You have a cube with 10 cm sides. Calculate its surface area.

2 The cube is now divided up into smaller cubes with sides 1 cm in length.

How many cubes can be made from the original 10 cm cube?

3 Calculate the total surface area of the smaller 1 cm cubes.

4 Which has the largest surface area?

5 In a chemical reaction the rate of collisions between reactants is the determining factor for the overall rate of the reaction.

Explain how changing the particle size, and hence the surface area, of one or more of the reactants can change the rate of the reaction.

Check your answers.

Now test your predictions by completing the following activity.

Activity 3:

How does the size of solid particles affect the rate of a chemical reaction?

In this activity you will again use vinegar and washing soda.

Method and Results

1 Place 100 mL of vinegar in each of two beakers or plastic cups.

2 Select two similar sized crystals of washing soda.

3 Crush one crystal until it is in powder form.

4 Place the single crystal into one container of vinegar and measure and record the time taken for the reaction to be completed. ______

5 Place the powdered washing soda into the other container of vinegar and measure and record the time taken for the reaction to be completed. _________

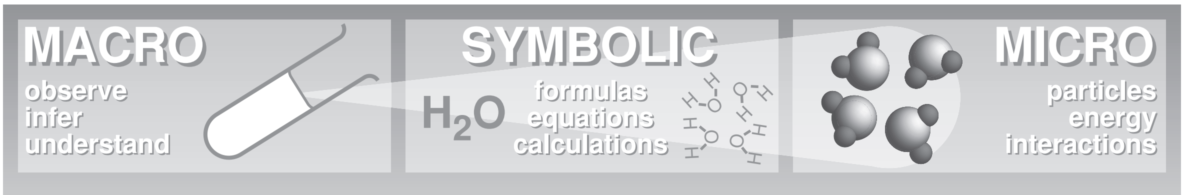
Conclusion:

What effect does the size of the particles of washing soda have on the rate of the reaction between washing soda and vinegar?

____

____

Check your answers.



Types of combustion

Most people are familiar with combustion. Everyone has seen a fire or a candle flame. This is, however, only one type of combustion. As it occurs fairly rapidly it is known as fast or rapid combustion.

There are other forms of combustion that are not quite so familiar but nevertheless important. These are:

- slow combustion
- explosive combustion.

Slow combustion

Whenever a combustible substance (fuel) is exposed to air a very slow reaction occurs between the fuel particles and oxygen in the air. This can occur at any temperature but proceeds faster at higher temperatures. Slow combustion proceeds at a very slow pace and generally goes unnoticed as it generates very little heat. Any heat generated is rapidly lost to the surroundings unless the reaction is insulated by surrounding material.

A good example of this can be seen with freshly mown grass.

Activity 4:

Investigating another type of combustion.

Collect two bucketfuls of freshly mown green grass. Make a large and a small pile with this grass. One pile should contain about a third of a bucketful. Make another pile with the remaining grass.

Leave undisturbed for about half an hour and then carefully place your hand into the centre of each pile.

Record your observations.

You should have noticed that the temperature was higher in the larger pile of grass. This is caused by two factors. Firstly the insulating properties of a large volume of grass prevent any heat energy from rapidly escaping to the outside. Secondly as the temperature rises so the rate of the reaction also increases. If the volume of grass is large enough the temperature may eventually rise to the point at which the ignition temperature of the grass is reached. At this point the grass will burst into flames and rapid combustion will occur. This process is known as **spontaneous combustion**.

There are a number of ways by which spontaneous combustion can occur. But the basic process is the same: a slow exothermic chemical reaction and a way of preventing the heat from the reaction escaping to the surroundings. The slow reaction may be in the form of slow combustion or, as is the case in the following article, another type of chemical reaction.

The extract is from: FDA Public Health Advisory:

> **Potential Risk of Spontaneous Combustion in Large Quantities of Patient Examination Gloves (June 27, 1996)**
>
> To: Hospital Administrators, Latex Glove Manufacturers, Hospital Risk Managers, Distributors/Importers, Hospital Procurement Managers
>
> 'In the spring and summer of 1995, the spontaneous combustion of powder–free latex patient examination gloves caused four fires in different states. The fires all occurred in warehouses and involved large quantities of non–sterile, powder–free, chlorinated latex gloves stored on pallets. All of the gloves were labeled "Made in China" and manufacturers' serial numbers indicate they were manufactured between 1992 and 1994. We are concerned about the potential for future fires involving powder–free latex patient examination gloves and about glove quality.
>
> This Advisory offers recommendations which we believe will help reduce risks.
>
> Investigations by the Food and Drug Administration (FDA), the Bureau of Alcohol, Tobacco, and Firearms (BATF), and local fire departments have identified the fires as having started within gloves stored in stacks on pallets. Having ruled out arson, investigators concluded the cause of the fires was spontaneous combustion of the gloves. High warehouse temperatures apparently accelerated an exothermic chemical reaction on the chlorinated gloves to the point where the latex ignited. This conclusion has been supported by current FDA research and raises continued concern as another hot season arrives. We are also concerned that heating short of ignition temperatures may cause the glove latex to deteriorate and lose its effectiveness as a barrier.

(Note that labeling on glove boxes instructs that gloves should be stored in a cool and dry place.)

Although our investigation is not complete and research continues, we have identified several factors that may increase the potential risk for fires. The most important of these are the storage environment temperature and mass of the gloves. Therefore, do not store large quantities of powder–free latex patient examination gloves in conditions of extreme heat.

Because all the known fires occurred in a quantity of at least one pallet in warehouses without temperature controls, we consider a large quantity of powder–free latex gloves to be one pallet or more stored in a warm to hot location. While it is not possible to identify a maximum safe storage temperature, research has confirmed that the greater the mass quantity of gloves, the cooler the temperature must be to avoid fires. The FDA recommends the following precautions:

- Avoid a large inventory of powder–free latex gloves.
- Remove shrink–wrap from pallets of stacked cartons.
- Break the stacked cartons on each pallet apart and restack or reconfigure cartons to facilitate cooling ventilation.
- Periodically check powder–free latex gloves for characteristics suggesting deterioration, such as brittleness, tackiness, or an acrid chemical odor or stench.
- Rotate your powder–free latex glove stock using "first–in–first–out" practices.

If gloves exhibit any characteristic suggesting deterioration, they should not be used; it is doubtful they provide an adequate protective barrier. Should these characteristics be noted, or if evidence of combustion is observed:

1 immediately break apart the stacks to dissipate heat,

2 identify gloves as hazardous and quarantine or remove,

3 contact your District FDA office or call FDA Emergency Operations at (301)443–1240, and

4 contact your local Health Department or local environmental agency regarding the proper disposition of hazardous materials.

FDA will continue to inspect glove manufacturers and distributors, and to work closely with U.S. Customs, to help ensure the quality of latex gloves in this country.'

1 What factors increase the chance of the latex gloves spontaneously igniting?

2 How can the risk of spontaneous combustion in the pallets of latex gloves be minimised?

Check your answers.

To find out more about spontaneous combustion visit the science website: http://www.lmpc.edu.au/science

Explosive combustion

Under certain circumstances the fuel and oxygen mixture is of a type and ratio that allows the mixture to burn virtually instantly. This almost instantaneous combustion produces gases at a very high temperature. This temperature rise creates a rapid build up in pressure. If the reaction is confined, for example in a container, the pressure builds up and ruptures the container explosively. The shock wave then travels outwards in all directions.

Conditions for explosive combustion

For combustion of any kind to occur, a fuel needs to come in contact with oxygen (or an oxidising agent.)

The rate of a chemical reaction will increase if one or more reactants consists of finely divided particles. Explain.

Check your answer.

Explosions are examples of very rapid combustion and can occur when the particles of a fuel are so finely divided that they are in the form of a vapour or dust. These particles also need to be confined so their concentration can increase to a level where they will allow a self-supporting reaction to occur. This is why explosions generally occur in confined spaces.

Explosions, therefore, may occur wherever there are high concentrations of gases, vapours or finely divided solid particles of combustible substances.

Catalysts

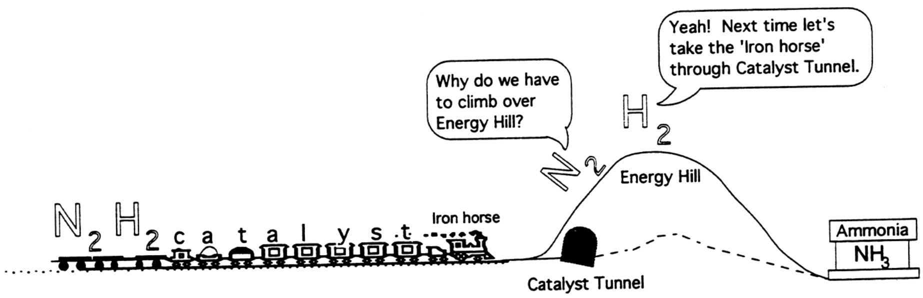
A **catalyst** is a substance that speeds up or allows a chemical reaction to occur at a lower than normal temperature without being consumed in the reaction.

Catalysts are many and varied. They can be organic or inorganic.

Many catalysts are important to the chemistry in living things as well as being very important in the industrial preparation of certain substances.

Catalysts and reaction rate

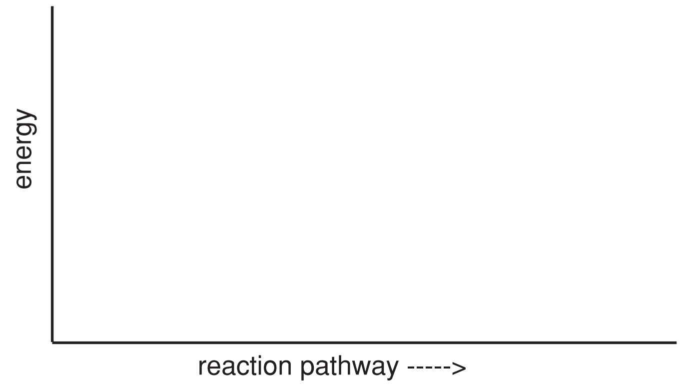
The diagram below is a summary of the formation of ammonia from hydrogen and nitrogen.



1 What is represented by the ‘energy hill’ in the diagram?

2 How does the catalyst speed up the reaction?

3 Use the energy profile diagram to simulate a chemical reaction with and without a catalyst.



Check your answers.

Activity 5:

Impact on reaction rate of adding a catalyst

For this activity you will need a fresh slice of raw potato and some hydrogen peroxide solution. Hydrogen peroxide solution (H_2O_2) is obtainable at chemists and supermarkets. It is used as a mild antiseptic.

Hydrogen peroxide is unstable and at room temperature in the presence of light will gradually decompose to water and oxygen.

Obtain two watchglasses or plates. Pour a small amount (one millilitre) of hydrogen peroxide in to each of the watchglasses or plates. Place a slice of fresh raw potato into the hydrogen peroxide of one of the watchglasses or plates.

1 a) Has a chemical reaction occurred? ______________________

b) How can you tell?

____

____

____

c) Has the potato acted as a catalyst for the decomposition of the hydrogen peroxide? Explain.

____

____

____

d) Why was hydrogen peroxide placed in a watchglass or plate without potato?

____

____

2 Complete the following sentence. (Part 4 may help you.)

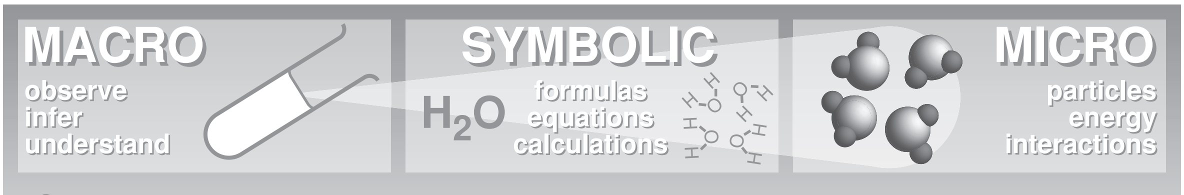
Before a substance can begin to burn ______________________

____

____

Check your answers.

Complete Exercise 5.1: *Reaction rates*.



Suggested answers

Temperature and kinetic energy

1 You would bump into another person:

every half second, every second, every five seconds, once a minute, every hour, never

2 a) The average kinetic energy of the people has increased.

b) The number of collisions has increased.

c) The faster people run the greater the distance they cover and the more likely they are to collide with each other.

Reaction rates

They all have something to do with temperature.

1 a) Yes a reaction is occurring.

b) Bubbles of gas have been released which indicates that a reaction has occurred.

2 The reaction has stopped when no more gas bubbles are released.

Conclusion

1 The higher the temperature the faster the reaction because more energy is available to provide activation energy.

2 The higher the temperature, the faster the acid particles move and the more often they collide with the carbonate crystal. Also the more likely the colliding particles are to exceed the activation energy and react.

Reaction rates and concentration

The lower the concentration of a reactant, the lower the rate of reaction.

Reaction rate and surface area

1 Each side has an area of 10 cm x 10 cm = 100 cm^2.

A cube has six sides, therefore:

total surface area: = 6 x 100 = 600 cm^2

2 10 x 10 x 10 = 1000

The 10 cm cube has a volume of 10 cm x 10 cm x 10 cm = 1000 cm^3

A 1 cm cube has a volume of 1 cm x 1 cm x 1 cm = 1 cm^3

Therefore a 10 cm cube (volume 1 000 cm^3) can produce 1000 one centimetre cubes (volume 1 cm^3).

3 Each side has an area 1 cm x 1 cm = 1 cm^2

Six sides, therefore, surface area = 6 cm^2

1000 1 cm cubes will have:

total surface area of 1000 x 6 cm^2 = 6000 cm^2

4 The smaller 1 cm cubes have the smaller surface area.

5 Smaller particles of the same amount of reactant have a greater surface area and therefore experience more collisions.

Conclusion

The finer particles in powdered washing soda react faster than a single large particle (crystal).

Slow combustion

1 High temperatures and large quantity (one pallet or more) increase the chance of the latex gloves spontaneously igniting.

2 The risk of spontaneous combustion in the pallets of latex gloves can be minimised by storing cartons apart in cool ventilated conditions.

Conditions for explosive combustion

Finely divided particles have a large surface area and as a chemical reaction requires collisions between reactants to occur for the reaction to proceed, the larger the surface area the faster the reaction.

Catalysts and reaction rate

1 The 'energy hill' represents activation energy.

2 Catalyst speeds up the reaction by providing an alternative pathway with a lower activation energy.

3 The uncatalysed pathway in the diagram should have a high activation energy while the catalysed pathway has a low activation energy.

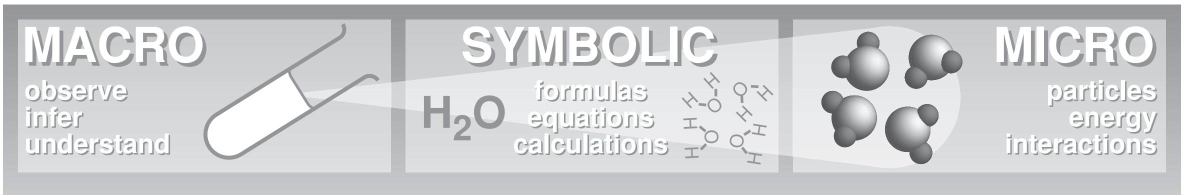
1 a) Yes

b) Release of gas bubbles

c) Potato cells contain catalase which has acted as a catalyst for decomposition of the hydrogen peroxide.

d) The hydrogen peroxide placed in a watchglass or plate without potato acted as a control. This control showed that the potato made a difference.

2 Before a substance can begin to burn it needs to be in contact with oxygen and the reacting particles need to have at least the activation energy.



Exercises – Part 5

Exercise 5.1 Name: ______________________________

a) i) Describe how slow combustion differs from explosive combustion.

ii) Give an example of how each can occur.

iii) Give two examples of industries that are exposed to the danger of accidental explosions. For each of these industries show how the explosions may occur and suggest ways that can be employed to minimise the risk of accidental explosion.

b) i) What is spontaneous combustion?

ii) How might spontaneous combustion occur?

c) Explain this statement:

'The rate of a chemical reaction is determined by the frequency of collisions between the reacting molecules.'

d) How does the temperature of a substance affect the kinetic energy of its particles?

e) What impact does each of the following have on the rate of a chemical reaction?

i) temperature

ii) concentration

iii) size of solid particles

iv) addition of catalysts

f) Obtain a sugar cube. Place it on a non-combustible surface, an inverted can is good. Try igniting it with a match.

i) What did you notice?

____

____

ii) Now rub a small amount of ash (from a dead match) onto the sugar cube and then try to light it as before.

Was there any difference?

____

iii) The ash has acted as a catalyst in this case.

What effect do you think the ash has had on the activation energy for this reaction?

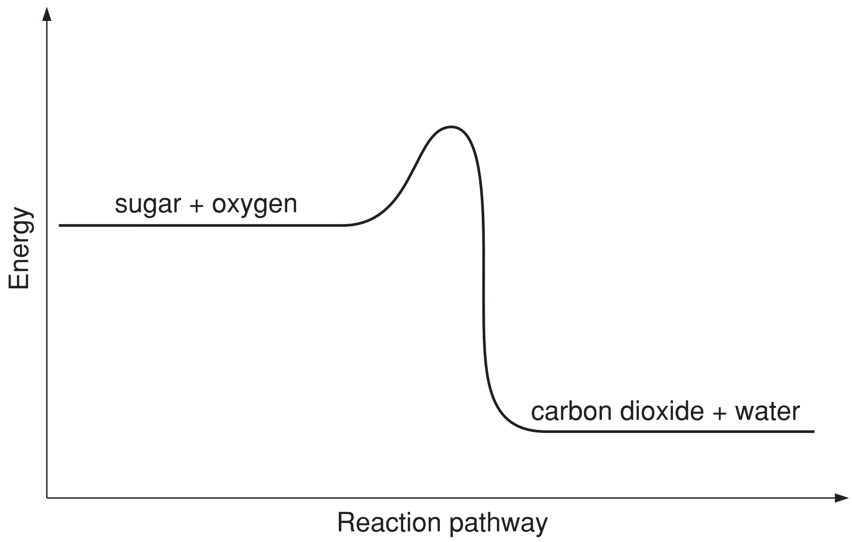
____

____

____

____

iv) The energy profile for the combustion of sugar is drawn below. Draw on, the energy profile above, the effect that you think the ash may have had.



g) Refer back to the model of a reaction being affected by the 'catalyst train'. Explain how this model demonstrates the role of catalysts in changing the rate of chemical reactions.

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Energy

Part 6: Review and research report

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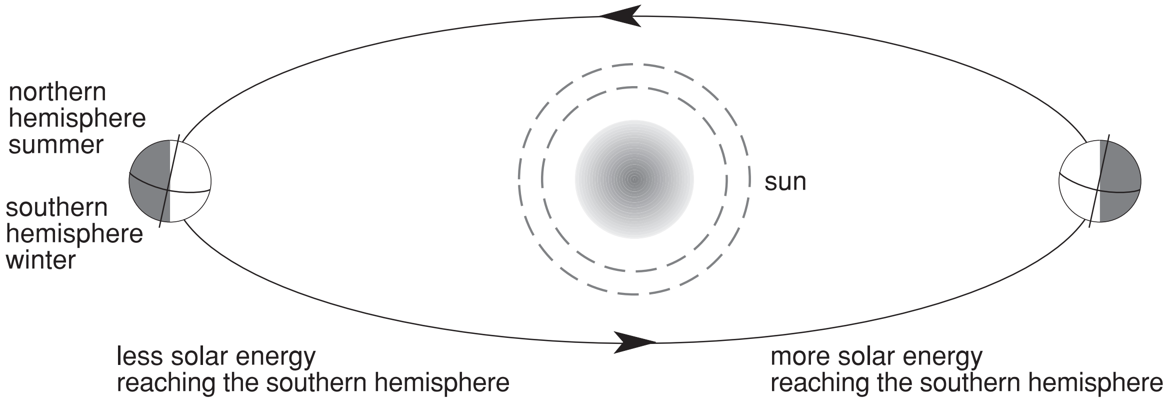
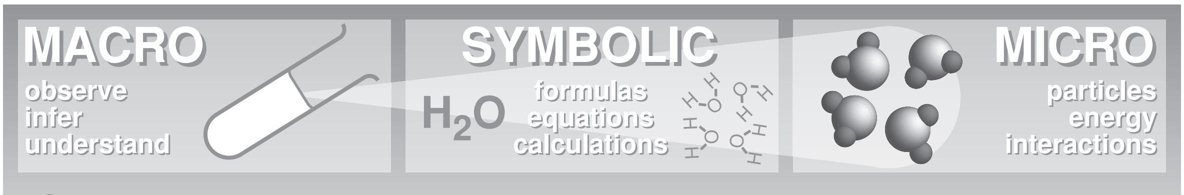

northern
hemisphere
summer
southern
hemisphere
winter
sun
less solar energy
reaching the southern hemisphere
more solar energy
reaching the southern hemisphere


MACRO
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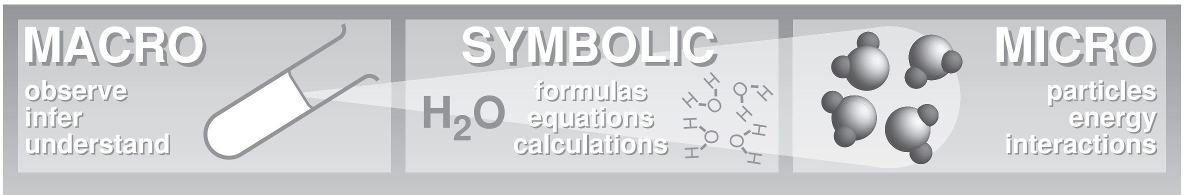
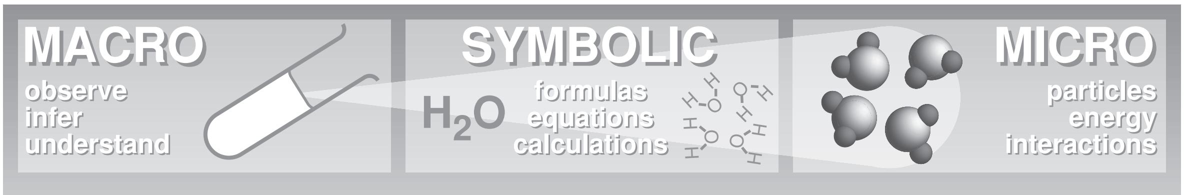
Contents



Introduction

In Part 6 you will be given opportunities to:

- review the first five parts of this module
- implement strategies to work effectively as a member of a team in completing a send–in exercise.



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.

Photosynthesis

- All the energy reaching the Earth from the Sun is in the form of visible light.
- All parts of the Earth receive the same amount of energy from the Sun.
- Photosynthesis produces carbon dioxide and water.
- Photosynthesis is an important process because it converts inorganic compounds into organic compounds.
- A lion does not depend on energy form the Sun because it does not eat plants.
- The carbon dioxide content of the atmosphere is about 0.04%.
- There is very little recycling of the carbon dioxide in the atmosphere.
- Coal is a sedimentary rock formed from layers of vegetable matter.
- Crude oil only contains a few dozen chemical compounds.
- Crude oil is found in large lakes below the surface of the Earth.

Check your answers.

Carbon and its compounds

- Carbon is a small atom containing four electrons in the outer shell.
- All carbon atoms have six neutrons and six protons in the nucleus.
- The only known allotropes of carbon are graphite and diamond.
- Positive carbon ions would be larger than the neutral atom.
- Carbon reacts with other elements by forming ionic bonds as it has the ability to donate four electrons.
- Because carbon atoms are able to join with other carbon atoms there is an infinite number of possible carbon compounds.
- Single covalent bonds involve one pair of electrons, double bonds involve two pairs of electrons and triple covalent bonds involve three pairs of electrons.
- Deoxyribose nucleic acid is not an example of a carbon compound.
- An unsaturated hydrocarbon will have one or more double or triple bonds.
- Ethane contains double covalent bonds.

Check your answers.

Hydrocarbons

- Hydrocarbons only contain the elements carbon and hydrogen.
- The prefix denoting seven carbon atoms is hept.
- The general formula for the alkanes is C_nH_{2n}
- The formula C_5H_{12} describes only one compound.
- The alkanes, alkenes and alkynes all show similar trends with regard to their melting point, boiling point and volatility.
- Liquid hydrocarbons that evaporate readily are more likely to form explosive mixtures than less volatile hydrocarbons.
- Fractional distillation is a process that is used to separate the various components of crude oil on the basis of their boiling points.
- When naming hydrocarbons it is important to keep the numbers as small as possible.
- Petrol that contains branched chain hydrocarbons is likely to increase the amount of 'knocking'.
- Most coal is used as a fuel for power generation and the production of steam for use in industry.

Check your answers.

Chemical reactions – combustion

- The basis of a chemical reaction is the destruction of atoms or ions.
- A rise in temperature is an indication that a chemical reaction is occurring.
- Emission of light from mixed chemicals is not an indicator of chemical reaction.
- Coal is easier to ignite than kerosene because it is solid.
- The temperature at which a substance will begin to burn is known as the ignition temperature.
- When a substance such as wood is burnt its mass appears to decrease
- Energy is taken in when bonds are made and released when bonds are broken.
- The amount of energy required to raise the temperature of 100 g of water by 10 degrees Celsius is 4.18 kJ.
- Complete combustion of hydrocarbons produces carbon dioxide and water.
- Incomplete combustion of hydrocarbons generally produces carbon monoxide only.

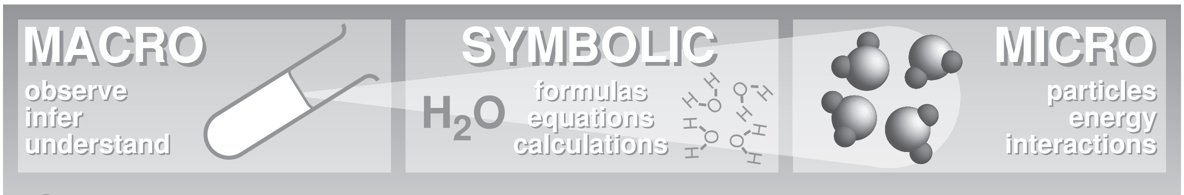
Check your answers.

The extent and rate of energy release

- The kinetic energy of a particle is dependent both on its mass and its velocity.
- The velocity of a particle decreases as the temperature increases.
- The rate of a chemical reaction partly depends on the frequency of collision between the reactants.
- The surface area of a solid reactant has no effect on the rate of a chemical reaction.
- Less concentrated solutions will react at a faster rate than more concentrated solutions because the water helps the substances react.
- Spontaneous combustion can occur when heat released by slow combustion raises the temperature to ignition temperature.
- Slow combustion occurs at a rate to low to be noticed.
- Explosive combustion only occurs in mixtures of gases.

- A catalyst is a substance that is completely consumed in speeding up a chemical reaction.
- An energy profile diagram is not changed by the introduction of a catalyst.

Check your answers.



Suggested answers

Photosynthesis

- All the energy reaching the Earth from the Sun is in the form of visible light. F.

  Only part of the energy reaching the Earth from the Sun is in the form of visible light. Infrared (heat) and UV energy also come.

- All parts of the Earth receive the same amount of energy from the Sun. F

  Areas closer to the equator receive more energy from the Sun than areas closer to the poles.

- Photosynthesis produces carbon dioxide and water. F.

  Photosynthesis produces oxygen and carbohydrates.

- Photosynthesis is an important process because it converts inorganic compounds into organic compounds. T

- A lion does not depend on energy form the Sun because it does not eat plants. F.

  A lion does depend on energy from the Sun because although it eats animals these animals have eaten plants.

- The carbon dioxide content of the atmosphere is about 0.04%. T

- There is very little recycling of the carbon dioxide in the atmosphere. F.

  The carbon dioxide in the atmosphere is continually recycled.

- Coal is a sedimentary rock formed from layers of vegetable matter. T

- Crude oil only contains a few dozen chemical compounds. F.
  At least 60 000 different chemical compounds have been identified from crude oil.

- Crude oil is found in large lakes below the surface of the Earth. F

  Crude oil is found in pores in rocks below the surface of the Earth.

Carbon and its compounds

- Carbon is a small atom containing four electrons in the outer shell. T
- All carbon atoms have six neutrons and six protons in the nucleus. F

  Only carbon 12 has six neutrons and six protons in the nucleus.
- The only known allotropes of carbon are graphite and diamond. F

  Other carbon allotropes include C_{60} buckminsterfullerene and other fullerenes such as C_{70}.
- Positive carbon ions would be larger than the neutral atom. F

  Positive carbon ions would be smaller than the neutral atoms as they have fewer electrons in their valence shell
- Carbon reacts with other elements by forming ionic bonds as it has the ability to donate four electrons. F

  Carbon reacts with other elements by forming covalent bonds. It has the ability to share four electrons.
- Because carbon atoms are able to join with other carbon atoms there is an infinite number of possible carbon compounds. T
- Single covalent bonds involve one pair of electrons, double bonds involve two pairs of electrons and triple covalent bonds involve three pairs of electrons. T
- Deoxyribose nucleic acid is not an example of a carbon compound F

  DNA contains carbon based sugars and nucleotides linked with phosphate groups.
- An unsaturated hydrocarbon will have one or more double or triple bonds. T
- Ethane contains double covalent bonds. F

  Ethane contains only single covalent bonds

Hydrocarbons

- Hydrocarbons only contain the elements carbon and hydrogen. T
- The prefix denoting seven carbon atoms is hept. T
- The general formula for the alkanes is C_nH_{2n} F

  The general formula for the alkanes is C_nH_{2n+2}
- The formula C_5H_{12} describes only one compound. F

  The formula C_5H_{12} describes a number of isomers.
- The alkanes, alkenes and alkynes all show similar trends with regard to their melting point, boiling point and volatility. T

- Liquid hydrocarbons that evaporate readily are more likely to form explosive mixtures than less volatile hydrocarbons. T
- Fractional distillation is a process that is used to separate the various components of crude oil on the basis of their boiling points. T
- When naming hydrocarbons it is important to keep the numbers as small as possible. T
- Petrol that contains branched chain hydrocarbons is likely to increase the amount of 'knocking'. F

  Petrol that contains branched chain hydrocarbons is likely to reduce the amount of 'knocking'
- Most coal is used as a fuel for power generation and the production of steam for use in industry. T

Chemical reactions – combustion

- The basis of a chemical reaction is the destruction of atoms or ions. F

  The basis of a chemical reaction is the rearrangement of atoms or ions
- A rise in temperature is an indication that a chemical reaction is occurring. T
- Emission of light from mixed chemicals is not an indicator of chemical reaction. F

  Emission of light is often an indicator of a chemical reaction
- Coal is easier to ignite than kerosene because it is solid. F

  Coal is more difficult to ignite than kerosene because it is harder to vaporise.
- The temperature at which a substance will begin to burn is known as the ignition temperature. T
- When a substance such as wood is burnt its mass appears to decrease. T
- Energy is taken in when bonds are made and released when bonds are broken. F

  Energy is taken in when bonds are broken and released when bonds are formed
- The amount of energy required to raise the temperature of 100 g of water by 10 degrees Celsius is 4.18 kJ. T
- Complete combustion of hydrocarbons produces carbon dioxide and water. T
- Incomplete combustion of hydrocarbons generally produces carbon monoxide only. F

Incomplete combustion of hydrocarbons generally produces carbon monoxide and water.

The extent and rate of energy release

- The kinetic energy of a particle is dependent both on its mass and its velocity. T
- The velocity of a particle decreases as the temperature increases. F

  The velocity of a particle increases as the temperature increases.
- The rate of a chemical reaction partly depends on the frequency of collision between the reactants. T
- The surface area of a solid reactant has no effect on the rate of a chemical reaction. F

  The rate of a chemical reaction will increase when the surface area of a solid reactant increases.
- Less concentrated solutions will react at a faster rate than more concentrated solutions because the water helps the substances react. F

  Less concentrated solutions will react at a slower rate than more concentrated solutions because fewer collisions occur between reacting particles.
- Spontaneous combustion can occur when heat released by slow combustion raises the temperature to ignition temperature. T
- Slow combustion occurs at a rate too low to be noticed. T
- Explosive combustion only occurs in mixtures of gases. F

  Explosive combustion can occur in mixtures of air and finely divided solids.
- A catalyst is a substance that is completely consumed in speeding up a chemical reaction. F

  A catalyst may change during a reaction but is completely present at the end of the reaction and not consumed.
- An energy profile diagram is not changed by the introduction of a catalyst. F

  An energy profile is lowered by the introduction of a catalyst.

Exercises – Part 6

Exercise 6.1 Name: ___________________________________

Exercise 6.1: Explosions in work environments

An important part of your study of chemistry, and indeed any branch of science, is to be able to conduct research in an area using information already published. Information that has already been published is known as a secondary source. Not only do you need to be able to collect, process and report on this information individually but you also need to be able to work as a member of a team.

You can approach working as a team member in either of two ways.

1 Approach another student, a friend or a family member to work with you in this team project.

2 Contact your teacher. Your teacher may be able to put you in touch with at least one other student, via email or the telephone, who is up to the same Preliminary module or, failing that, the teacher may act as a member of your team.

You will need to contact the other team member(s) at least twice while conducting this project to discuss sources of information.

Many important industrial processes involve the production of fine particles of solid. This can be intentional eg. in a flour mill, or unintentional eg. in a coal mining or coal handling facility.

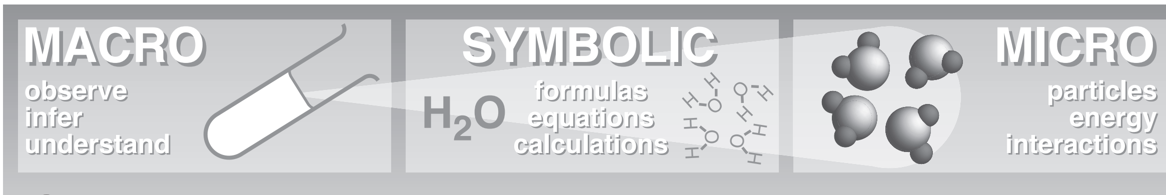
Using secondary sources, such as your chemistry text, encyclopaedias or the internet, select an industry that implements safety procedures to prevent explosions where fine particles mix with air. If you are very lucky you may be able to find somebody who has worked in an industry where these precautions are needed.

Prepare a report on safety procedures to prevent explosions within that industry.

The report should contain the following information:

- The name and contact details of the other team member(s).
- Name of the industry.
- A brief history of the industry and its processes.
- Description of how explosions of fine particle with air can occur.
- Explanation of how safe working procedures can reduce the chances of an explosion.
- List of the secondary sources that assisted you to prepare this report.
- A summary of the discussions you have had with the other member(s) of your team.

This report is to be done on your own paper.



Student evaluation of module

Name: ________________________ Location: ________________________

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 Did you find the information in the module clear and easy to understand?

____

2 What did you most like learning about? Why?

____

____

3 Which sort of learning activity did you enjoy the most? Why?

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4 Did you complete the module within 30 hours? (Please indicate the approximate length of time spent on the module.)

____

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5 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.

Learning Materials Production
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