SURFING

NSW CHEMISTRY 3&4

Module 3 Reactive Chemistry
Module 4 Drivers Of Reactions

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Module 4 Drivers Of Reactions

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Entropy and Gibbs Free Energy

INQUIRY QUESTION

How can enthalpy and entropy be used to explain reaction spontaneity?

Introduction

This book covers the Chemistry content specified in the NSW Chemistry Stage 6 Syllabus. Sample data has been included for suggested experiments to give you practice to reinforce practical work in class.

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Surfing

NSW CHEMISTRY 3&4

Module 3

Reactive Chemistry

Content Focus

In this module you will:

- Understand that all chemical reactions involve the creation of new substances and associated energy transformations. These are commonly observable as changes in the temperature of the surroundings and/or the emission of light.
- Investigate how these reactions are harnessed and controlled by chemists to produce substances that lead to the development of useful products.
- Observe how chemicals can react at many different speeds and in many different ways. Yet they basically involve the breaking and making of chemical bonds.
- Study how chemicals react and observe the changes in matter and energy that take place during these reactions.
- Explore how chemical reactions and changes relate to the chemicals used in everyday life.
- Engage with all the Working Scientifically skills for practical investigations involving the focus content to design and conduct investigations to interpret trends in data and to solve problems related to reactive chemistry.

1 Indicators Of Chemical Change

In this module, you will start by carrying out investigations to determine how you can tell whether or not a chemical change has occurred. You have already carried out quite a few chemical reactions, and you will recall many of these.

In this topic, you will look at more examples of a range of chemical reactions, including:

- Synthesis.
- Decomposition.
- Combustion.
- Precipitation.
- Acid-base reactions.
- Acid-carbonate reactions.

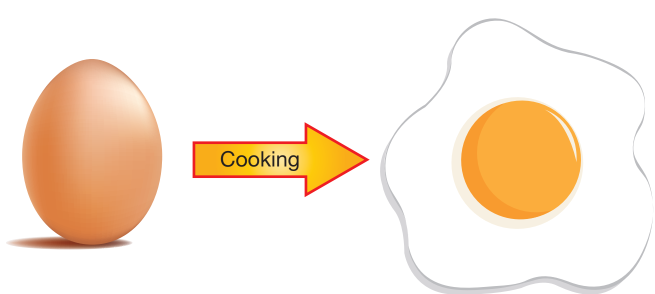
In Module 1, you revised the theory that matter is made of particles and that during a chemical reaction the particles are rearranged to form products which differ from the reactants. You also looked at the following four differences between physical and chemical changes shown in Table 1.1.

Table 1.1 Physical and chemical change.

Factor	Physical change	Chemical change
New substances	No new substance is formed.	A new substance is formed.
Particles	Particles stay the same (they just move differently).	New particles are formed (atoms have been rearranged).
Reversal	Usually easy to reverse.	Usually difficult to reverse.
Energy involved	Small energy changes usually involved.	Energy changes are usually large.
Examples	Filtration. Centrifuging. Change of state, e.g. melting, boiling, evaporation, condensation.	Combustion (burning). Acids on metals. Decomposition by heat or by electrolysis.

You do not have to go into a laboratory to see chemical changes, they are occurring in your home. Figure 1.1 shows some examples.

(a) Cooking an egg.



(b) Cooking a cake.

(c) Candles burning.

(d) Rusting of iron.

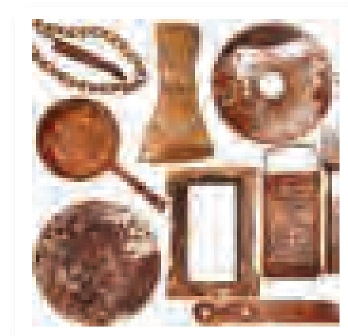


Figure 1.1 Chemical changes in the home.

In each of the examples in Figure 1.1 you can see that new substances have formed.

A new substance is formed

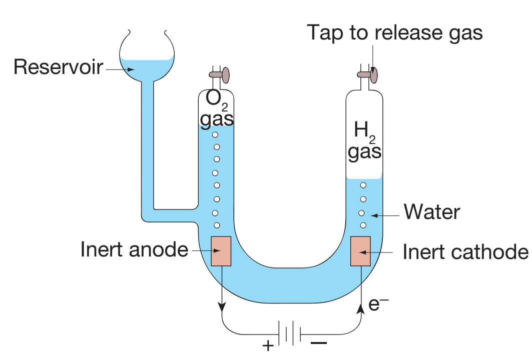
Whenever a chemical change occurs, a new substance is produced. Signs of a new substance being produced include:

- A change in colour.
- Production of a gas – which may be indicated by bubbles or a smell being released.
- A precipitate is formed (a precipitate is a solid formed when two clear solutions are mixed).
- Heat is released or taken in.

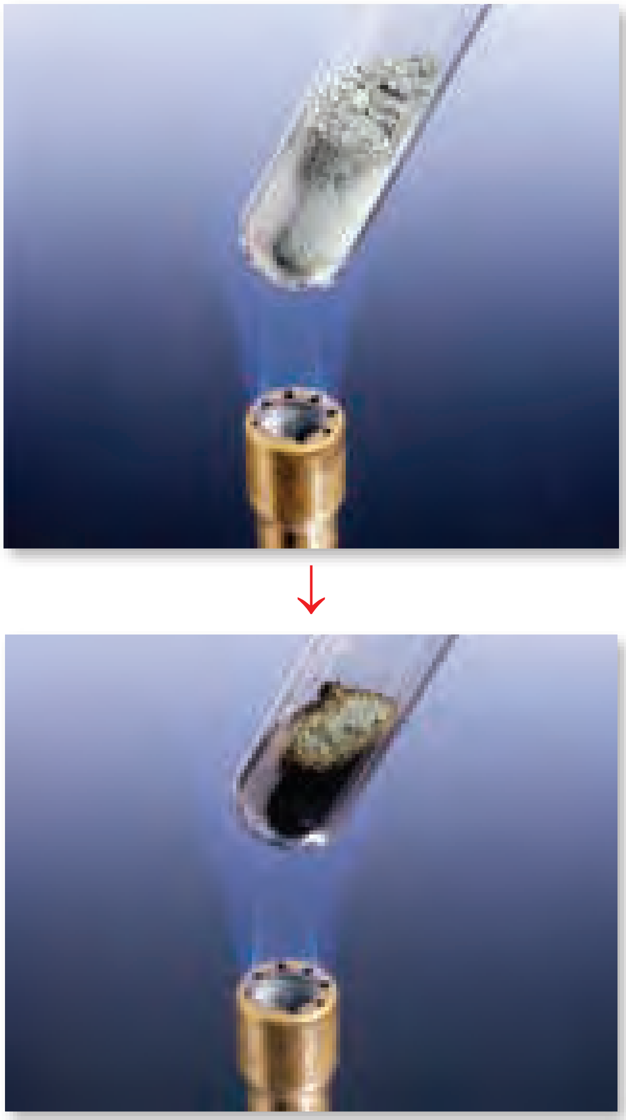
Remember that some of these changes occur in physical changes such as when water changes state to form a water vapour – but in that case there is no new substance formed, it is still water (H_2O), so it is not a chemical reaction.

You will recall seeing the following chemical reactions in the laboratory.

(a) Electrolysis of water to form hydrogen and oxygen.



(b) Decomposition of green copper(II) carbonate to black copper(II) hydroxide.



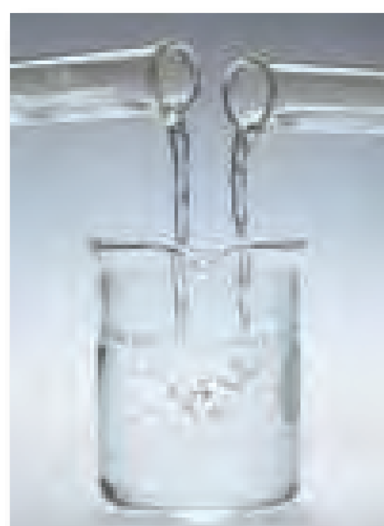
(c) Precipitation. A yellow solution of sodium chromate is being added to a clear solution of silver nitrate, producing a red precipitate of silver chromate.

(d) A piece of copper metal is placed in a flask containing colourless nitric acid.

Figure 1.2 Chemical changes in the laboratory.

QUESTIONS

1. For each of the illustrations in Figure 1.1, justify the statement that a chemical reaction has occurred.
2. For each of the illustrations in Figure 1.2, justify the statement that a chemical reaction is taking place.
3. Describe the chemical reactions you carried out in the laboratory to investigate possible indicators of change. For each reaction identify the indicators of change that you observed.
4. List four changes that can indicate a chemical reaction has occurred.
5. The diagram shows the mixing of two colourless solutions – dilute hydrochloric acid and sodium hydroxide.



You cannot see or smell any sign of a chemical reaction taking place. What else could you look for as a sign that a chemical reaction has occurred?

2 Models Of Chemical Reactions

You have already learned about the conservation of atoms in a chemical reaction – the number of each type of atom present in the reactants stays the same during a reaction and is unchanged at the end of the reaction. This is because a chemical reaction just involves a rearrangement of atoms so that new substances are produced.

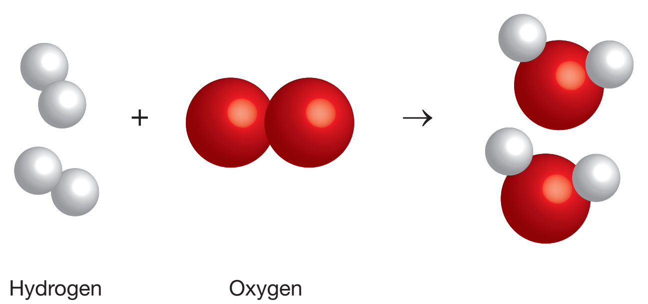
During a chemical reaction, no atoms are made or destroyed.

As you study different types of reactions you should make models to demonstrate that during a chemical reaction:

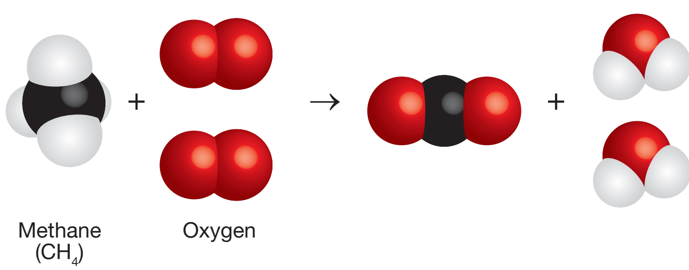
- Atoms are being rearranged to form new substances.
- Atoms are being conserved.

The illustrations in Figure 2.1 show some examples of how you could model these concepts.

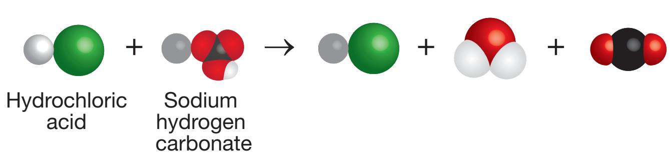
(a) A synthesis reaction.



(b) A combustion reaction.



(c) An acid-carbonate reaction.



(d) A decomposition reaction.

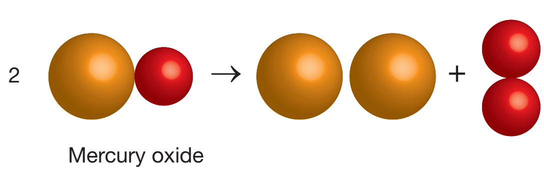
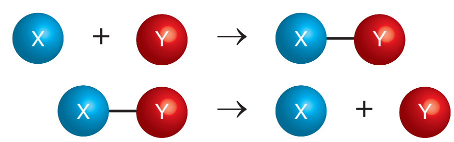


Figure 2.1 Models of the rearrangement and conservation of atoms in chemical reactions.

QUESTIONS

1. Answer the following questions about the models illustrated in Figure 2.1.
   (a) Name the product for this synthesis reaction.
   (b) Write an equation to show what model (b) represents.
   (c) Model (c) illustrates the reaction between hydrochloric acid and sodium hydrogen carbonate. Identify the names of the products based on this model.
   (d) Write a chemical equation to show the decomposition of mercury oxide.

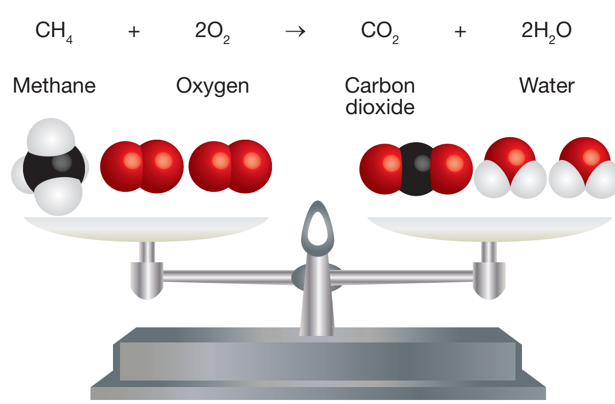
2. Indicate whether each of the following illustrates a synthesis reaction or a decomposition reaction. Justify your answer.



3. The following model indicates a precipitation reaction.
   (a) Justify this statement.

   (b) Could this model also represent an acid-base reaction? Explain.

4. How does the following model support the concept of the conservation of atoms?



5. Describe a model that you made to represent a reaction that you carried out in the laboratory and evaluate how well it demonstrated that atoms are being rearranged to form new substances and that atoms are being conserved during this reaction.

3 Synthesis and Decomposition

All chemical reactions involve the formation of at least one new substance, and indications that this has taken place include:

- The release of a gas (often indicated by bubbling or the release of a smell).
- Colour change.
- A precipitate (solid) formed from reacting solutions.
- Energy change – which may be seen as a temperature change or the emission of light and/or sound.

In this chapter we will look at two types of chemical reactions – synthesis and decomposition.

Synthesis

A **synthesis reaction** is a chemical reaction in which simple substances combine to produce more complex substances.

For example, when a mixture of **iron and sulfur** is heated (without any oxygen present) then the iron and sulfur atoms combine to form the compound iron sulfide.

Iron + sulfur → iron sulfide

$Fe(s) + S(s) \rightarrow FeS(s)$

Another example of synthesis would be the production of **sodium chloride from sodium and chlorine**. Notice that the products of a chemical reaction usually look completely different from the reactants.

$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$

Figure 3.1 When sodium burns in greenish yellow chlorine gas, they produce sodium chloride.

Decomposition

A **decomposition reaction** is a chemical reaction in which energy is used to break down a compound into simpler compounds or elements.

An example of decomposition is the breakdown of the compound copper(II) carbonate on heating. Copper(II) carbonate is a green, powdery solid. When heated, two completely new compounds are formed – a black solid called copper(II) oxide and the gas carbon dioxide.

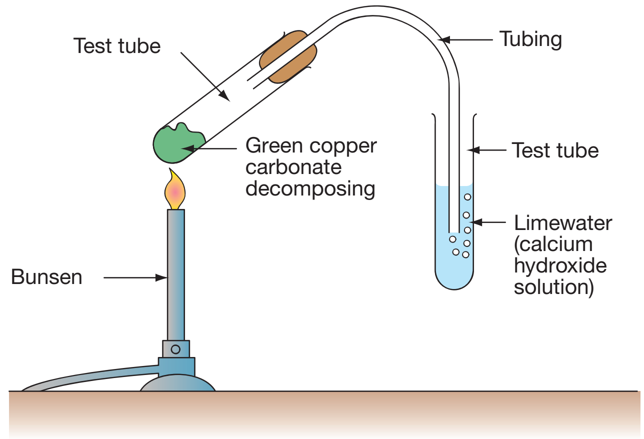


Figure 3.2 Decomposition of copper carbonate.

Compounds vary in the ease with which they can be decomposed. The amount of energy needed to decompose a compound indicates the strength of its bonds. Many compounds can be decomposed by heat, as shown in Table 3.1. Those that have the weakest bonds can be decomposed most easily. For example, the less active metals, such as silver and gold, are less likely to form compounds, but those that do form are most easily decomposed by heat.

Compounds such as those containing the active metals of groups 1 and 2, will form stable compounds with strong bonds, so these compounds need more energy to decompose. Some cannot be decomposed by heat at all. Stable compounds such as sodium chloride cannot be decomposed by heat, but can be decomposed by electrolysis – the passing of an electric current through the molten compound.

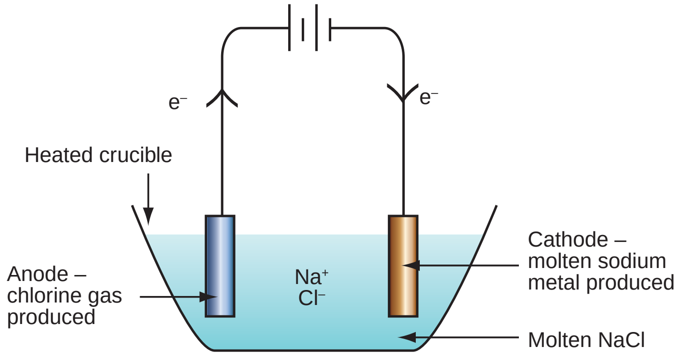


Figure 3.2 Decomposition of molten sodium chloride by electrolysis.

Table 3.1 Decomposition of compounds by heat.

<table>
<tr><th>Metal</th><th>Chloride</th><th>Carbonate</th><th>Hydroxide</th><th>Nitrate</th><th>Oxide</th><th>Sulfate</th></tr>
<tr><td>Potassium
Sodium</td><td rowspan="4">Stable</td><td>Stable</td><td>Stable</td><td>Forms nitrite and oxygen</td><td rowspan="4">Stable</td><td rowspan="2">Stable</td></tr>
<tr><td>Barium
Calcium</td><td rowspan="3">Forms metal oxide and carbon dioxide</td><td rowspan="3">Forms metal oxide and water</td><td rowspan="3">Forms metal oxide, nitrogen dioxide and oxygen</td></tr>
<tr><td>Magnesium
Aluminium
Zinc
Iron
Tin
Copper</td><td>Forms metal oxide and sulfur trioxide</td></tr>
<tr><td>Lead</td><td>Stable</td></tr>
<tr><td>Mercury</td><td>Sublimes</td><td rowspan="3">Forms metal, oxygen and carbon dioxide</td><td rowspan="3">Do not exist</td><td rowspan="3">Forms metal, nitrogen dioxide and oxygen</td><td rowspan="3">Forms metal and oxygen</td><td rowspan="3">Forms metal, sulfur trioxide and oxygen</td></tr>
<tr><td>Silver</td><td>Forms silver and chlorine</td></tr>
<tr><td>Platinum
Gold</td><td></td></tr>
</table>

QUESTIONS

Use Table 3.1 to help you answer the following questions where needed.

1. List the indicators of a chemical reaction.
2. The following equation shows a decomposition reaction.
   $ZnSO_4(s) \rightarrow ZnO(s) + SO_3(g)$
   (a) Identify the reactants and the products.
   (b) Identify an easily observable sign that a chemical reaction has taken place.
3. (a) Distinguish between the terms ‘synthesis’ and ‘decomposition’ and describe one example of each type of reaction.
   (b) Identify three forms of energy that may be released or absorbed during chemical reactions such as decomposition and synthesis.
4. Identify each of the following reactions as synthesis or decomposition.
   (a) Sodium reacting with chlorine gas.
   (b) Heating copper carbonate.
   (c) Heating magnesium in air.
   (d) Electrolysis of water.
   (e) Heating mercury oxide.
5. Write equations for the synthesis of the following compounds from their elements.
   (a) Sodium chloride.
   (b) Iron sulfide.
   (c) Carbon monoxide.
   (d) Methane.
6. Research and outline an example of an industrial process, used to manufacture useful products, which makes use of:
   (a) A synthesis reaction.
   (b) A decomposition reaction.
7. When copper carbonate is heated it decomposes.
   (a) Identify the reactant(s) and product(s).
   (b) Write an equation for this reaction.
   (c) State whether heat is absorbed or released during this decomposition reaction.
   (d) Explain why copper(II) carbonate seems to change from green to black on heating.
   (e) The black substance produced is said to be copper(II) oxide. You could confirm this by adding dilute sulfuric acid to see if it produces blue copper sulfate. Write an equation for this reaction.
   (f) The gas produced when copper(II) carbonate is heated is said to be carbon dioxide. Describe how you could confirm this.
8. Complete the following three general rules about decomposition of compounds on heating.
   (a) Most hydroxides, carbonates and sulfates .... on heating.
   (b) Most oxides and chlorides are .... when heated.
   (c) Most sodium and potassium compounds are .... when heated.
9. Using Table 3.1, identify the products formed when the following solid compounds are heated and decompose, then write symbolic equations for the reactions.
   (a) Calcium hydroxide.
   (b) Magnesium carbonate.
   (c) Copper hydroxide.
   (d) Aluminium sulfate.
   (e) Copper carbonate.
   (f) Zinc carbonate.
   (g) Silver oxide.

4 Combustion

Another type of chemical reaction is combustion.

Combustion reactions:

- **Involve oxygen**.
- Result in the **formation of one of more oxides** (compounds containing oxygen).
- Always **release energy to the environment** – we say they are **exothermic** chemical reactions.

Metals, non-metals and some compounds can undergo combustion.

- Metals burn in air/oxygen to form basic oxides (they turn red litmus blue). For example: calcium oxide, magnesium oxide are basic oxides.
- Non-metals burn in air to form acidic oxides (they turn blue litmus red). For example, sulfur dioxide and chlorine oxide are acidic oxides.
- Combustion of carbon compounds such as methane (CH_4) and ethane (C_2H_6) produces carbon monoxide, carbon dioxide and water. Most of our fuels are carbon based. Their combustion provides us with energy.

Complete and incomplete combustion

The products of combustion reactions depend on the fuel used and the amount of oxygen available for combustion. This determines whether combustion will be complete or incomplete.

Complete combustion

Complete combustion occurs when there is plenty of oxygen available. The reactant combines with as much oxygen as possible and produces carbon dioxide.

Carbon + oxygen → carbon dioxide

$C(s) + O_2(g) \rightarrow CO_2(g)$

Ethane + oxygen → carbon dioxide + water

$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$

Ethanol + oxygen → carbon dioxide + water

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

Incomplete combustion

Incomplete combustion occurs when less oxygen is available. The products of incomplete combustion of carbon and its compounds can include carbon (soot) and/or carbon monoxide.

Carbon + oxygen → carbon monoxide

$2C(s) + O_2(g) \rightarrow 2CO(g)$

Ethane + oxygen → carbon monoxide + water

$2C_2H_6(g) + 5O_2(g) \rightarrow 4CO(g) + 6H_2O(l)$

Ethane + oxygen → carbon + water

$2C_2H_6(g) + 3O_2(g) \rightarrow 4C(g) + 6H_2O(l)$

Ethanol + oxygen → carbon monoxide + water

$C_2H_5OH(l) + 2O_2(g) \rightarrow 2CO(g) + 3H_2O(l)$

Combustion of a candle

To burn a solid fuel, such as the large chain hydrocarbons that make up candle wax (e.g. $C_{30}H_{62}$), it must be both melted and vaporised (two changes of state). The wax melts, the molten wax moves up the wick and then this molten wax vaporises. The wax vapour (gas) around the wick is what actually burns.

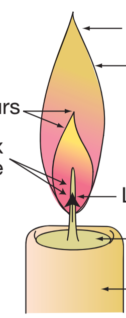


Figure 4.1 Burning a candle.

Combustion terms

The following terms are frequently associated with the use of fuels.

- **Volatile** – a volatile fuel is one that has a low boiling point and thus turns to a vapour easily. Volatile fuels may have low flash points.
- **Flash point** – is the lowest temperature at which a fuel's vapour, when mixed with air or oxygen, can be ignited by a spark or a flame.
- **Ignition temperature** – is the temperature to which a fuel must be heated in order for it to ignite in the absence of a spark or flame. Spontaneous combustion occurs at this temperature. A diesel engine reaches its ignition temperature (about 300°C) when the air/fuel mixture is compressed (there are no spark plugs in a diesel engine).

Respiration

Respiration is an example of slow combustion of glucose, an exothermic reaction. This reaction provides the energy for life, so it must take place continually in every cell of every living thing.

Glucose + oxygen → carbon dioxide + water

$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)$

Combustion of fuels

Fuels are chemicals that are burnt to produce usable energy. Combustion of fuels releases the energy stored in their bonds.

In early times the main source of energy was wood from trees. Today the main energy sources in the world are the **fossil fuels** – coal and liquid petroleum and natural gas. Fossil fuels are produced from once-living organisms when they are buried and compressed for millions of years. In Australia, fossil fuels provide 95% of the energy consumed – approximately 40% coal, 34% petroleum and 21% natural gas.

Biofuels such as ethanol are being used to supplement fossil fuels in some areas. Biofuels are produced from living organisms such as plants and algae, so they are renewable resources. Examples of biofuels are bioethanol and biodiesel.

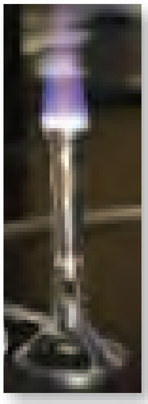
Fossil fuels and biofuels contain **chemical energy** which came originally from the Sun. Photosynthesis converts solar energy into chemical energy which is stored within molecules of glucose. The conversion, by living things (mainly plants), of inorganic carbon (e.g. in carbon dioxide) into organic compounds is called carbon fixation.

Carbon dioxide + water $\xrightarrow{\text{solar energy}}$ glucose + oxygen

$6CO_2(g) + 6H_2O(l) \xrightarrow{\text{solar energy}} C_6H_{12}O_6(aq) + 6O_2(g)$

QUESTIONS

1. Distinguish between complete and incomplete combustion.
2. Combustion always involves the addition of oxygen. Write balanced chemical equations, in words and symbols, for the following reactions.
   (a) Combustion of magnesium to form magnesium oxide.
   (b) Combustion of nitrogen to form nitrogen monoxide (nitric oxide).
   (c) Combustion of nitrogen monoxide to form nitrogen dioxide.
3. Petrol used in cars contains octane (C_8H_{18}). Write equations to show the combustion of octane under the following conditions.
   (a) Excess oxygen available.
   (b) Limited oxygen available.
4. (a) When you use a Bunsen burner to heat chemicals, do you have the hole in the barrel open or closed? Explain.
   (b) If you heat a beaker of water using the safety flame of the Bunsen burner, the beaker becomes black. Explain.



5. Pentane is burned in a limited supply of oxygen and forms water vapour, carbon monoxide and particles of carbon. Write an equation for this reaction.
6. (a) Identify the changes of state involved in the combustion of a burning candle.
   (b) Research the reason why a candle flame has an orange glow.

7. Identify whether each of the following statements is true or false and justify your answer.
   (a) When a candle burns, it is the wick that burns to make light, not the candle wax.
   (b) More oxygen must be available for complete combustion than for incomplete combustion.
   (c) Spontaneous combustion occurs at the flash point.
   (d) Respiration is an exothermic reaction.
   (e) Carbon burns in plenty of air to form a basic oxide.
8. Methane (CH_4) is present in natural gas and is a common fuel. Water is one product of the combustion of methane. Identify three other possible products of the combustion of methane as the supply of oxygen decreases. Use equations to justify your answer.
9. (a) What is meant by the term fossil fuel?
   (b) Name three fossil fuels.
   (c) For one of these fossil fuels, explain the photosynthetic origin of its energy.
10. Check your knowledge with this quick quiz.
   (a) Identify the element always used during every combustion reaction.
   (b) Name the compound produced by the combustion of aluminium.
   (c) Combustion in a plentiful supply of oxygen is called .... combustion.
   (d) What do we call any substance that can be burnt to produce usable energy?
   (e) Name three fossil fuels.
   (f) Identify the original source of the energy in fossil fuels.

5 Fossil Fuels

In junior science, you will already have learned about fossil fuels, biofuels, the products formed by their combustion and effects of these on the environment. Brief coverage of these topics is included here to remind you of the importance of combustion reactions in our lives and the undesirable effects on our environment of the combustion of fuels, especially fossil fuels.

Fossil fuels

Fossil fuels are energy sources that have been made by the action of geological processes (heat and pressure), over millions of years, on carbon compounds which are present in the buried remains of once living organisms. Fossil fuels include coal and petroleum (crude oil and natural gas), coal seam gas and also shale oil and gas. Fossil fuels are finite and **non-renewable** – they take millions of years to form and once we have used up available supplies, we cannot replace them.

Coal

Coal is a rock consisting mainly of carbon (from 50% to 98%). It also contains hydrogen, oxygen and small amounts of other elements such as nitrogen and sulfur, together with varying amounts of water and inorganic matter. The inorganic matter does not burn, it remains as ash after the coal burns.

Formation of coal

Coal is formed from the heat and compression of buried remains of plants over millions of years to form peat, then brown coal, black coal and finally anthracite.

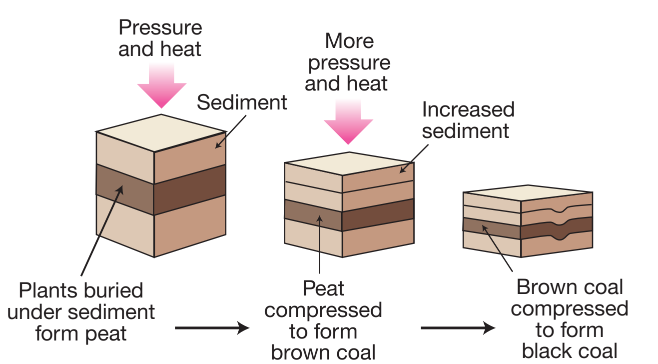


Figure 5.1 Formation of coal.

Coal resources

The largest coal reserves are found in the USA, Russia, China and Australia. World coal consumption has been growing rapidly, especially in developing areas such as China, which is now the biggest producer and consumer of coal.

Coal in Australia

In Australia, coal is found in every state and in the Northern Territory. However, New South Wales, Victoria and Queensland are our main producers. It has been estimated that Australia has 6% of the world's black coal and about 25% of the world's brown coal deposits. Most (95%) of our black coal is mined in New South Wales and Queensland, and most (96%) of our brown coal is mined in Victoria.

Uses of coal

- Coal is a major source of energy, especially for the generation of electricity. In Australia, coal produces about 80% of our electricity.
- Coal is also a major source of export income for Australia. Australian black coal is highly valued because of its high energy, low ash and low sulfur content.
- Coal is used in industry, to make products such as cement, glass and aluminium.
- In some areas, coal is used for domestic heating.
- Some black coal is heated without air or oxygen to make coke which is used in the production of iron and steel.

Petroleum – crude oil and natural gas

Petroleum consists of **crude oil and natural gas**. These are both formed from once-living organisms, mainly single celled marine organisms, so they are called fossil fuels. Supplies of petroleum are finite and non-renewable.

Formation of petroleum

Petroleum has been formed by the action of geological processes (heat and pressure) on the remains of animals, especially microscopic marine organisms such as diatoms. These must be buried under sediment and compressed for millions of years to form petroleum. The petroleum formed is trapped in porous rocks when the rock layers above and below are impervious (won't let liquids through). Natural gas forms with the liquid petroleum and slowly rises to the top.

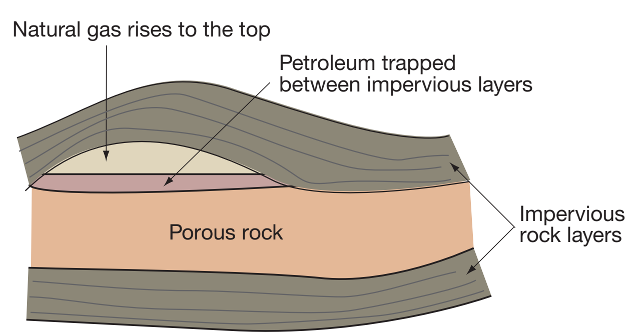


Figure 5.2 Formation of petroleum.

Composition of petroleum

Crude oil is a mixture of **liquid** compounds, mainly hydrocarbons. Petroleum contains up to 300 compounds of hydrogen and carbon (hydrocarbons) as well as sulfur and nitrogen. It undergoes fractional distillation to separate out groups of chemicals (called fractions) which can be used for specific purposes, for example petrol for motor vehicles, aviation fuel, kerosene, diesel fuel and lubricating oil.

Liquefied petroleum gas (LPG) mainly consists of propane (C_3H_8) and/or butane (C_4H_{10}). It can be produced during natural gas processing and during the refining of crude oil. LPG is stored and transported as a cooled liquid under pressure.

Natural gas is a mixture of combustible **gases**, mostly methane with small amounts of other gases. The composition of natural gas varies, but typical figures are as follows.

Hydrocarbons such as:

- methane 91.6%
- ethane 5.0%
- propane 0.4%
- butane 0.1%

As well as small amounts of other substances such as nitrogen, oxygen and carbon dioxide.

Petroleum resources

The largest oil reserves are in Venezuela, the Middle East (especially Saudi Arabia, Iran, Iraq and Kuwait) and Canada. The world's largest reserves of natural gas are in the Middle East (about 40%) and the Russian Federation (about 27%). At the current rate of production and consumption, resources worldwide could last about 50 to 60 years.

Figure 5.3 Offshore oil rig.

Petroleum in Australia

Australia has about 0.3% of the world oil reserves, mostly associated with giant offshore gas fields, off the coast of Western Australia. We also have large reserves of natural gas. At present we export liquefied natural gas (LNG) to other countries such as Japan, China and South Korea.

Using fossil fuels

Crude oil – the liquid part of petroleum is mainly used for the production of fuels – petrol, diesel fuel, heating oil and jet fuel. At present, about 80% of the transport fuels used worldwide are derived from petroleum. Other uses include the production of lubricants, waxes and asphalt. A small percentage is used as petrochemical feedstock – to manufacture other chemicals, e.g. polymers.

Natural gas is used mainly to produce energy for:

- Manufacturing (36%), e.g. for making bricks, cement, glass and aluminium.
- Producing electricity (32.5%), e.g. to produce steam to turn turbines.
- Mining (12.5%).
- Homes (12.0%) – heating, cooling and cooking.
- Commercial (3.8%), e.g. smelting ore.
- Transport (3.2%), e.g. as a fuel in vehicles.

Natural gas is also used as a source of chemicals to manufacture plastics and other chemicals such as fertilisers.

As a fuel, natural gas has the following advantages.

- It produces less carbon dioxide per energy unit than any other fossil fuel.
- It is a cleaner burning fuel, producing less sulfur dioxide, nitrogen oxides, particles and volatile products than other fossil fuels.
- Methane is lighter than air and boils at –181°C, so natural gas will easily disperse if there is a leak.

Coal seam gas is natural gas, mostly methane, which has collected near underground coal seams. The surrounding rock is fractured using a mixture of water, sand and chemicals pumped in at high pressure. This is called fracking. Fracking is noisy and the waste water from extracting coal seam gas is often contaminated with salt, toxic or radioactive substances and heavy metals.

Recently there has been growth in the development of this gas associated with coal seams. Most (about 90%) of Queensland's gas supply is coal seam gas.

Australian coal seam gas resources (mainly methane) may be particularly useful as they are close to our major population centres along the east coast.

However, this proximity to population centres is making the mining of coal seam gases very controversial, and there is a great deal of opposition to its extraction. This is because of the noise and possible associated pollution. Coal seam gas has 20 times the global warming effect of carbon dioxide if it escapes to the atmosphere.

Shale oil and gas are fuels extracted from fine-grained sedimentary rocks (oil shale) which contain a solid mixture of organic compounds. Major deposits occur in the United States and Canada. There are also deposits in other countries including Australia.

There is controversy about the use of shale oil as it is presently more costly to extract than petroleum and its extraction involves fracking with multiple wells and has considerable environmental impact.

Figure 5.4 A block of shale oil and beaker of crude oil extracted from this type of rock.

QUESTIONS

1. (a) Outline how coal is formed.
   (b) Use the data in the table to help explain why black coal and anthracite are the most highly regarded forms of coal.

Factor	Peat	Brown coal	Black coal	Anthracite
Carbon content (%)	60	60 to 71	77 to 87	94
Average energy value (kJ kg^{-1})	16 000	23 000	36 000	35 000

2. (a) Explain why carbon, hydrogen, oxygen, sulfur and nitrogen are present in fossil fuels.
   (b) A sample of coal was analysed and found to contain 75% carbon, 10% ash, 8% oxygen, 5% hydrogen, 1.5% nitrogen and 0.5% sulfur. Use these figures to graph the composition of coal – use a pie or column graph.
   (c) Why would a line graph not be suitable to represent this information?
3. (a) Describe the range of compounds found in natural gas and include the structural formulas of the main components.
   (b) Use the information in the text to construct a pie graph to summarise the uses of energy produced from natural gas.
   (c) Outline three advantages of natural gas, as a source of fuel, over other fossil fuels.
   (d) Do you think it would be a good idea to replace all other fossil fuels with natural gas?
   (e) Research to find when natural gas was first used in Australia.
4. Liquefied petroleum gas (LPG) is a source of energy that is sometimes confused with natural gas. Compare the composition of liquefied petroleum gas to natural gas.
5. Research the elemental composition of crude oil.
6. (a) Justify the application of the term fossil fuel to petroleum.
   (b) Research the use of petroleum as a petrochemical feedstock.
7. (a) Explain why carbon dioxide is produced when fossil fuels are burnt to produce energy.
   (b) Define the term ‘non-renewable’.
   (c) Justify the use of the term non-renewable being applied to fossil fuels.
8. Decide whether each of the following statements is true or false and justify your decisions.
   (a) Natural gas is a compound.
   (b) Methane is a hydrocarbon.
   (c) Coal, oil, natural gas and metals come from the ground, so they are all fossil fuels.
9. (a) What is fracking?
   (b) Identify pros and cons of the use of this technique.
10. Use a diagram or tables to revise and summarise the carbon cycle.
11. Check your knowledge with this quick quiz.
    (a) Name three types of coal.
    (b) Identify the type of coal that is best for fuel.
    (c) Is coal formed mainly from plants or animals?
    (d) Identify the main use for coal in Australia.
    (e) Identify the original source of the chemical energy in coal.
    (f) Identify two geological processes that contribute to the formation of fossil fuels.
    (g) Name the main type of energy in fossil fuels.
    (h) Name the main component of coal.
    (i) Fossil fuels that we use cannot be replaced; we say they are a .... resource.
    (j) Identify the fossil fuel that produces the least carbon dioxide per unit of energy.
    (k) Identify the main compound in natural gas.
    (l) Name two chemicals, other than methane, that may be present in natural gas in small amounts.

6 Biofuels

Biofuels are produced from **biomass**, material that comes from living or recently living organisms, either plant or animal. The main types of biofuels in use are **biogas**, **bioethanol** and **biodiesel**.

The development of biofuels has been in response to concerns about:

- Pollution caused by the combustion of fossil fuels, especially by transport vehicles such as cars which are among the top emitters of greenhouse gases.
- Fears that supplies of fossil fuels are running out as they are a finite resource and non-renewable.
- Lack of availability of fuels at times of political unrest.
- Instability of world markets, the cost of importing fuel and its effect on inflation. In Australia we import petrol.

The first production of biofuels used sugar cane, corn and vegetable oils as **biomass**. These are sometimes called **first generation biofuels**. The sugars are extracted from these crops and then fermented by yeast to produce bioethanol. Biodiesel produced from vegetable oils is also considered a first generation biofuel.

Other **biomass sources** now being used as feedstocks, include waste residues from the production of crops such as sugar cane, corn, sorghum, grains such as wheat, sugar beets, olives and palm nuts. Wastes from the wood industry are also used. These crop residues are mostly cellulose which is more difficult to treat.

Garbage, **as well as animal waste** (including human waste) can be used to produce methane gas as a biofuel (called **biogas**). Animal fats and vegetable oils are used, including waste cooking oil, to produce biodiesel. Also **algae** are being cultivated and fermented to produce biomass for the production of biofuels.

Biofuels are renewable

Biofuels obviously have the advantage that they are **renewable**, whereas fossil fuels are non-renewable. They are renewable because we can replace them as they are used up. The use of fossil fuels for energy production is not sustainable as they are a finite resource – they will eventually run out and we cannot make new supplies.

Are biofuels carbon neutral?

Biofuels do **produce less carbon dioxide** overall than fossil fuels. This is because the amount of carbon dioxide released when they burn is the same as the amount absorbed by the plants (during photosynthesis) as they grow.

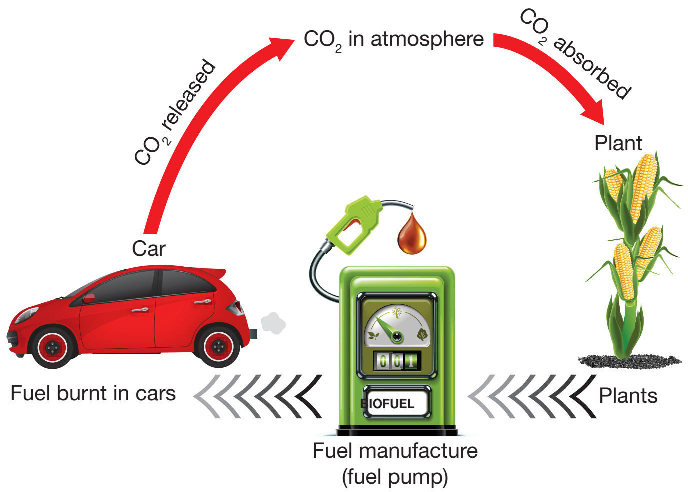


Figure 6.1 Carbon neutral.

Of course, fossil fuels such as coal were also once living plants using carbon dioxide to photosynthesise and grow, but that was millions of years ago. The carbon dioxide released when fossil fuels burn has been trapped in the coal or petroleum for millions of years. When biofuels burn they release carbon dioxide into the atmosphere which was only recently absorbed by the plants used to make them.

However, biofuels are **not carbon neutral** because fossil fuels are also used in their production, for example in the making of fertilisers and pesticides, for growing plants to produce biomass and for providing the energy for industrial processes, such as distillation, that are needed to produce the biofuel.

Disadvantages of biofuels

The production of biofuels such as bioethanol and biodiesel in large quantities is difficult because **sustainable and acceptable raw materials** and **affordable energy sources** for their production are not always available.

The use of food crops to produce biofuels contributes to **increases in food prices**. The production of crops such as corn and sugar in the United States and sugar in Brazil has increased by 30% to 50% over recent years. This might have been expected to stabilise food prices and help the thousands of hungry people throughout the world. However, this has not happened because these crops were grown not for food but for the production of biofuels.

Other issues associated with the use of crops to make fuels such as ethanol include the spread of **large scale commercial agriculture** and the spread of **monoculture**. This leads to a decrease in the diversity of species and also if an infection or insect pest attacks the crop, then the whole crop is more likely to be wiped out than if there is variation. These crops also tend to use a **large volume of water** in their production.

There is no doubt that we need to stop burning fossil fuels, but we must be careful that we do not choose alternatives with even worse problems.

Fuels from cellulose

The answer may lie in the production of **second generation biofuels** which are made from a wider variety of biomass types. This includes cellulose sources such as the non-food parts of crops, the waste from food production, human and animal waste, and industrial waste such as woodchips. **Cellulose** in many of these sources can be thought of as a potential source of sugars, which can be released by processes such as hydrolysis by enzymes, and then fermented to produce biofuels. The biofuels are extracted from the fermentation mix by distillation. This cellulosic biofuel is the fuel with lowest carbon emissions. Unfortunately, most of the production by this method so far has used corn or similar crops as the source of cellulose.

Research into the use of biomass wastes as a source of cellulose is ongoing. There are a number of processes that have been developed to break down such waste materials, but high cost and the disposal of waste products tend to be problems for their implementation.

Present use of biofuels

With present methods of production, biofuels can only be considered as a **supplement to petrol**, for example E10 petrol which contains 10% ethanol. It is not yet possible to manufacture nearly enough biofuel to replace the amount of petrol currently used in motor vehicles.

The three biggest producers and users of biofuels are China, Brazil and the USA, and many countries, including Australia, have established targets aimed at reducing their reliance on fossil fuels and increasing their consumption of biofuels such as ethanol and biodiesel, or using other sustainable and more environmentally friendly energy sources such as solar energy. The European Commission aimed to replace 10% of its transport fuels with renewable fuels by 2020, but this has now been reduced. Brazil already has 20% ethanol content of fuel and aims to increase this.

Current research and development projects on biofuels are focused on developing cost-competitive advanced technologies to convert wastes into fuels and producing fuels that are compatible with existing engines.

QUESTIONS

1. (a) Define 'biofuel' and name two examples of biofuels.
   (b) Outline three concerns that have led to the development of biofuels.
2. Biofuels are claimed to be 'carbon neutral'.
   (a) What is meant by this term?
   (b) Is it correct to describe biofuels as carbon neutral?
3. Biofuels are made from biomass.
   (a) What is meant by the term biomass?
   (b) Identify five sources of biomass used to produce biofuels.
4. Research and write a report about the production of a named biofuel in Australia and consider whether or not this is a sustainable practice.
5. Distinguish between first and second generation biofuels.
6. Why is the production of biofuels from cellulose more difficult than production from sugars?
7. The governments of several countries, including the United States of America and Canada have invested millions of dollars into research on the use of algae to manufacture biofuels.
   Research the use of algae to produce biofuels.
8. Global conferences in chemical engineering frequently include sessions that target the spread of up to date information about biofuels. Identify some examples of this.
9. Check your knowledge with this quick quiz.
   (a) Plant and animal matter from recently living organisms is used to make biofuels. What is this called?
   (b) Identify three possible sources of biomass.
   (c) Fuels made from biomass are collectively called ....
   (d) The three main biofuels are ...., ... and ....
   (e) Identify the three countries which are the biggest producers and users of biofuels.

7 Products Of Combustion

Some of the products of combustion of fossil fuels and biofuels are pollutants. Fossil fuels and biofuels all contain carbon and hydrogen so they release carbon dioxide, carbon monoxide and water as products of combustion. Most fuels contain sulfur and nitrogen so oxides of these elements are formed during combustion. Also, unburned particles and ash are formed.

Carbon dioxide is a colourless, odourless gas formed by complete combustion of carbon and carbon compounds. Large amounts of carbon dioxide are produced by power plants burning coal (mainly carbon), gas (mainly methane), by motor vehicles burning petrol (e.g. octane) and by burning biofuels (e.g. ethanol).

$C(s) + O_2(g) \rightarrow CO_2(g)$

$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$

$CH_4(g) + 2O_2 \rightarrow CO_2(g) + 2H_2O(l)$

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

Carbon dioxide is acidic. It is a major cause of the enhanced greenhouse effect and it also contributes to acid rain and acidification of rivers, lakes and oceans.

Carbon monoxide is a colourless, odourless gas produced by incomplete combustion when the oxygen supply is restricted, e.g. when a car is idling. It is toxic because it combines with haemoglobin in red blood cells in preference to oxygen, reducing the ability of blood to transport oxygen. The use of unflued heaters and barbecues inside homes where there is not a free flow of fresh air can cause carbon monoxide poisoning.

$2C_8H_{18}(l) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(l)$

$C_2H_5OH(l) + 2O_2(g) \rightarrow 2CO(g) + 3H_2O(g)$

$CH_4(g) + \frac{3}{2}O_2 \rightarrow CO(g) + 2H_2O(l)$

Carbon monoxide is not acidic, so it does not contribute to acid rain.

Sulfur dioxide is formed by the combustion of sulfur which is present in fossil fuels.

$S(s) + O_2(g) \rightarrow SO_2(g)$

Sulfur dioxide is one of the main causes of acid rain and it also causes respiratory problems such as asthma.

Australian black coal generally has low sulfur content, but unfortunately we export most of our high quality black coal, burning the inferior, polluting coal here.

Nitrogen oxides (e.g. NO and NO_2) are formed by the combustion of nitrogen in fuels and atmospheric nitrogen when fuels undergo combustion at high temperatures.

$N_2(g) + O_2(g) \rightarrow 2NO(g)$

$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Nitrogen oxides cause respiratory problems. Nitrogen dioxide is acidic and contributes to the formation of acid rain and photochemical smog.

Particulates are small particles, of solids (such as ash and carbon) and tiny droplets of liquids, that stay suspended in the air. Some coals contain up to 30% mineral matter (e.g. silicates and carbonates) which produces large amounts of ash when the fuel burns.

$2C_8H_{18}(l) + 19O_2(g) \rightarrow 6C(s) + 10CO_2(g) + 18H_2O(l)$

Particulates reduce visibility, cause respiratory problems, damage machinery and contribute to photochemical smog. Some are also carcinogens (cause cancer).

Figure 7.1 Photochemical smog over Sydney, NSW.

Additives in petrol can include a vast array of chemicals including antioxidants, stabilisers, antiknock agents, corrosion inhibitors, lubricants and fuel dyes, all of which can pollute the environment.

Reducing pollution

Steps taken to reduce pollution include the following.

1. **Ensure complete combustion**.
   - Adjust the carburettor/fuel injector of motor vehicles so there is a lean fuel/air mixture to increase engine fuel efficiency and thus reduce exhaust emissions.
   - Recirculate the exhaust to burn any fuel that was not burnt initially.
   - Use catalysts in the exhaust system to reduce the toxic pollutants emitted. Carbon monoxide and unburned hydrocarbons undergo complete combustion with the help of a catalyst and nitrogen oxides are reduced to nitrogen gas. Catalysts can also be used to remove nitric oxide by increasing the rate of its reaction with carbon monoxide.
     $2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)$
     Ensuring complete combustion not only produces less pollution it also results in more energy being produced per kilogram of fuel.

2. **Lower combustion temperatures** to prevent the formation of nitrogen oxides – use cooled air, and use multistage combustion.

3. **Remove pollution**.
   - Power stations use filtering devices and electrostatic precipitators to stop particulates being emitted into the atmosphere.
   - Water scrubbers are used to dissolve out carbon and sulfur oxides, e.g.
   - Carbon dioxide + water → carbonic acid
   - $CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$
   - Some industries find uses for waste products rather than releasing them into the environment. Sulfur dioxide is used to make sulfuric acid and carbon dioxide is used in fire extinguishers and to make soft drinks.

4. **Develop other less polluting energy sources** such as wind power, solar energy and tidal generators. Australia has the highest average solar radiation per square metre of any continent in the world. What do you think we should be developing as our main energy source in Australia?

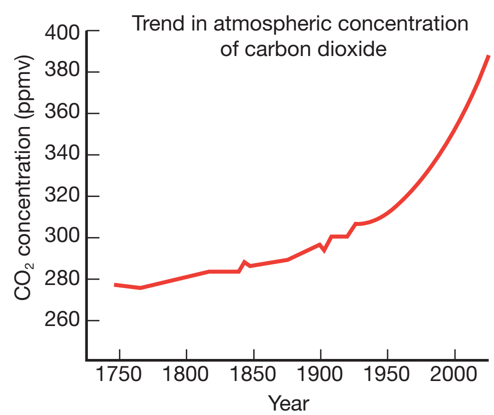
QUESTIONS

1. Write balanced equations to show the incomplete combustion of:
   (a) Methane to produce carbon monoxide and water.
   (b) Methane to produce carbon and water.
   (c) Propane to produce carbon and water.
2. Write equations to show the complete combustion of:
   (a) Butane. (b) Hexane.
3. Copy and complete the following table about the products of combustion of fossil fuels.

Name of product	Formula	Harmful effect
	CO_2	
		Toxic – preferentially combines with haemoglobin.
Particulates, e.g. carbon		
	NO and NO_2	
	SO_2	
Volatile organic compounds (VOCs)		

4. Research photochemical smog and answer the following questions about it.
   (a) Define photochemical smog.
   (b) What causes photochemical smog?
   (c) Account for the concern about photochemical smog.
   (d) What gives the brown tinge to photochemical smog?
   (e) When is photochemical smog most common?
5. Many countries recommend turning off your car's engine if you are stopped for longer than 10 to 60 seconds. Account for the presence of the following road sign placed outside a primary school.

6. For every litre of petrol used in a car, approximately 2.3 kilograms of carbon dioxide is produced.
   (a) If a car uses, on average, 40 L of petrol per week, calculate how much carbon dioxide this car would release in one year.
   (b) Calculate how much carbon dioxide your family produces per year and consider how you could reduce this.
7. Carbon dioxide is present naturally in the atmosphere. The graph below shows changes in atmospheric concentration of carbon dioxide over time.
   (a) Describe the trend shown by the graph.



   (b) Outline the main causes of this change in atmospheric carbon dioxide concentration.
8. Check your knowledge with this quick quiz.
   (a) Name a toxic gas that combines with haemoglobin in blood in preference to oxygen.
   (b) Identify a device used to remove small particles from exhaust gases.
   (c) Name a colourless, odourless gas produced by complete combustion of carbon-based fuels.
   (d) Name an acidic nitrogen oxide.
   (e) Name an acidic gas produced by combustion of sulfur present in coal.

Answers

1 Indicators Of Chemical Change

1. (a) The white of the egg has changed colour - from a colourless liquid to a white solid indicating a new substance has been produced by heating.
   (b) New substances have been produced, a gas is released during cooking. This gas causes the mixture to expand as bubbles are trapped within the cake as the liquid mixture forms new solid substances. The cooked cake does not look like the original mixture and you cannot separate out the components it was made from, e.g. eggs and flour.
   (c) A chemical reaction is taking place in two of the candles. The wax (hydrocarbon compounds) of the candle vapourises (a physical change) and then burns – this is a chemical change in which the hydrocarbons of the candle are converted to mainly carbon dioxide and water.
   (d) The nail is changing colour – a new brown substance (rust) is being formed, indicating a chemical reaction is taking place.
2. (a) Liquid water is disappearing and being replaced by two different gases. Oxygen gas forms at the positive electrode and hydrogen gas forms at the negative electrode. This is not a change of state, the gases are not water vapour, they are two new substances formed as the liquid water decomposes.
   $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
   (b) The copper carbonate undergoes a change of colour as it is heated, indicating a new substance is being formed. (Green copper(II) carbonate is being changed to copper(II) oxide which is black.) Also the bubbles indicate that a gas is being released and this is another indication of a new substance being formed and thus a chemical reaction taking place. In this case the gas would be carbon dioxide. $CuCO_3(s) \rightarrow CuO(s) + CO_2(g)$
   (c) A solid is produced when the two clear solutions mix together. The solid is red, the original solutions were yellow and colourless. The production of a solid and change in colour are indications that a new substance has formed and thus that a chemical reaction has taken place.
   (d) The colourless nitric acid has changed colour, indicating the formation of a new substance. Also, a brown gas is being released indicating the formation of a new substance. New substances are formed so a chemical reaction has taken place.
3. Various.
4. A chemical change occurs when a new substance is produced (atoms must have rearranged to form new particles). The formation of a new substance may be indicated by a change in colour, production of a gas, formation of a precipitate and/or the release or absorption of heat.
5. A change in temperature. A neutralisation reaction such as this is an exothermic reaction – heat is released to the environment so you could use a thermometer or probe to detect any change in temperature.

2 Models Of Chemical Reactions

1. (a) Various. For example, two molecules of hydrogen ($2H_2$) and and one molecule of oxygen (O_2) could be reacting to form two molecules of water ($2H_2O$).
   (b) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
   This is the combustion of methane.
   (c) The products are (in the order shown), sodium chloride, water and carbon dioxide.
   (d) $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$
2. The first equation illustrated an example of synthesis as two reactants combine to form one product. The second equation illustrates an example of decomposition as one reactant is forming two products.
3. (a) AB and CD could represent two soluble compounds in solution, when they are mixed, the atoms rearrange to form two new compounds, one of which is insoluble and so it precipitates out.
   (b) No, because water is formed in a neutralisation reaction, and neither of the products could represent H_2O.
4. The stable balance shown in this model indicates that when methane undergoes combustion the mass of the reactants equals the mass of the products. This can only happen if the atoms are conserved (stay the same) during the reaction. If the number and type of each type of atom stays the same, then the new products must be formed by rearrangement of the existing of atoms.
5. Various. Describe the reaction you carried out and include an equation. Describe how you modelled the reactants and products in this reaction. Did your model show that the same number of each type of atoms is present both before and after the reaction? Could you see clearly that atoms were being rearranged to form products? If both of these ideas were very clearly demonstrated by your model then you should state this – you must evaluate the success of your model in demonstrating these two concepts. If there were any problems, suggest how your model could be improved.

3 Synthesis and Decomposition

1. Indicators that a chemical reaction has occurred are:
   - Gas released (bubbling).
   - Change in colour.
   - Precipitate (solid) produced.
   - Change in energy – temperature change, light or sound released.
2. (a) Reactant: zinc sulfate ($ZnSO_4$); products: zinc oxide (ZnO) and sulfur trioxide (SO_3).
   (b) A gas is released – you would smell the sulfur dioxide being released. (Caution: Do not inhale sulfur dioxide.)
3. (a) Synthesis means substances joining to form a new substance, e.g. magnesium and oxygen joining to form magnesium oxide.
   Magnesium + oxygen → magnesium oxide
   $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
   Decomposition means splitting a compound into simpler substances, e.g. copper carbonate → copper oxide + carbon dioxide
   $CuCO_3(s) \rightarrow CuO(s) + CO_2(g)$
   (b) Heat, light, sound.
4. (a) Synthesis.
   (b) Decomposition.
   (c) Synthesis.
   (d) Decomposition.
   (e) Decomposition.
5. (a) Sodium + chlorine → sodium chloride
   $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$
   (b) Iron + sulfur → iron sulfide
   $Fe(s) + S(s) \rightarrow FeS(s)$
   (c) Carbon + oxygen → carbon monoxide
   $2C(s) + O_2(g) \rightarrow 2CO(g)$
   (d) Carbon + hydrogen → methane
   $C(s) + 2H_2(g) \rightarrow CH_4(g)$
6. There are many possible examples that could be used here. A couple of examples are outlined here. Discuss with your teacher the depth of answer required.
   (a) • The synthesis of ammonia from hydrogen and atmospheric nitrogen using the Haber-Bosch process.
   $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
   • The synthesis of sulfuric acid by the combustion of sulfur to form sulfur dioxide and then sulfur trioxide, followed by dissolving the sulfur trioxide in water to form dilute sulfuric acid.
   $S(s) + O_2(g) \rightarrow SO_2(g)$
   $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
   $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$
   (b) • Decomposition of iron oxide to produce iron (used to make steel) in a blast furnace.
   • Decomposition of stable compounds by electrolysis. For example, the electrolysis of the aluminium ore bauxite (Al_2O_3) to produce aluminium; the electrolysis of salt water to produce sodium hydroxide and chlorine; the electrolysis of molten sodium chloride in a Downs cell to produce sodium metal and chlorine gas.