Chemistry

Preliminary Course
Stage 6

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

Metals

Incorporating October 2002
AMENDMENTS

Acknowledgments

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- Board of Studies NSW 1999. *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

- NATCAP *The periodic table*, LMPC, OTEN 1994

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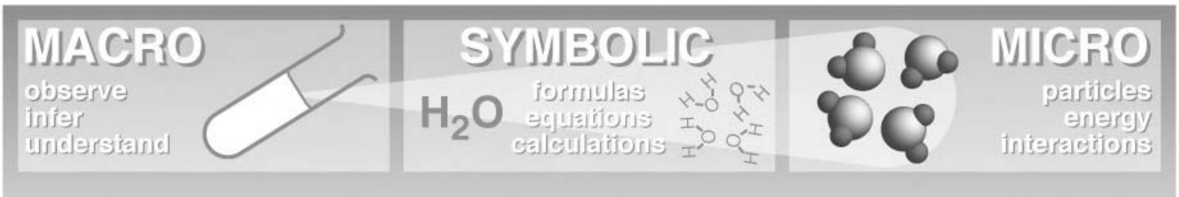
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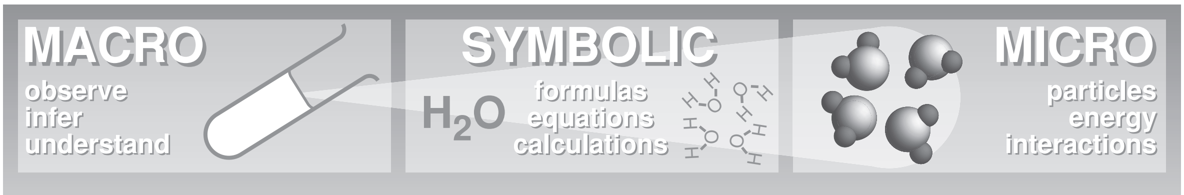

Module overview

The indented extracts below are from the *Chemistry Stage 6 Syllabus*. Board of Studies NSW 1999, Amended October 2002.

> 'The cultural development of humans has been closely connected with their discovery of materials and invention of tools to the point where major advances in cultural achievement have been described in terms of the materials they learned to use.'

Humans and their ancestors have used stone tools made from brittle minerals for about 2.5 million years. The shattering of brittle minerals such as flint produced sharp edges useful for cutting and weaponry. Sometimes tools could be repaired by breaking a new cutting edge but the brittleness often made the tools difficult to repair. Metals are malleable and so broken metal tools were more easily repaired and the metal recycled.

The Ages of human development – Stone, Bronze and Iron – have been named after the materials which provided the working edges of tools. The word chemistry may be derived from the Greek *chemica* meaning the art of metalworking. One view of human development considers humans to have changed from tool–making animals to chemical–using animals.

> 'This included their use of metals and discoveries of increasingly sophisticated methods of extraction of metals from their ores.'

Human use of fire as an energy source and the firing of clay shapes in kilns probably led to the discovery of ways of extracting metals from minerals. Clay shapes can be made more attractive and non–porous by covering the clay surface with glazes that are metal compounds. Early potters probably noticed small amounts of metal were formed from certain glazes when the pottery was fired at high temperatures and in reducing conditions with minimal air. Further investigations led to the development of more efficient ways of using kilns to change metal compounds to metals. Pottery kiln technology laid the foundations of metal ore smelter technology.

> ‘Because metals make up the majority of elements, an examination of the physical and chemical properties of metals is also an appropriate context in which to consider the organisation of the common Periodic Table. The development of a Periodic Table represented a breakthrough in the systematic organisation and study of chemistry and enabled scientists to predict the discovery of further elements.’

Ninety two of the 115 elements known today are metals. Mendeleev was not the first scientist to organise a seemingly unconnected mass of information into a Periodic Table based on the properties of elements. However Mendeleev was the first scientist to use a Periodic Table to predict the properties of unknown metals needed to fill gaps in the table. His 1869 predictions were confirmed in 1875 for gallium, 1879 for scandium and 1886 for germanium. This dramatically demonstrated the value of the Periodic Table as a tool for prediction in chemistry.

The emphasis in this module is on Prescribed Focus Areas 1, 3 and 5.

Indicative time

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

Resources

Materials and equipment you need to carry out activities are listed below. Access to a computer and the 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 actually carrying out the action. Make sure all the resources you need are available when you start an activity.

For Part 1 you will require:

- a packet of 50 to 100 Jaffas® (about 14 mm in diameter)
- larger Koolmints® or Koolfruits® (about 16 mm in diameter)
- smaller Jilamints® (about 10 mm in diameter)

- a small tray or lid to hold the lollies or 4 paper back books about 15–20 mm thick that could be arranged in a square to surround a layer of Jaffas®
- a rule

For Part 2 you will require:

- pieces of the three metals copper, iron and magnesium
- iron/steel wool to clean the three metal surfaces
- a wooden peg or metal tweezers to hold the metal pieces when you heat them
- a burner (gas Bunsen burner/methylated spirits burner/pencil torch burner) and matches see *Appendix 1* on using a pencil torch burner
- 3 transparent glass or plastic containers able to hold hot water
- 'white vinegar' that is colourless

For Part 4 you will require:

- copper(II) carbonate
- a burner (gas Bunsen burner/methylated spirits burner/pencil torch burner) and matches
- small heat resistant test tube or ignition tube
- wooden peg or test tube holder
- 'white vinegar' that is colourless
- glass beaker or transparent plastic container
- iron/steel wool

For Part 5 you will require:

- 20 cm length of magnesium ribbon
- steel wool or emery paper to clean the surface of the magnesium
- a balance weighing to 0.01 g
- a porcelain crucible and lid
- tongs for holding the crucible
- pipeclay triangle to fit the crucible
- tripod
- burner (Bunsen or pencil torch) and matches

Icons

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

You need to use a computer for this activity.

Listen to an audiotape.

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.

Additional resources

Lambert, J B. (1997.) *Traces of the Past – Unravelling the Secrets of Archaeology through Chemistry*. Perseus.

Tylecote, R F. (1992.) *A History of Metallurgy* Second edition. The Institute of Materials.

Raymond, R. (1984.) *Out of the Fiery Furnace*. Videotapes of the ABC TV series supplemented by this book 'Out of the Fiery Furnace' may be still available in many schools.

Hellemans and Bunch. (1988.) *The Timetables of Science*. Simon and Schuster.

Silver, B L. (1998.) *The Ascent of Science*. Oxford University Press.

Asimov, I. (1987.) *Asimov's New Guide to Science*. Penguin.

Elemental, a 3 CDROM set. Board of Studies NSW. Disc 1 visits the North Parkes mine; disc 2 covers minerals.

Chemical bonding: Inner forces, CDROM. VEA Multimedia. Windows 95 or later. Covers metallic substances and atomic theory.

Glossary

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

activity series	arrangement of metals from the most active to the least active
alchemy	chemistry 500–1500 years ago which sought to change base metals into gold, discover a universal solvent and an elixir of life
alloy	mixture of metal with other element(s) (usually another metal)
amalgam	alloy that includes mercury
anvil	heavy iron block with flat steel surface for hammering red hot or white hot metal
archaeology	scientific study of cultures especially by examining the remains of ancient cultures
atomic mass	mass of an atom; usually relative to the carbon–12 isotope taken as 12 exactly
atomic number	number of protons in the nucleus of an atom
atomic weight	average weight of atoms of an element in nature
Avogadro’s law	equal volumes of gases, at the same conditions of temperature and pressure, contain the same number of molecules
Avogadro’s number/constant	number of atoms in exactly 12 g of carbon–12; 6.02×10^{23}
balanced equation	chemical equation with same (balanced) number of each type of atom on both sides; if ions are in the equation the total electric charge on both sides must be the same (balanced)
brass	alloy of copper and zinc
bronze	alloy of copper and tin
Bronze Age	Age between Stone Age and Iron Age when most valued tools and weapons were made of bronze
charcoal	material produced by heating wood out of air; mainly contains carbon
chronology	order of past events in time

coke	substance produced by heating coal out of air; contains approximately 80% carbon
commercial	capable of being sold
corrosion	chemical change involving ionisation of metal atoms to ions
Dalton’s atomic theory	matter is made up of indivisible atoms; each element consists of identical atoms with the same atomic weights; in a reaction atoms are rearranged – not created or destroyed
diffuse	to spread
electrolytic	involving electrolysis, a chemical reaction caused by electrical energy
electronegativity	ability of a neutral atom to attract extra electrons
exothermic	reaction releasing energy
ferrous	iron–containing
flux	substance added to a mixture to lower the melting point and make the mixture flow
forge	fireplace or furnace in which metal is heated
formulae equation	balanced equation using neutral formulas for all reactants and all products
formula mass	the mass of all the atoms in a formula relative to the carbon–12 isotope’s mass taken as exactly 12
froth flotation	technique of separating minerals from ore using froth
furnace	place for burning fuel to generate heat
gangue	waste materials associated with an ore in a deposit
Gay–Lussac’s law	the volumes of gases in a reaction are always in a simple whole number ratio when measured at the same temperature and pressure
gilding	technique for giving a metal the appearance of gold
half equation	equation showing half of a reaction, either reduction or oxidation
ionic equation	balanced equation containing ions

ionisation	change of a neutral atom or molecule to a charged particle
ionisation energy	energy required to remove an electron from a gaseous atom, molecule or ion
Iron Age	Age between Bronze Age and the modern era when most valued implements were made of iron
isotopes	atoms of the same element; atoms with the same number of protons in the nucleus
kWh	kilowatt hours
mass number	number of protons and neutrons in the nucleus of an atom
matte	unfinished metallic product of smelting
metalloid	semi–metal
mineral	useful element or compound from the Earth
meteorite	rock from out of space that has reached the surface of the Earth
molar mass	mass of one mole of a substance
molar volume	volume of one mole of a substance
mole	the number of atoms in exactly 12 g of carbon–12
molecular formula	chemical formula showing the actual number of each type of atom in a molecule
molecular mass	the mass of all atoms in a molecule relative to carbon–12 isotope's mass taken as exactly 12
non–economic	not financially profitable
non–renewable	resource that is available in fixed amount and could be used up completely
ore	metal bearing substance eg. rock, from the Earth with a commercial value
oxidation	loss of electrons
oxidising conditions	conditions under which oxidation is likely; often an environment containing oxygen gas
quenching	rapid cooling of metal from high temperature
recycling	re–use of waste material
reducing conditions	conditions under which reduction is likely; often an environment containing carbon or carbon monoxide gas

reduction	gain of electrons
refinery	establishment where a substance is purified
slag	waste matter separated from metal during reduction of an ore
smelter	place where ore is heated to separate metal
solder	alloy usually of lead and tin
steel	iron containing 0.1–1.5% carbon
stoichiometry	quantitative relationships in chemical reactions
Stone Age	time before the Bronze Age when most valued implements were made of stone
sublimes	solid changes directly to gas phase without going through liquid phase
thought experiment	thinking your way through a situation without actually doing anything physical
trend	gradual change
visualising	forming mental images or pictures
yield	in a chemical reaction or series of reactions the ratio of the amount of product actually formed to that theoretically possible; usually expressed as a percentage yield

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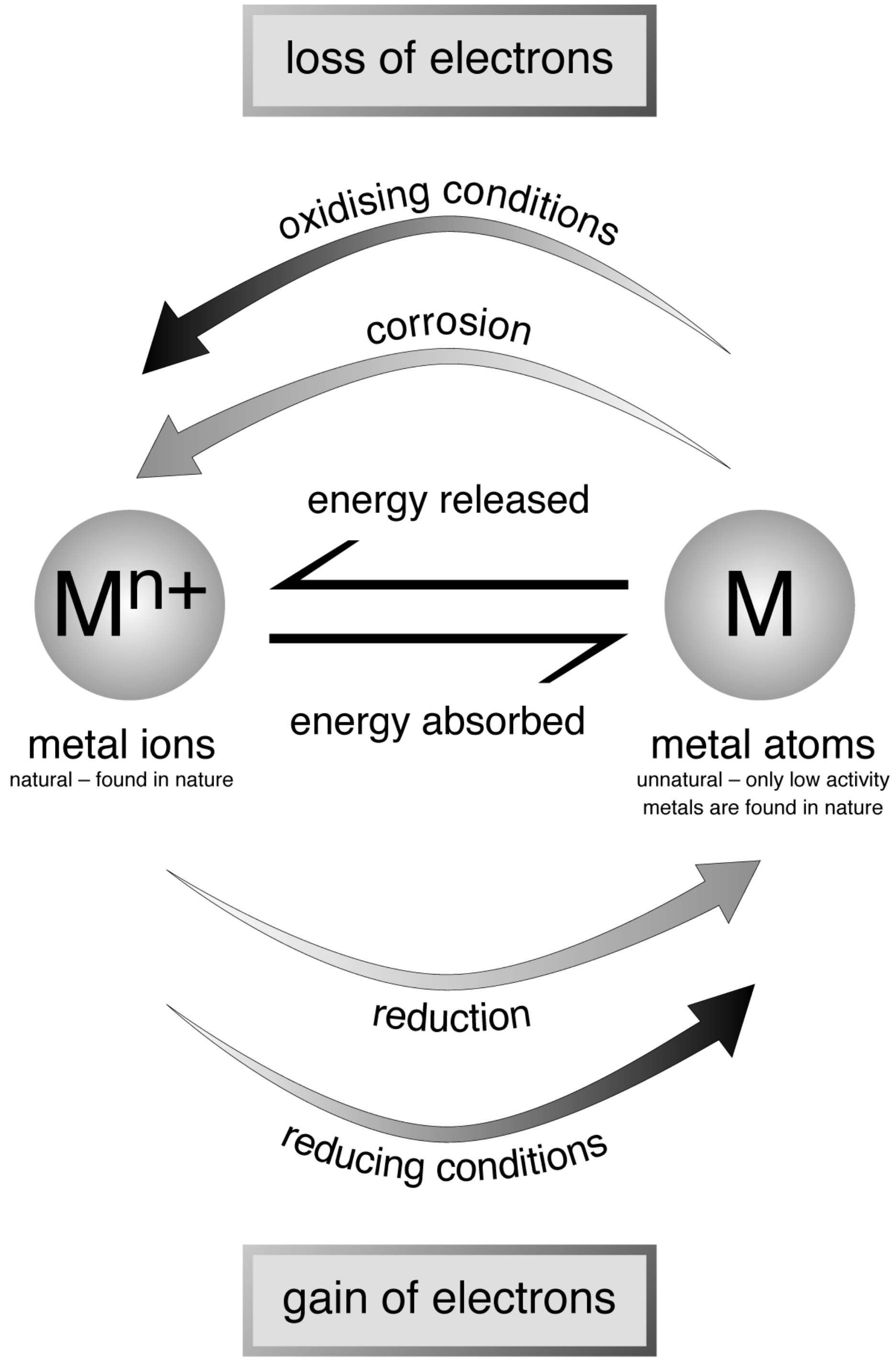
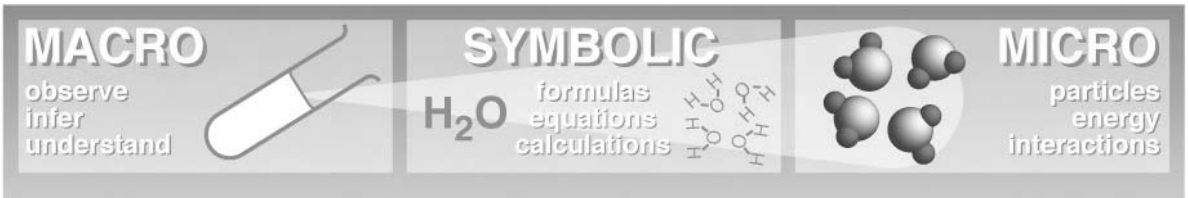
NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING
OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

Metals

Part 1: Metal extraction and uses

Incorporating October 2002
AMENDMENTS


loss of electrons
oxidising conditions
corrosion
energy released
M^{n+}
M
energy absorbed
metal ions
natural – found in nature
metal atoms
unnatural – only low activity metals are found in nature
reduction
reducing conditions
gain of electrons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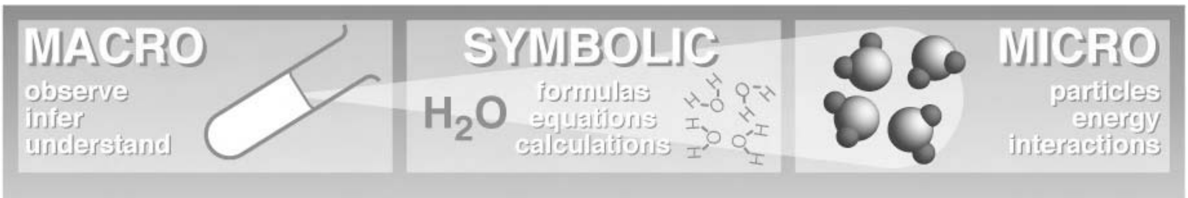


Introduction

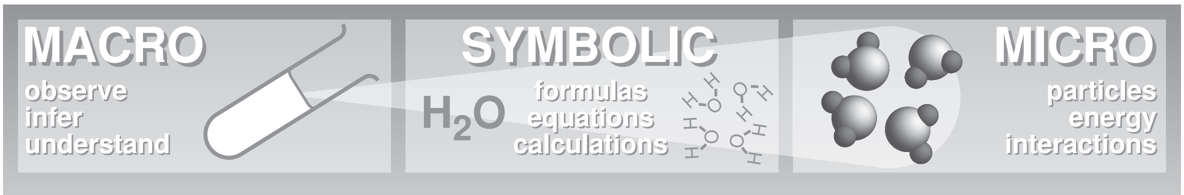
In Part 1 you will learn how metals have been extracted and used for many thousands of years.

In this part you will be given opportunities to learn to:

- outline and examine some uses of different metals through history, including contemporary uses, as uncombined metals or as alloys
- describe the use of common alloys including steel, brass and solder and explain how these relate to their properties
- explain why energy input is necessary to extract a metal from its ore
- identify why there are more metals available for people to use now than there were 200 years ago.

In this part you will be given opportunities to:

- gather, process, analyse and present information from secondary sources on the range of alloys produced and the reasons for the production and use of these alloys
- analyse information to relate the chronology of the Bronze Age, the Iron Age and the modern era and possible future developments.



Metal extraction and uses

Read through the information provided in **chronological** order (in order of time). Use this table to answer the questions that follow.

The approximate dates given are before present (BP) dates in years.
2000 BP means 2000 years before present time and is about 0 AD.
10 000 BP is about 8 000 BC.

- 2 500 000 BP Human ancestors using stone tools.

  Stone tools were made by chipping or flaking brittle minerals eg flint or volcanic rocks eg. obsidian.

  Can you understand why humans are often defined as 'toolmaking animals'?

- 1 000 000 BP Use of fire by human ancestors.
- 100 000 BP Use of fire to make food more digestible by breaking down protein structure and making starch more soluble.

  a) A tool can be defined as something used to do work. Explain why fire can be considered a tool:

  ____

  ____

  ____

- 20 000 BP Clay objects baked by heating in campfires
- 15 000–12 000 BP End of the last Ice Age.
- 10 000 BP Pins and beads made from hammered native copper; hammering makes the copper harder.

  Native metals are unreactive metals found as the element in nature eg gold, copper, silver, **meteorite** iron, electrum (natural alloy of silver and gold). Other metals are locked up as parts of compounds, usually oxides or sulfides, invisible in rocks.

  Unlike stone and wood, metal can be bent and shaped, reused and repaired easily. Metals often have attractive lustre and colours.

b) Explain why humans 10 000 years ago could be attracted to investigate any metal that they saw in nature:

____

____

- 10 000 BP Pottery made from the same clay is found in red form Fe_2O_3 (oxidising conditions) and black form Fe_3O_4 (reducing conditions).

  Smelting of a metal compound to the metal requires temperatures higher than a campfire (600 – 700°C) such as in a pottery kiln (1000°C). Reducing conditions are required to change the metal ions of the compound to metal atoms. To obtain reducing conditions the kiln would need to be blocked up, smoky and full of carbon monoxide (CO) gas or carbon (C). Pottery makers using metal oxides in glazes (fired on the outside of pots, to decorate and make the pottery waterproof) probably noticed globules of metal forming in the reducing conditions.

  Can you imagine how important careful observations, inferences, curiosity and trying out ideas through experiments could have been in the development of new materials? The people carrying out these activities would have applied methods that are called scientific methods today.

  c) Describe how metal could accidentally be formed inside a pottery kiln:

  ____

  ____

  ____

- 5 000 BP Copper ore mining and smelting in the Sinai desert between Israel and Egypt.

  Soft copper could be hammered and heated (work hardening) to stop cracking thus producing cutting tools and weapons. These tools and weapons gave human groups power to dominate other groups.

  Copper and arsenic ores found together in some locations produced Cu/As mixtures. Mixtures melt at lower temperatures than pure substances eg Cu MP 1085°C. Cu/As was a type of bronze alloy, harder than pure copper and able to be produced at a lower temperature.

  d) Using your knowledge of elements, compounds and mixtures from the first module explain why the properties of an alloy vary:

  ____

  ____

- 4000 BP Copper and tin (Cu/Sn) bronzes were the next development. Tin oxide, like gold, can be separated from river sands by panning and dredging. Reaction of tin (IV) oxide, SnO_2, with hot charcoal produces tin.

  e) Poisonous arsenic **sublimes** at 613°C. Why do you think Cu/Sn bronzes replaced Cu/As bronzes?

  ____

  ____

  ____

  Iron oxide used as a **flux** in copper smelting can form small pieces of iron mixed with **slag**. If this material called bloom is hammered the slag is driven out and wrought iron forms.

  Iron has a MP of 1535°C, a temperature beyond the reach of most kilns and smelters. Pure iron was not as hard as bronze.

- 3500 BP The Hittites of Anatolia (present day Turkey) heated iron bloom in charcoal at 800-1200°C. The carbon of the charcoal diffused into the iron and formed steel. 0.3% C iron was as hard as bronze while 1.2% C iron was harder than the hardest bronze.
- 2500 BP Iron casting in moulds developed in China. Better kiln design and better bellows to pump air into the smelter enabled them to cast an Fe/4%C alloy which flowed at 1150°C.
- 2500 BP In India the Wootz method of making iron in crucibles is developed. This method distributes carbon evenly throughout the steels . Other well known steels made much later using a crucible method included Damascus steel swords, Toledo steel swords and Sheffield steel cutlery.

  f) The diagram on the next page summarises various ways of making steel developed in three different places.

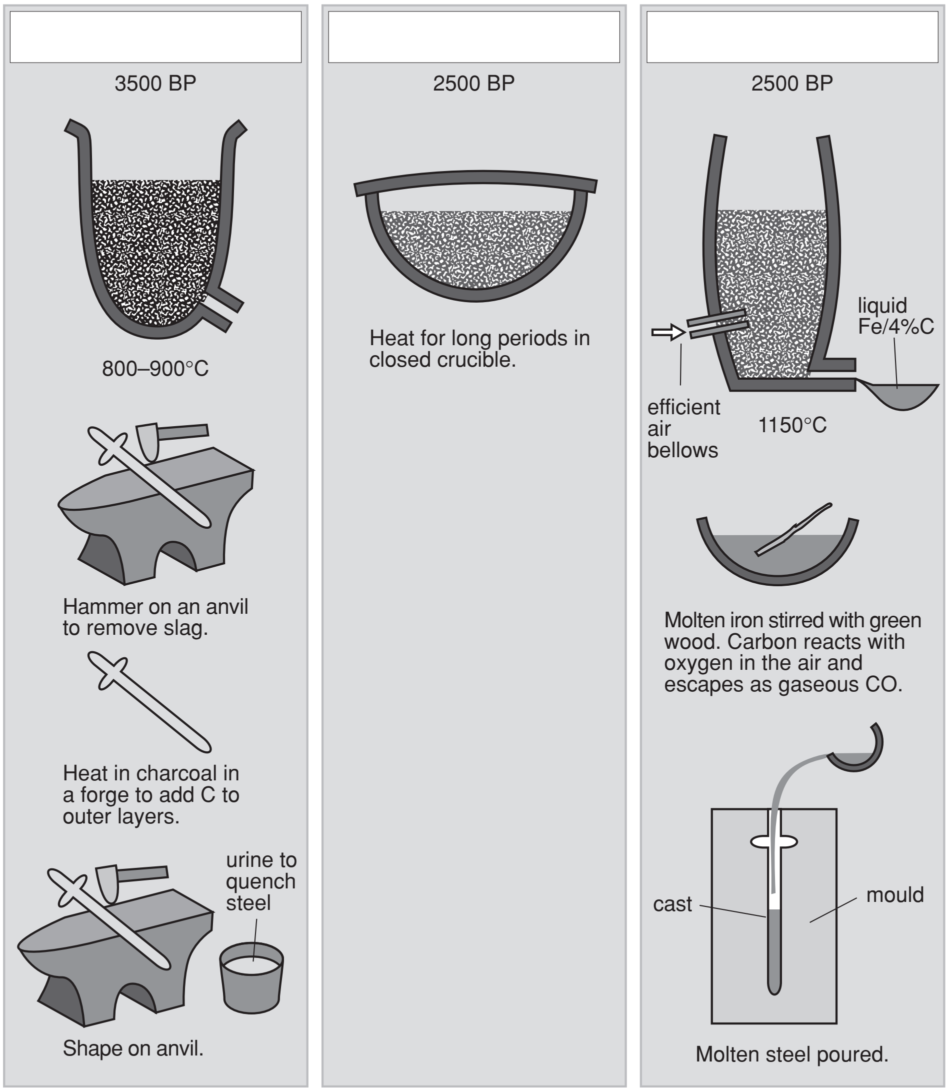
  After looking at the diagram label each location labels in the appropriate heading box. (East Asia; Europe and West Asia; South Asia)

Check your answers.

The terms **Stone Age**, **Bronze Age** and **Iron Age** were developed about 150 years ago to describe the chronology of human development.
This is an artificial division as illustrated by the fact that bronze tools were used for thousands of years after the introduction of iron tools.

Until recently different societies in different parts of the world could be found using all stone tools, all bronze tools or all iron tools at the same time. Even today in modern societies it is possible to buy stone ground flour and grinding stones for sharpening blades.

Three ways of making steel by heating iron oxide with charcoal



Summary

Using the information you have just read complete this metal timeline:

Time (years BP)	Development
2 500 000	human ancestors using stone tools
1 000 000	fire
	cooking
	baked clay
	hammered native copper
	pottery made under oxidising and reducing conditions
5000	smelting of copper ores and lead ores
	Cu/Sn bronze
	iron made from bloom
3000	tin, mercury
	casting of molten iron, crucible iron
2000	Cu/Zn brass

Check your answers.

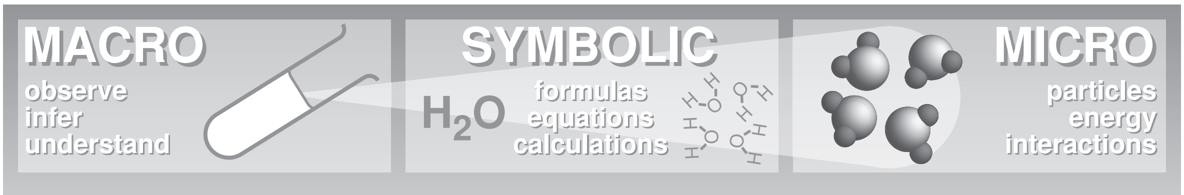
Developments in metal technology in the last 2000 years from Roman times until the present modern era can be more accurately dated. The dates used from here on are AD years:

0 –400 AD — Romans used gold, silver, iron, copper, lead, tin, zinc and mercury. Extensive use of metals in engineering and metal coins.

900 — Arabian **alchemy**. Alchemists searched for ways to change readily available metals ('base' metals) into gold. This search led to the discovery of useful chemical techniques such as distillation and substances such as strong acids.

1040	Chinese use gunpowder in rockets. The use of gunpowder in warfare stimulated metal technology as metalworkers tried to make cannons capable of withstanding explosions.
1340	First European furnace producing cast iron.
1440	Gutenberg, an ex-metalworker, develops suitable alloys for movable type in printing presses.
1520	First book published on assaying (analysing) metals.
1603	Coke first made by heating coal out of contact with air.
1700s	Industrial revolution in Europe. Demand for iron and steel to make machines to use the energy released by burning coal. Lavoisier puts together a scientific, quantitative view of chemistry.
1800s	Discovery of many new elements as electrical energy from batteries and new analytical techniques are developed. Methods of minimising **corrosion** develop such as galvanising with zinc and painting. Expanding use of electrical energy increases demand for copper and magnetic metals (iron, cobalt and nickel).
1900s	Special steels such as stainless steels were developed using chromium and nickel. Aluminium use increases as electrical energy needed to make it becomes cheaper. Uranium used as an energy source in nuclear reactors. Titanium and magnesium used for lightweight alloys.

2000s Can you find out about a new use for a metal in the modern era? In the next month if you read, hear or see of a new use for a metal in the media (newspapers, magazines, radio, TV.) Record what you have learnt in the space below.



Metals and alloys

An alloy is a mixture with metallic properties. It is composed of two or more elements, one of which must be a metal. You already probably know the names of many alloys such as bronze, brass, solder and steel.

It is unusual to find objects made of pure metal. Pure gold is 24 carat but is extremely rare in jewellery because it is too soft. Gold jewellery is more often 18 carat (18/24) or 9 carat. Similarly, aluminium window and door frames contain a small percentage of copper to harden the aluminium.

Complete the table below.

Alloy	**Uses**	**Elements present**	**Names of metals present**	**Names of non-metals present**
bronze	ship propeller	Cu, Sn		
solder	joining metals	Pb, Sn		
brass	brass band instruments	Cu, Zn		
steel	structures	Fe, C		
dental **amalgam**	filling ________ cavities	Hg, Sn, Ag, Cu		
cupro-nickel	Australian 5,__,20 & 50 cent coins	Cu, Ni		
'goldish' coin	one dollar and ___ dollar coins	Cu, Al, Ni		
stainless steel	corrosion resistant steel	Fe, Cr, Ni, C		
duralumin	aluminium frames, aircraft bodies	Al, Cu, Mg, Mn		

Properties and uses of alloys

There are many different alloys. Different proportions of the elements in the alloys can produce very different properties.

Bronze and **brass** are similar in appearance. Bronze was first made about 4000 years ago at the beginning of the Bronze Age from copper and tin and is a slightly red or orange yellow colour. Brass is made from copper and zinc and is a brighter yellow as seen in brass handrails, doorknobs and brass band musical instruments.

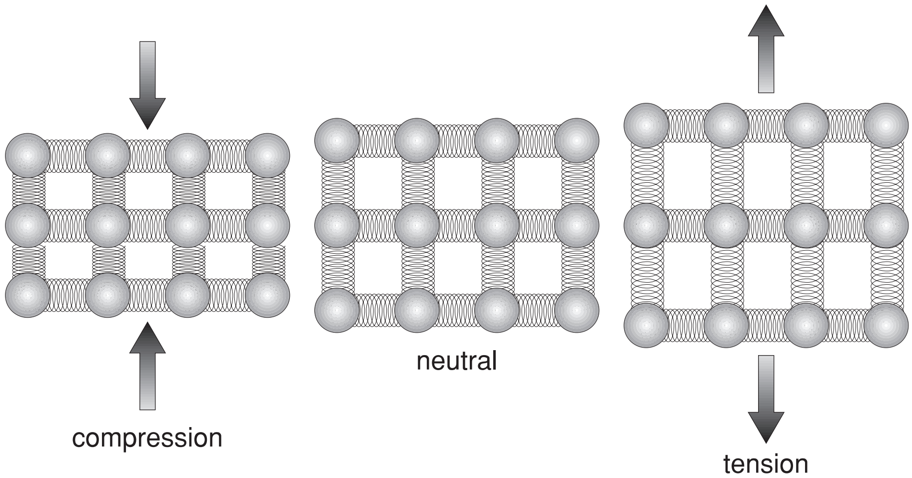
Plumber's solder 70% Pb/ 30% Sn by mass takes a long time to solidify and provides time for making sure joined metal pipes are lined up. Electrician's solder 40% Pb/ 60% Sn by mass solidifies quickly so less heat is released that could damage electrical components.

Steel % carbon	Uses
0.1	automobile bodies
0.2	building structures
0.4	engine parts
0.7	tools
1.0	knives

Visualising metal structure

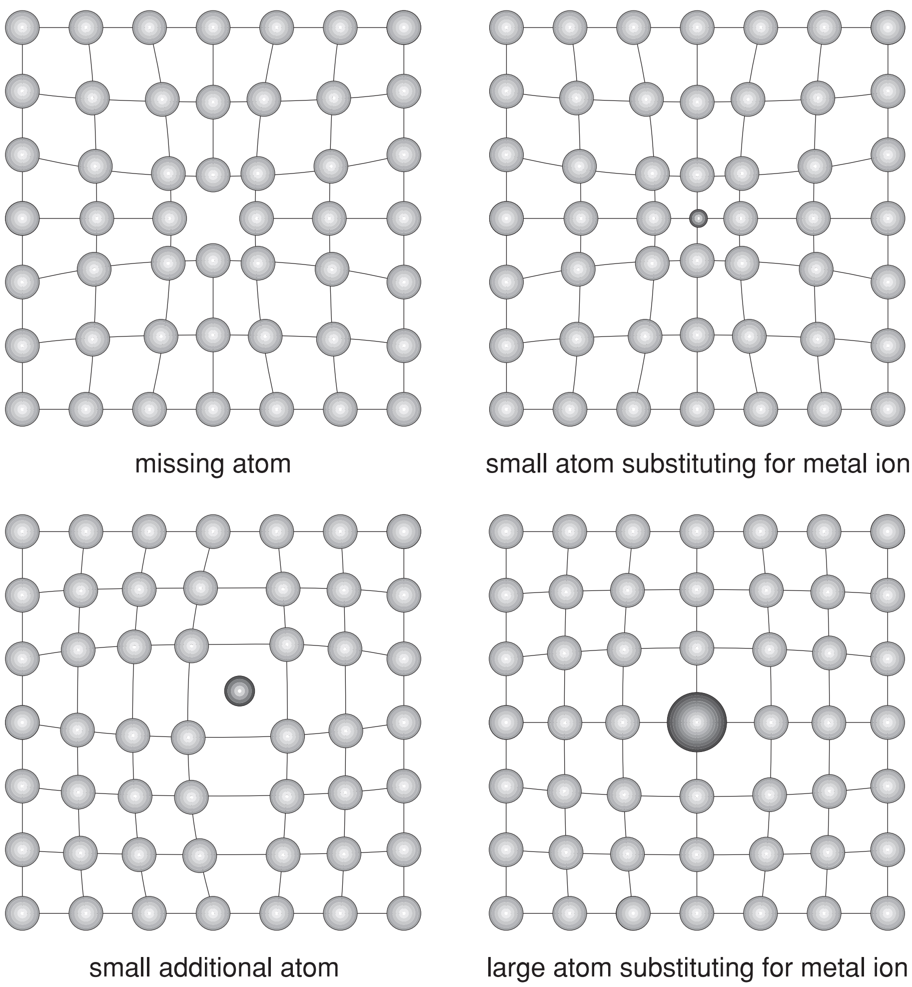
In the first module, *The Chemical Earth*, you compared two models for metals. The simplest model was the metallic lattice model where the metal was visualised as regularly arranged balls. The metallic bond model where you visualised cations in a sea of delocalised electrons was more useful. This model could explain physical properties such as conductivity and malleability.

Another way of visualising metal structure is by imagining the effects of stretching forces (tension) and compressing forces (compression).
This is the spring model. The atoms are imagined to be joined by springs representing metallic bonds.



Like many models this can be misleading. Metallic bonds act in all directions, not in the fixed directions suggested by this model. Models are useful for visualising but they all have limitations. Models represent the situation but not perfectly.

A net-like model is useful for understanding the effect of defects, impurities and alloying on metal structure.



It is rare for one scientific model to provide satisfactory explanations for all properties. Using a variety of models can stimulate and enhance the imagination of scientists and increase the accuracy of predictions. These predictions can often be tested and used to improve models and visualisation of matter.

In the next activity you will use the metallic lattice model to help understand why alloys containing a small amount of second metal are so much harder than a pure metal.

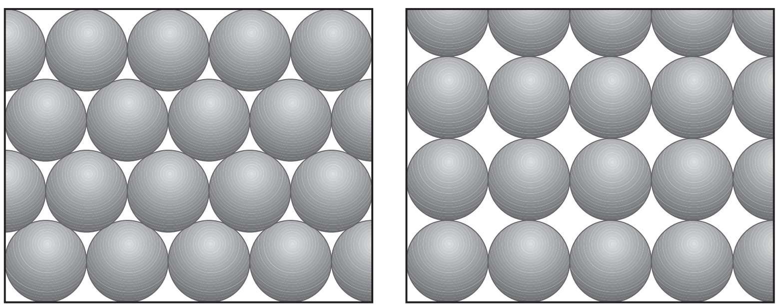
Modelling an alloy using different sized round lollies

You will need:

- A packet of 50 to 100 Jaffas® (about 14 mm in diameter)
- A packet of larger Koolmints® or Koolfruits® (about 16 mm in diameter)
- A packet of smaller Jilamints® (about 10 mm in diameter).
- A small tray or lid to hold the lollies or 4 paper back books about 15–20 mm thick that could be arranged in a square to surround a layer of Jaffas®
- A rule

Method:

1 Pour Jaffas® into the tray to form a lower layer of closest packed atoms. Each Jaffa (atom) should be surrounded by and almost touching six others. This arrangement is called hexagonal closest packing and is shown on the left in the diagram below.



Compare the number of atoms in each diagram of the same size.
Then compare the amount of space left between atoms in both diagrams.
If the atoms were arranged in rows and columns as shown on the right of the diagram each atom would touch __ others in the same layer
This arrangement would not be closest packing as it takes up more room.

2 Place a single Jaffa® (atom) on top of the lower layer. How many atoms in the lower layer are touching this single Jaffa® (atom)?

____

3 Now you will do a **thought experiment**! Just think your way through a situation without actually doing anything physical. Imagine that a complete layer like the bottom layer was above this single Jaffa® (atom). How many atoms in this imaginary upper layer would be touching the single Jaffa® (atom)? ____

4 When the atoms in layers are closest packed each atom has 6 (own layer)+ __ (bottom layer) + __(upper layer) = 12 nearest neighbours. Many metals have this closest packed arrangement with each atom surrounded by 12 nearest neighbour atoms.

5 Cover half of the bottom layer with atoms that are closest packed. The second layer atoms fit (on top of the atoms in the bottom layer/ in the spaces between atoms in the bottom layer). [cross out the wrong answer].

Check your answers.

6 Place the rule up against the second layer. Push the second layer over the bottom layer at a low speed.

7 Now replace three of the Jaffas in the exposed bottom layer with larger Koolmints® or Koolfruits®. Repeat Step 6. What difference could you feel? ____

8 Now replace the three large Koolmints® with three small Jilamints® in the exposed bottom layer. Repeat Step 6. What difference could you feel? ____

Conclusion:

1 Does replacing some atoms in a metal structure with different sized atoms make it easier or harder for atoms to move over one another? Would the alloy produced be harder or softer than the pure metal?

____

2 Sterling silver is an alloy of silver atoms (diameter 289 pm) and copper atoms (diameter 256 pm). (1 pm = 10^{-12} m) Why do you think sterling silver is harder than pure copper or pure silver?

____

____

3 Alloys are generally harder but less malleable than the metals from which they are made. Use the diagrams on the next page to explain why an alloy is less malleable than the pure metal.

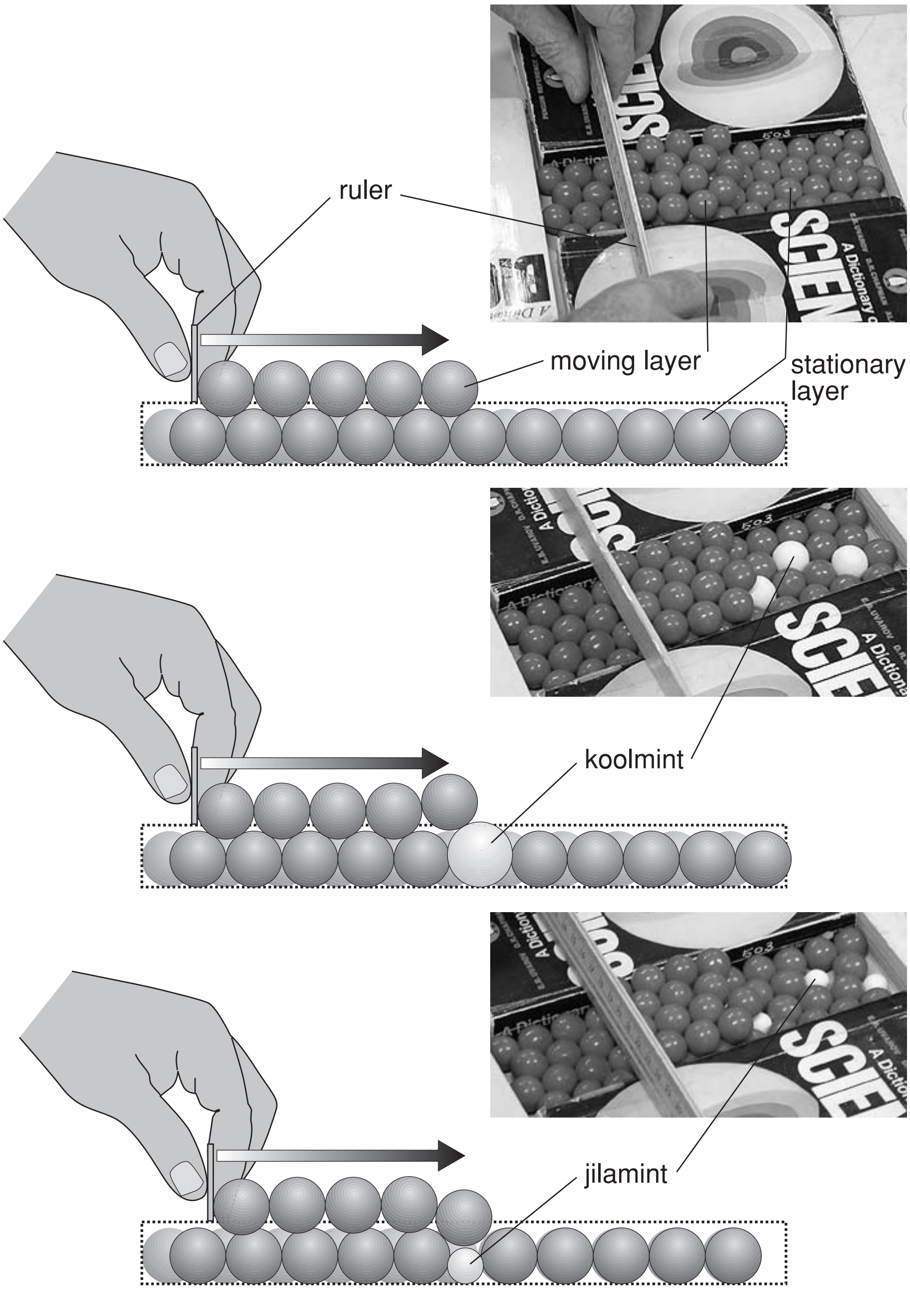
____

4 Why do you think alloys are usually poorer electrical conductors than the metals from which they are made? Choose a model to explain this observation.

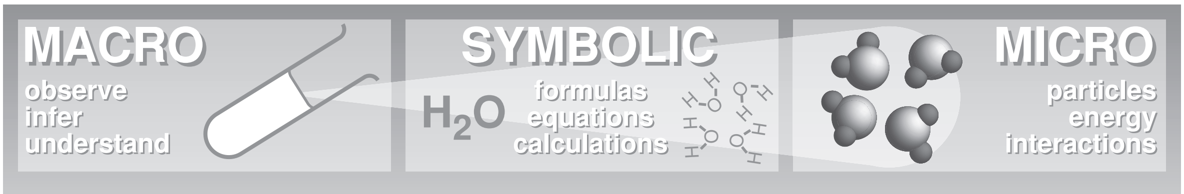
____

____

Check your answers.



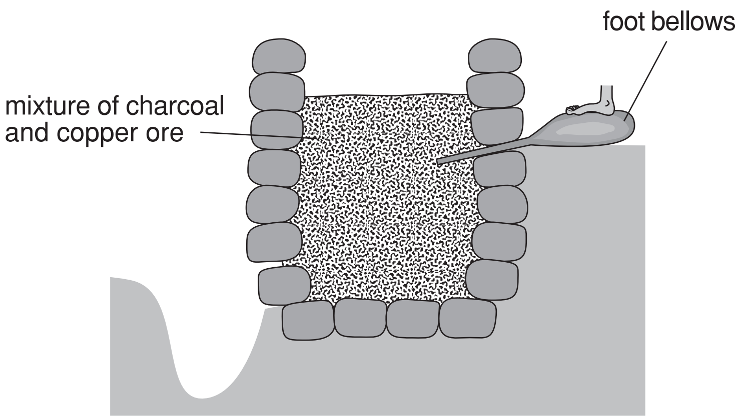
Using lollies to visualise the structure of alloys.



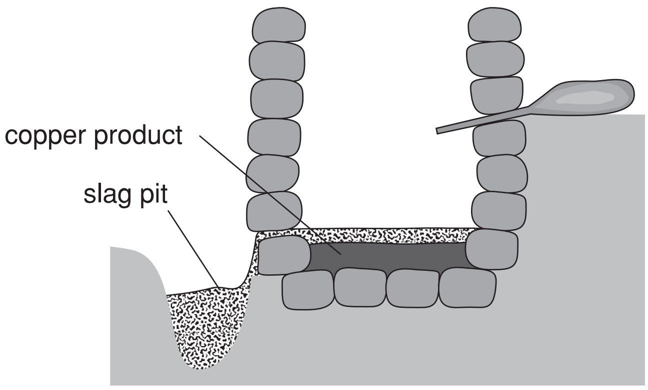
Equation construction from observations

Ancient paintings in a tomb near the Valley of the Kings at Luxor, Egypt depict the melting of copper to cast temple doors. The paintings provide detail such as furnaces blown by bellows to increase the oxygen supply and raise the temperature. Other archaeological observations have helped develop theories on how ancient groups extracted metal from ore. Such a theory is best tested by scientists going to a site and trying out their ideas using only local materials.

In the early 1980s a group from the London Institute for Archaeo-Metallurgical Studies trialled their ideas in the Sinai desert. They copied a furnace which had been excavated nearby in the 1970s. The type of furnace built is shown below:



At the end of the firing the furnace looked like this:



At the beginning of the experiment the furnace was filled with a mixture of green malachite ore, charcoal and iron ore flux. Oxygen in the air was pumped into the kiln with bellows to burn the charcoal. This provided heat which decomposed the malachite to copper (II) oxide.

$$CuCO_3.Cu(OH)_2 \rightarrow 2CuO + CO_2 + H_2O$$

In this exercise you will construct balanced equations in symbols from observations.

1 The rate of disappearance of hot charcoal increased as the bellows pumped in air. Carbon monoxide formed from carbon in charcoal and oxygen in air. Write a balanced equation for this reaction.

2 Two substances able to reduce the copper (II) ions Cu^{2+} in copper(II) oxide to copper atoms were present in the furnace – carbon monoxide and carbon.

Carbon monoxide reduces the copper (II) oxide formed to copper metal. The carbon monoxide changes to carbon dioxide. Write down the formulas of the two reactants then the formulas of the two products. Complete the equation and make sure it is balanced.

3 Hot carbon can also reduce the copper (II) oxide forming copper metal and carbon dioxide. Complete the equation for this reaction making sure it is balanced.

4 Both of the two previous equations occur at temperatures high enough to produce liquid copper. Liquid copper could be run off into a mould and cast. Insert (s), (l) and (g) after each of the reactants and products in these two equations to indicate the state of each substances.

5 Iron oxide flux reacted with silica to form iron silicate slag.

$$FeO + SiO_2 \rightarrow FeSiO_3$$

The molten slag floated on top of the molten copper at the bottom of the furnace. Why didn't the molten copper float on the slag instead?

6 Explain why heat energy was required to extract copper metal atoms from the copper metal ions in the ore. The diagram below might help you to decide what to write.

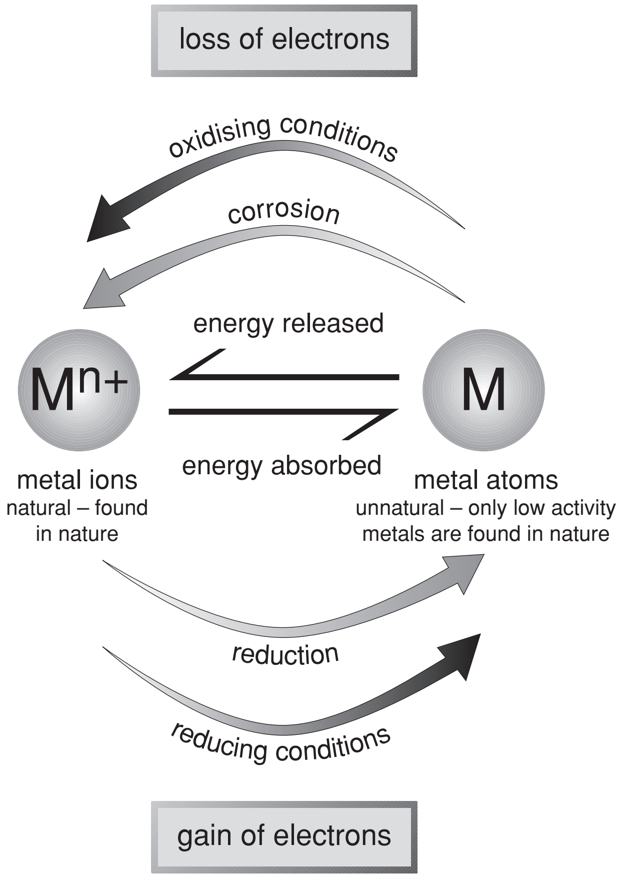
____

____

____

____

Check your answers.



Energy is required to produce metals.

Only a small amount of copper was made during this experiment in the Sinai desert. The observations made on site supported the theory on how the Egyptians made copper. Further experiments and observations would probably have enabled the archaeologists to work out more efficient ways of making metal, the way ancient metal workers had, thousands of years before.

Suggested answers

Metal extraction and uses

a) Fire can be considered a tool because humans have used fire to do work eg make food more digestible, make clay objects into pottery, make metals.

b) Metals are unusual in nature. The unusual appearance, lustre and colour in the case of gold and copper would have interested curious people.

c) Metal could accidentally form in the high temperatures of a pottery kiln. Metal oxides or carbonates decorating the outside of the kiln could react with carbon monoxide or carbon forming metal.

d) Alloys are mixtures. The proportions of the elements in the mixture can vary. This causes the properties of the mixture to vary.

e) Workers operating smelters heating copper and arsenic ores would have been poisoned by escaping arsenic gas.

f) Europe and West Asia South Asia East Asia

Summary

Time (years BP)	Development
2 500 000	human ancestors using stone tools
1 000 000	fire
100 000	cooking
20 000	baked clay
10 000	hammered native copper
10 000	pottery made under oxidising and reducing conditions

5000	smelting of copper ores and lead ores
4000	Cu/Sn bronze
3500	iron made from bloom
3000	tin, mercury
2500	casting of molten iron, crucible iron
2000	Cu/Zn brass

Alloys

Alloy	**Uses**	**Elements present**	**Names of metals present**	**Names of non-metals present**
bronze	ship propeller	Cu, Sn	copper, tin	
solder	joining metals	Pb, Sn	lead, tin	
brass	brass band instruments	Cu, Zn	copper, zinc	
steel	structures	Fe, C	iron	carbon
dental **amalgam**	filling dental cavities	Hg, Sn, Ag, Cu	mercury, tin, silver, copper	
cupro-nickel	Australian 5,10,20 & 50 cent coins	Cu, Ni	copper, nickel	
'goldish' coin	one dollar and two dollar coins	Cu, Al, Ni	copper aluminium, nickel	
stainless steel	corrosion resistant steel	Fe, Cr, Ni, C	iron, chromium, nickel	carbon
duralumin	aluminium frames, aircraft bodies	Al, Cu, Mg, Mn	aluminium, copper, magnesium, manganese	

Method

1. If the atoms were arranged in rows and columns like the right diagram each atom would touch four others.
2. There are three atoms in the lower layer touching a single Jaffa® (atom).
3. Three atoms would be touching the upper layer.
4. 6 (own layer)+ 3 (bottom layer) + 3 (upper layer) = 12 nearest neighbours
5. The second layer atoms fit in the spaces between atoms in the bottom layer.

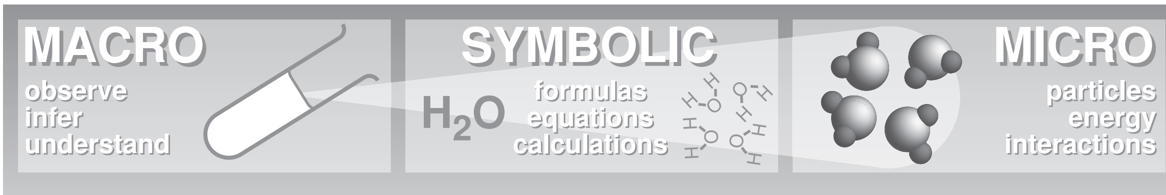
Conclusions

1. The alloy produced would be harder.
2. Layers of mixed sized atoms would require more energy to move over one another.
3. More energy is needed to move atoms over layers containing mixed sized atoms.
4. Choosing the metallic bond model which pictures the metal as made up of cations and delocalised electrons. Delocalised electrons would find it more difficult to move past different sized atoms in alloys.

Equation construction from observations

1. $2C + O_2 \rightarrow 2CO$
2. $CO + CuO \rightarrow Cu + CO_2$
3. $C + 2CuO \rightarrow 2Cu + CO_2$
4. $CO_{(g)} + CuO_{(s)} \rightarrow Cu_{(l)} + CO_{2(g)}$

   $C_{(s)} + 2CuO_{(s)} \rightarrow 2Cu_{(l)} + CO_{2(g)}$
5. Molten copper is denser than molten slag so the molten slag will float on the molten copper.
6. Heat energy was required to extract copper metal atoms from the copper metal ions because energy is required to:
   - separate the positive copper ions from the negative oxide ions (overcome attraction between oppositely charged ions)
   - have the C or CO transfer electrons on to the copper ions and change them to copper atoms.



Exercises – Part 1

Exercises 1.1 to 1.2 Name: ________________________________

Exercise 1.1: Alloy properties and uses

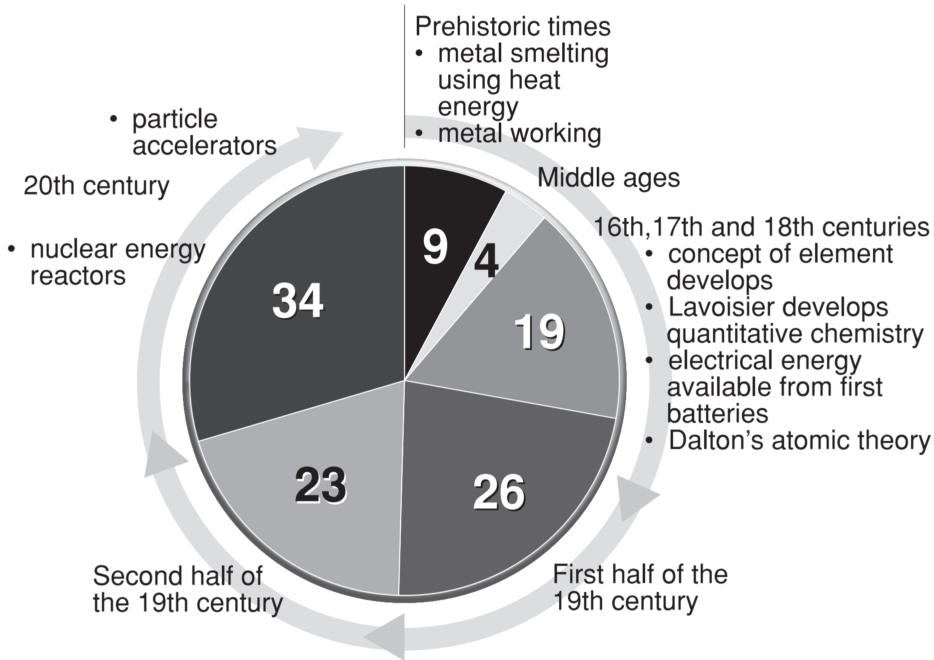
In Part 1 of this module you have learnt about alloys. In the previous module you learnt about physical and chemical properties. Complete the last two columns of the table with properties that are related to the uses.

Alloy	**Uses**	**Elements present**	**Physical property**	**Chemical property**
bronze	ship propeller	Cu, Sn	hard	corrosion resistant
solder	joining metals	Pb, Sn	_____ MP	unreactive metals
brass	brass band instruments	Cu, Zn	l_stre	corrosion resistant
dental amalgam	filling dental cavities	Hg, Sn, Ag, Cu	small expansion and contraction	____________
cupro-nickel	Australian 5,10,20 & 50 cent coins	Cu, Ni	____________	____________
stainless steel	corrosion resistant steel	Fe, Cr, Ni, C	____________	____________
duralumin	aluminium frames	Al, Cu, Mg, Mn	low density	____________

What is the most important chemical property of alloys? ____________

Exercise 1.2: Interpreting graphs and timelines

The pie graph below shows the periods in human history when 115 of the elements were discovered or made. The timeline around the pie graph shows important developments in chemistry.



a) Use the information in the pie chart to complete the passage below.

The 92 elements that occur naturally on earth have been discovered. The remaining __ elements have been made using nuclear _________ reactors and _________ accelerators. These artificially produced elements are not very useful because they are:

- usually made in very small quantities
- unstable and undergo radioactive decay changing to other elements
- expensive to make.

b) Refer to the column graph on the next page showing the number of elements discovered or made in each decade from 1750 to 1999.

Can you suggest explanations for the large number of elements:

i) discovered in 1800-1809

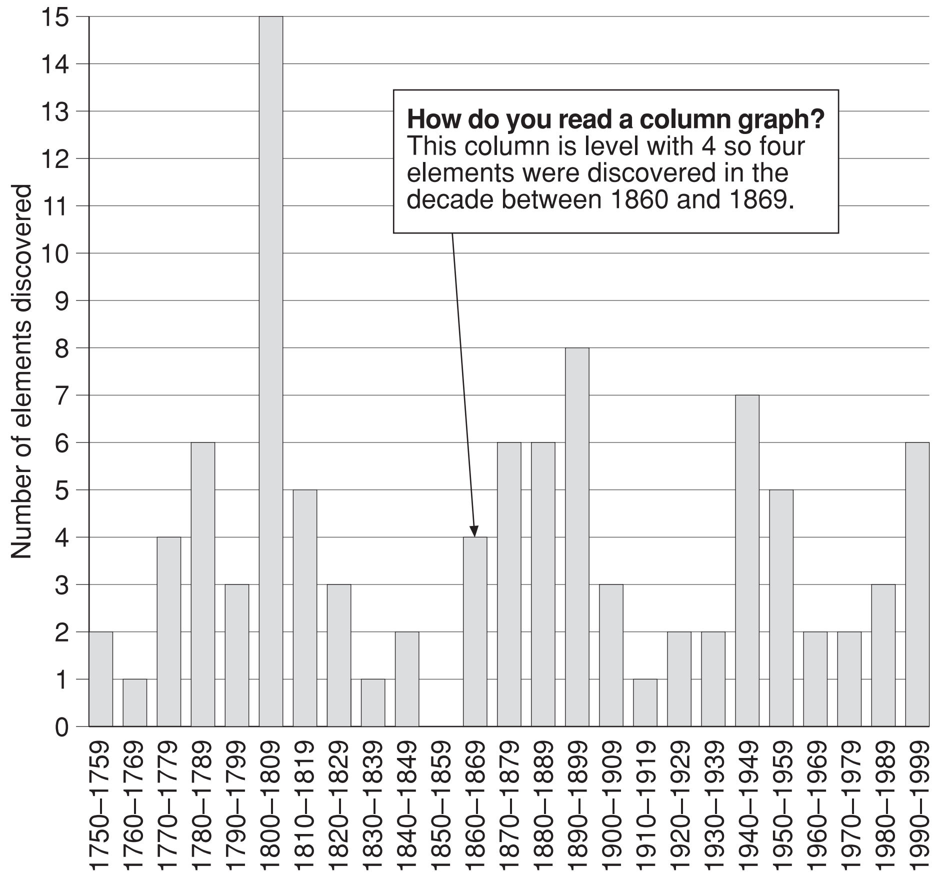
____

ii) made in 1940-1949

____

iii) made in 1990-1999?

____



b) Why are more metals available for people to use now than there were 200 years ago? [*hint: use the term energy at least once in your answer*]

Chemistry

Preliminary Course

Stage

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING

TAFE NSW

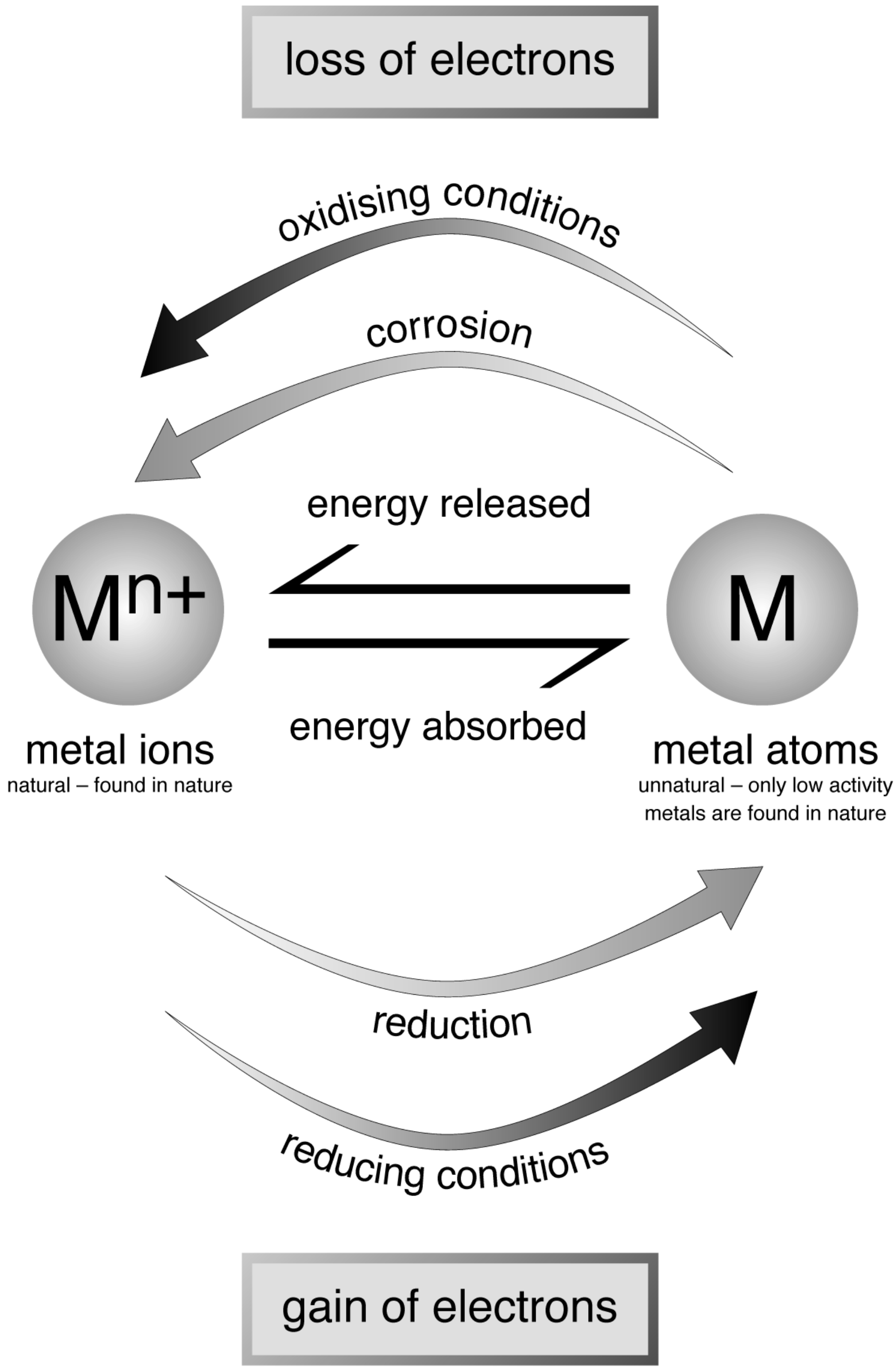
OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

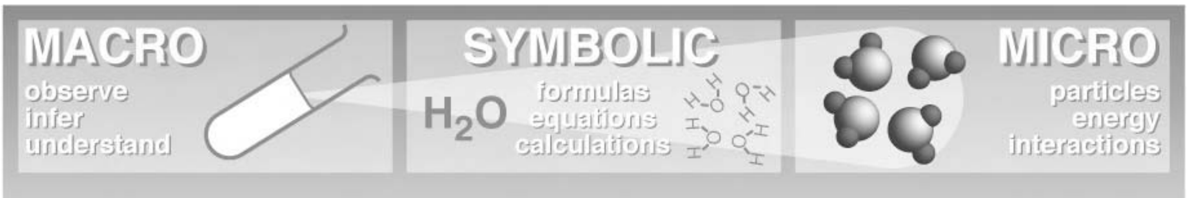
Metals

Part 2: Metal reactivity

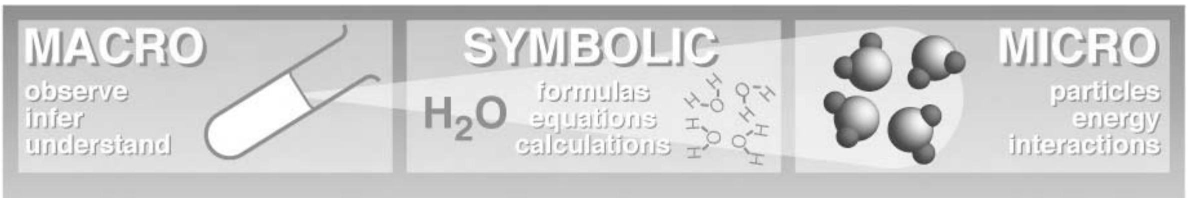
Incorporating October 2002

AMENDMENTS


loss of electrons
oxidising conditions
corrosion
energy released
Mn+
M
energy absorbed
metal ions
natural – found in nature
metal atoms
unnatural – only low activity metals are found in nature
reduction
reducing conditions
gain of electrons


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

Contents



Introduction

In Part 2 you will study the differences in rates of reaction of pure metals and how this influences their uses.

In this part you will be given opportunities to learn to:

- describe observable changes when metals react with dilute acid, water and oxygen
- describe and justify the criteria used to place metals into an order of activity based on their ease of reaction with oxygen, water and dilute acids
- identify the reaction of metals with acids as requiring the transfer of electrons
- outline examples of the selection of metals for different purposes based on their reactivity, with a particular emphasis on current developments in the use of metals
- outline the relationship between the relative activities of metals and their positions on the Periodic Table
- identify the importance of first ionisation energy in determining the relative reactivity of metals.

In this part you will be given opportunities to:

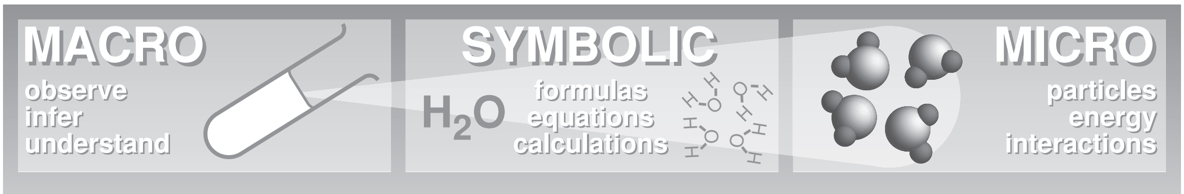
- perform a first–hand investigation incorporating information from secondary sources to determine the metal activity series
- construct word and balanced formulae equations for the reaction of metals with water, oxygen, dilute acid
- construct half equations to represent the electron transfer reactions occurring when metals react with dilute hydrochloric and dilute sulfuric acids.

In Part 1 you learned of the impact that metal extraction and uses have had on human development over the last five thousand years.

In Part 2 you will learn about:

- the observable chemical reactions of pure metals (macro level)
- how these are related to removal of electrons from their atoms (micro level)
- how these changes can be represented (symbolic level).

Examine the diagram on the inside cover page of this part. The work you do in this part will give you a better understanding of what happens to metals at the micro level.



Observing metal activity

Have you noticed any acids at home? Some can be found in solid form but most are found as aqueous (water) solutions. Acids are rarely kept in metal containers. This activity will help you to understand why this is so.

In this activity you will observe reactions of different metals (copper, iron and magnesium) with oxygen, water and dilute acetic acid (vinegar).

You will need:

- pieces of the three metals copper, iron and magnesium:
  - copper can be purchased from craft stores or cut out of waste electrical wiring
  - iron can be obtained as ungalvanised iron nails or iron (steel) wool
  - magnesium is best obtained as ribbon about 5 mm wide and 1 mm thick; if this is not available some camping stores sell magnesium blocks as fire starters and pieces of magnesium can be cut off the block with a pen knife
- steel wool to clean the three metal surfaces
- a wooden peg or metal tweezers to hold the metal pieces when you heat them
- a burner (gas Bunsen burner/methylated spirit burner/pencil torch burner) and matches; see Appendix 1 on how to use a pencil torch burner
- 3 transparent glass or plastic containers able to hold hot water
- ‘white vinegar’ that is colourless.

To carry out a ‘fair’ experiment to compare reactivity of the metals you should try and keep all conditions the same except the type of metal. Ideally the metal pieces you use should be all the same size, same surface area, same thickness and so on.

If it is difficult to find the three metals in the same form then by cutting and folding you should be able to get similar pieces about the same size, surface area and so on. Clean the metal surfaces with steel wool before cutting and folding or carrying out any reaction.

What you will do:

1 Record the appearance of each metal in the table *Metal reaction with air* below.

If the magnesium starts to burn and give out a white light look away and move the burning magnesium out of the flame. Ultra–violet radiation emitted from the burning magnesium may cause eye damage.

2 Heat a piece of each metal in the hottest part of the flame (usually just above the top of the inner, light blue cone) for at least 10 seconds. Hold the hot metal in air for a minute to cool it down.

Complete the table *Metal reaction with air* in the *Results* section.

3 Add about 10 mL of recently boiled hot water (water free of dissolved air) to a piece of each metal in separate transparent containers. Look carefully for small bubbles of gas forming on the metal due to reaction with water. Record your observations in the next table.

4 Pour off the water and replace it with vinegar at room temperature. The vinegar is a dilute solution of acetic acid CH_3COOH. Look for signs of reaction (colour change, decrease in amount of metal, formation of gas bubbles, change in temperature) both after a few minutes and after a few hours. Record your observations in the table *Metal reaction with water and dilute acid*.

Results:

	Magnesium	**Iron**	**Copper**
Appearance before heating			
Appearance after heating			
Signs of chemical change			

Metal reaction with air

	Magnesium	**Iron**	**Copper**
Signs of reaction with hot water			
Signs of reaction with dilute CH_3COOH			

Metal reaction with water and dilute acid.

Check your answers.

Conclusions and predictions:

1 Which of the three metal is the most reactive? ________________

2 Which of the three metals is the least reactive?________________

3 List the three metals from most reactive to least reactive.

____

4 Your list is called an activity series. Activity series are sometimes listed vertically from most active at the top to least active at the bottom. List the three metals vertically.

____ most active

____ active

____ least active

5 Which metal would you use for a pipe to carry small amounts of water through your house? __________________________________

6 Which metal would you use for a strong pipe to carry large amounts of water to a town or city?__________________________________

7 Which metal would you not use for a pipe carrying water? ________

8 Write equations in words for any reactions that occurred for these metals. Assume that any gas released by reaction of a metal with water or acid is hydrogen H_2.

____

____

____

____

Check your answers.

Dilute acid solutions, such as acetic acid CH_3COOH, hydrochloric acid HCl and sulfuric acid H_2SO_4, all contain hydrogen ions. When a metal reacts it transfers electrons to hydrogen ions forming hydrogen gas.
$2H^+ + 2e^- \rightarrow H_2$.

Metal activity series

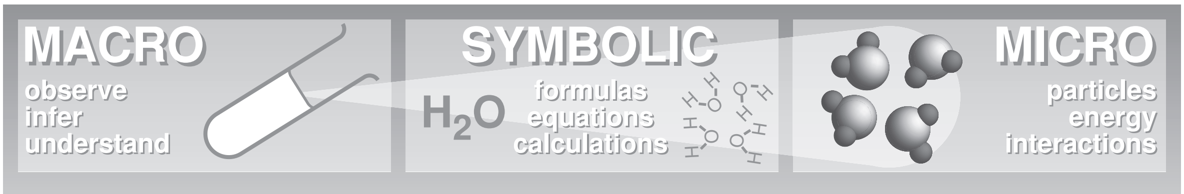
The symbols for the metals that you are most likely to come in contact with or use (as the element, in a compound or mixed in an alloy) are shown in the periodic table below.

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

Can you put a name to each of these symbols? If not, look at a full periodic table and learn the names that go with these symbols. Doing this now will save you a lot more time in your future study of chemistry. In the notes for the rest of this module the symbols will be used as a type of shorthand for the metal names.

Listed horizontally, from most active to least active, you get a metal activity series:

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



Reactions of metals

Metals in dilute acid

If these metals are placed in dilute acids, that is, solutions containing hydrogen ions H^+, all the metals from K to Pb will react spontaneously. The metal ions formed go into solution and if the solution is evaporated crystals of salt will be seen. Acetic acid gives acetate salts, hydrochloric acid gives chloride salts and sulfuric acid gives sulfate salts.

metal + acid → salt + hydrogen

You should never react K (banned in most schools) or Na with acid as the reactions are explosive. Li, Ba and Ca react vigorously even with very dilute acid solutions (that is solutions made by dissolving a small amount of acid in a lot of water).

Word equations

Complete these word equations. If the metal does not react write 'no reaction' after the arrow.

•	magnesium	+	hydrochloric acid	→	magnesium chloride	+	
•	zinc	+	sulfuric acid	→		+	hydrogen
•	lead	+		→	lead acetate	+	
•		+	hydrochloric acid	→	iron chloride	+	hydrogen
•	silver	+	hydrochloric acid	→			

Check your answers.

Formulae equations

In solution acetic acid molecules can form hydrogen ions H^+ and acetate ions CH_3COO^-. Zinc acetate salt containing Zn^{2+} requires two acetate ions to be electrically neutral and so its formula is $Zn(CH_3COO)_2$.

Many equations, such as those involving formation of or reaction of metal ions, are written as formulae equations using neutral formulas.

The formula equation for the reaction between zinc and dilute acetic acid would be written as:

$Zn + 2\ CH_3COOH \rightarrow Zn(CH_3COO)_2 + H_2$

(Note: Only the H attached to an O in CH_3COOH can be released; the three bonds joining H to the C in CH_3 are strong and difficult to break.) Although the acid solution and the salt contain ions, because this is a formula equation only neutral formulas are used.

Write formulae equations using neutral formulas for the four reactions that occurred in the previous exercise. Assume the iron reacted to form iron (II) salts and the lead reacted to form lead (II) salts.

Check your answers.

Ionic equations

When a dilute acid reacts with a metal it is the hydrogen ions that react with the metal atoms. Electrons are transferred from the metal atoms to the hydrogen ions producing metal ions and hydrogen molecules. For a metal M producing M^{2+} the equation can be written as an ionic equation as follows.

M	+	$2H^+$	$\rightarrow$	M^{2+}	+	H_2
metal	+	dilute acid	$\rightarrow$	salt solution	+	hydrogen

The anions in the dilute acid solution are the anions in the salt solution. Because these anions take no part in the reaction they are called spectator ions.

A simplified ionic equation like $Ca + 2H^+ \rightarrow Ca^{2+} + H_2$ summarises the idea that calcium reacts with different acids forming a salt and hydrogen. The anion in the salt comes from the acid used.

Use ionic equations to summarise what happens when the metals Mg, Zn, Pb, Fe and Ag are placed in dilute acid. If an ion is formed, assume it has a charge of 2+.

Check your answers.

Half equations

When a metal atom reacts with acid a metal ion is formed. The changing of a neutral atom (or molecule) to a charged particle is called **ionisation**. The ionisation of a metal can be shown as:

$M \rightarrow M^{n+} + ne^-$

The electron(s) lost by the metal atom are transferred to other atom(s), molecule(s) or ion(s). This can be shown as:

$2\,H^+ + 2e^- \rightarrow H_2$

The two equations above are called half equations because they show half of what happens in a reaction. A half equation shows either loss of electrons by an electron donor or gain of electrons by an electron acceptor.

If the two half equations are added a full equation is obtained. Note that the electrons on the LHS and RHS cancel out in the example below.

$$
\begin{array}{ccccccc}
 & & M & \rightarrow & M^{2+} & + & 2e^- \\
2\,H^+ & + & 2e^- & \rightarrow & H_2 & & \\
\hline
M & + & 2\,H^+ & \rightarrow & M^{2+} & + & H_2
\end{array}
$$

This reaction is called an electron transfer reaction because electrons have transferred from one reactant to another reactant. Here 2 electrons have transferred from a metal to 2 hydrogen ions in the acid solution. This results in the formation of a metal ion and a hydrogen gas molecule.

If the number of electrons in the two half equations are different one or both of the half equations will need to be multiplied. The half equations are multiplied so that the number of electrons lost equals the number of electrons gained.

For example, in the reaction of aluminium with dilute acid, each atom of aluminum loses three electrons. The hydrogen ions gain one electron each to form hydrogen atoms which pair up forming a diatomic hydrogen molecule.

$$Al \rightarrow Al^{3+} + 3e^-$$

$$2H^+ + 2e^- \rightarrow H_2$$

Multiply the terms in the half equations to get an equal number of electrons gained and lost.

$$2\ (Al \rightarrow Al^{3+} + 3e^-)$$

$$3\ (2\ H^+ + 2e^- \rightarrow H_2)$$

$$2Al + 6H^+ \rightarrow 2Al^{3+} + 3H_2$$

The full equation must be balanced for atoms and charge. No electrons are shown in the full equation.

Note: The reaction between aluminium and dilute acid is often delayed because aluminium forms an oxide layer that strongly adheres to the metal below. This oxide layer stops further corrosion. It may take minutes or hours before the oxide layer is dissolved by the dilute acid and the exposed aluminium underneath starts to react.

Rewrite the ionic equations for the previous exercise as two half equations that can be added together.

Check your answers

Metals in water

The most active metals K, Na, Li, Ba and Ca react at room temperature with water; Mg however requires hot water. All these metals react producing a hydroxide and hydrogen gas.

metal + water $\rightarrow$ metal hydroxide + hydrogen

eg. Ca + $2H_2O$ $\rightarrow$ $Ca(OH)_2$ + H_2

The metals Al, Cr, Zn, Fe, Co and Ni require heating until they are red hot and contact with gaseous water (steam) before they react.
Under these conditions, a metal oxide and hydrogen form.

metal + water $\rightarrow$ metal oxide + hydrogen

eg. Zn + H_2O $\rightarrow$ ZnO + H_2

The less active metals do not react with water at all.

Metals in oxygen

The most active metals K, Na, Li, Ba and Ca react quickly with oxygen in the air at room temperature. It only takes a matter of seconds, or minutes, for these metals to become covered with white oxides.

The metals Mg, Al, Cr, Zn, Fe, Co and Ni react slowly at room temperature. If they are powdered and heated they can react quickly emitting heat and light, eg. in fireworks such as sparklers.

Other, less reactive, metals Sn, Pb, Cu and Hg react very slowly when heated to form oxides: metal + oxygen $\rightarrow$ metal oxide

The least reactive metals Ag, Pt and Au do not react in air. This has enhanced their value as jewellery.

Most metal oxide layers that form on the outside of active metals do not adhere. These layers flake off or are knocked off so that more of the metal underneath corrodes. However, the oxide layers that form on Al, Cr and Zn adhere strongly and protect the underlying metal from further corrosion. Stainless steel contains Cr which forms a thin protective layer of Cr_2O_3 over the steel.

If the dull oxide layer on the outside of Al or Zn is scratched shiny metal is seen underneath – this gradually dulls as the protective oxide layer forms.

Summary of metal reactions

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

dilute acids react

water reacts | steam reacts

oxygen fast | oxygen slow reaction | very slow

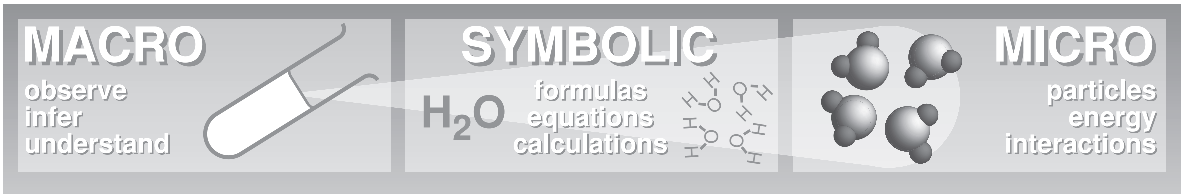
Note that Fe Co Ni have a very significant physical property – they are all magnetic. They are extensively used in the making of magnets.

Metal activity and the periodic table

Can you relate the order of metal activity to the periodic table below? Using coloured pencils colour K Na Li red, Ba Ca Mg orange, Al Cr Zn yellow, Fe Co Ni brown, Sn Pb Cu green, Hg Ag Pt Au blue.

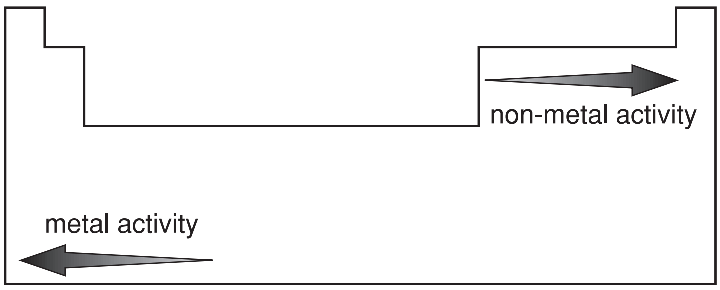
Li																	
Na	Mg											Al					
K	Ca				Cr		Fe	Co	Ni	Cu	Zn						
										Ag			Sn				
	Ba								Pt	Au	Hg		Pb				

Check your answer.



Ionisation energy

In *The chemical earth* you saw how chemical and physical properties of elements could be related to their position in the periodic table.
This pattern could be explained by the electronic configuration of atoms.
You also became aware of trends in metal activity and non–metal activity.



Trends in metal and non–metal activity.

Can you add a vertical arrow to the LHS of this periodic table to show the trend in metal activity in a group? Use the metal activity series and look at the order of the group 1 and group 2 metals.

Check your answer.

In this section you will learn how the position of a metal in the activity series can be explained by the energy required to remove outer electrons from atoms. You will also see how the chemical properties of metals are related to a physical property – the ionisation energy.

Amongst scientists, ionisation energy is broadly defined as the energy required to remove electron(s) from a gaseous atom, molecule or ion.

In this section you will concentrate on the first ionisation energy of elements. The first ionisation energy is defined as the energy required to remove one electron from a gaseous atom of an element.

$M_{(g)} \rightarrow M_{(g)}^{+} + e^{-}$

Ionisation energies are usually given in kilojoules per mole (kJ/mol) or megajoules per mole (MJ/mol).

Assume that ionization energy refers to the first ionization energy (removal of one electron from an atom) unless an equation or further information indicates differently.

Use the information for converting kilojoules (kJ) to megajoules (MJ) to answer the following questions.

- 1 MJ = 10^6 J
- 1 kJ = 10^3 J

1 a) Complete the following sentences.

The ionisation energy of Li is 526 kJ/mol = 0.526 MJ/mol.

The ionisation energy of Na is 502 kJ/mol = ________ MJ/mol

The ionisation energy of K is 425 kJ/mol = ________ MJ/mol.

b) What is the trend in ionisation energy as you go down group 1?

____

c) As less energy is needed for ionisation energy the group 1 metals become (less/more) active.

2 The periodic table below shows the ionisation energies of the metals in your activity series in kJ/mol.

526																	
502	744											584					
425	596				659		766	765	743	752	913						
										737			715				
	509								870	896	1013		722				

a) Look at the ionisation energies for the group 2 metals. Predict a value for strontium (between Ca and Ba): ____ kJ/mol.
Check your prediction against the answer in the suggested answers.

b) As less energy is needed for ionisation energy the group 2 metals become (less/more) active.

3 a) Examine the period starting with K. Is there a trend in ionisation energy as you go across the period? ______________

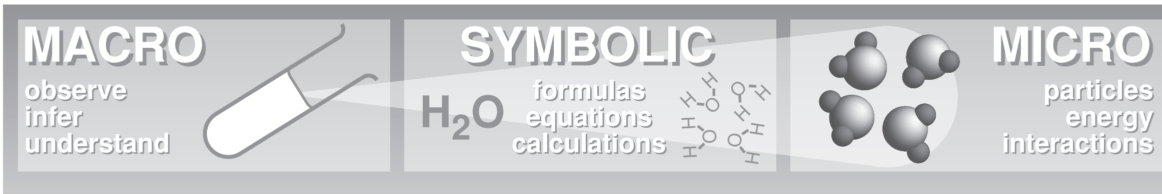
b) Is there a trend in activity as you go across the period? _______

c) The lower the ionisation energy the (less/more) active the metal.

4 Could the periodic table be used to predict the properties of unknown elements? If you wanted to predict the properties of elements 113 and 115 would it be better to concentrate on trends in groups or the period?

____

____



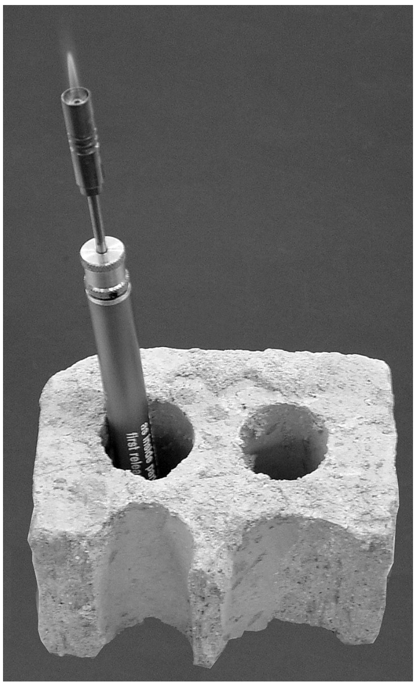
Appendix 1

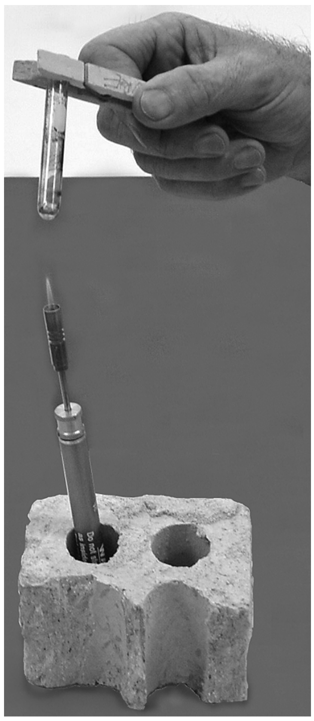
Using a pencil torch burner

A pencil torch burner uses butane as fuel and can produce a flame hotter than a Bunsen burner. The contents of a test tube can often be heated sufficiently by holding the bottom of the test tube above the top of the flame.

Always use the pencil burner with great care. When the burner is lit the flame is difficult to see especially when sunlight shines on the flame. Read and follow the instructions provided with the pencil torch. It is very important that the pencil torch is not stored in hot areas.

Make sure the burner does not move while it is being used. A brick made with extrusion holes is ideal. Heated objects can be placed on the brick to cool.





A half brick can be used to hold a pencil torch burner when heating.

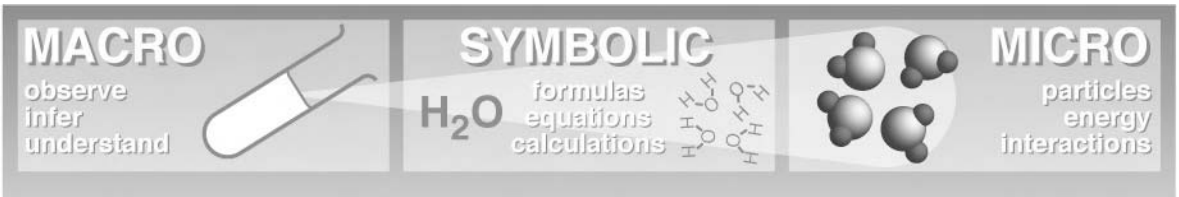
When refilling the pencil torch make sure there are no flames or sparks nearby. Ensure that the torch is extinguished. Follow instructions on the filler can. (Usually the torch is inverted, the filler can inverted and a pumping action used for about 10 s; wait a few minutes for the gas in the torch to stabilise before use.) The end of the pencil torch near the filter can should feel cool as gas from the filler can expands into the pencil torch.

Take care when refilling a pencil torch burner.

Appendix 2

Metal properties

Metal	Density (g cm^{-3})	MP (°C)	Electrical conduct. (MS m^{-1})	Thermal expansion coefficient ($10^6 K^{-1}$)	Toxic level in human (g)
K	0.86	63	14	83	6
Na	0.97	98	21	71	non–toxic
Li	0.53	180	11	56	0.1
Ba	3.50	725	3	20	0.2
Ca	1.55	842	29	22	non–toxic
Mg	1.74	650	22	26	non–toxic
Al	2.70	660	37	23	5
Cr	7.19	1857	8	6	0.2
Zn	7.14	420	17	25	0.15
Fe	7.86	1535	10	12	0.2
Co	8.90	1495	16	13	0.5
Ni	8.90	1455	14	13	0.05
Sn	7.30	232	9	21	2
Pb	11.3	327	5	29	0.001
Cu	8.96	1085	58	16	0.25
Hg	13.5	–39	1	180	0.0004
Ag	10.5	962	63	19	0.06
Pt	21.4	1772	9	9	?
Au	19.3	1064	44	14	non–toxic



Suggested answers

Metal reaction with air

	Magnesium	Iron	Copper
Appearance before heating	shiny, silvery	shiny, grey	shiny, brown
Appearance after heating	white powder	dull black	dull brown
Signs of chemical change	metal changed to powder of different colour	surface changed from dull grey to dull black	shiny to dull

Metal reaction with water and dilute acid

	Magnesium	Iron	Copper
Signs of reaction with hot water	small bubbles on surface after 5 minutes	no change	no change
Signs of reaction with dilute CH_3COOH	many bubbles of gas formed and released; lifted Mg to surface	small bubbles on surface after 5 minutes	no change

Conclusions and predictions

1 magnesium

2 copper

3 magnesium, iron, copper

4 magnesium

iron

copper

5 Copper pipes can be used to carry small amounts of water.

6 Iron pipes can be used to carry large amounts of water.

7 Magnesium cannot be used as a water pipe.

8 magnesium + oxygen → magnesium oxide

magnesium + water → magnesium hydroxide + hydrogen

magnesium + acetic acid → magnesium acetate + hydrogen

iron + acetic acid → iron acetate + hydrogen

Word equations

•	magnesium	+	hydrochloric acid	→	magnesium chloride	+	hydrogen
•	zinc	+	sulfuric acid	→	zinc sulfate	+	hydrogen
•	lead	+	acetic acid	→	lead acetate	+	hydrogen
•	iron	+	hydrochloric acid	→	iron chloride	+	hydrogen
•	silver	+	hydrochloric acid	→	no reaction		

Formulae equations

$Mg + 2HCl \rightarrow MgCl_2 + H_2$

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

$Pb + 2CH_3COOH \rightarrow Pb(CH_3COO)_2 + H_2$

$Fe + 2HCl \rightarrow FeCl_2 + H_2$

Ionic equations

- $Mg + 2H^+ \rightarrow Mg^{2+} + H_2$
- $Zn + 2H^+ \rightarrow Zn^{2+} + H_2$
- $Pb + 2H^+ \rightarrow Pb^{2+} + H_2$
- $Fe + 2H^+ \rightarrow Fe^{2+} + H_2$

Half equations

$Mg \rightarrow Mg^{2+} + 2e^-$

$2H^+ + 2e^- \rightarrow H_2$

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

$2H^+ + 2e^- \rightarrow H_2$

$Pb \rightarrow Pb^{2+} + 2e^-$

$2H^+ + 2e^- \rightarrow H_2$

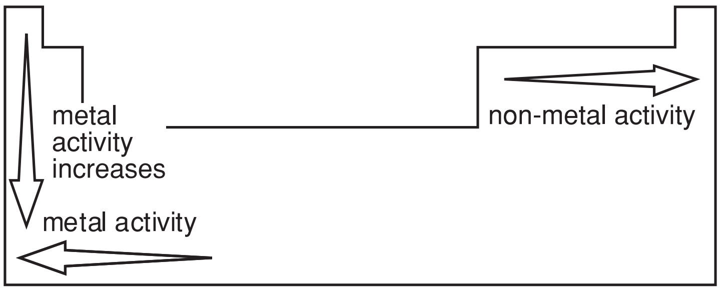
$Fe \rightarrow Fe^{2+} + 2e^-$

$2H^+ + 2e^- \rightarrow H_2$

Metal activity and the periodic table

Metal activity generally decreases from left to right. In the first two columns, metal activity decreases up the group. The most active metal is in the bottom left hand corner of the periodic table.

Ionisation energy



Trends in metal and non–metal activity

1 a) The ionisation energy of Na is 502 kJ/mole = 0.502 MJ/mol

The ionisation energy of K is 425 kJ/mole = 0.425 MJ/mol.

b) Ionisation energy decreases down group 1.

c) As less energy is needed for ionisation energy the group 1 metals become more active.

2 a) The ionisation energy of strontium, Sr is 556 kJ/mole

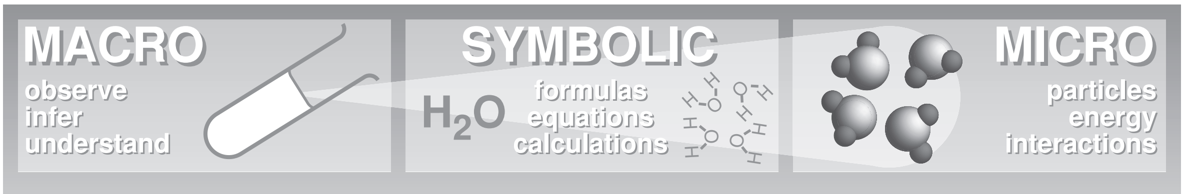
b) As less energy is needed for ionisation energy the group 2 metals become more active.

3 a) Yes. Ionisation energy increases across the period starting with K.

b) Yes. Activity decreases as you go across the period.

c) The lower the ionisation energy the more active the metal.

4 Better to concentrate on trends in groups as the trends are strong (eg. group 15 goes from non–metals through semi–metals to metals). The surrounding metals in the period (112, 114, 116) are only made in extremely small amounts and undergo radioactive decay quickly. Little is known of their chemical properties.



Exercises – Part 2

Exercises 2.1 to 2.2 Name: ________________________________

Exercise 2.1: Trends in oxide formulas

When group 1 (alkali metals) and group 2 (alkaline earth metals) elements react with oxygen different sorts of oxides can be formed.

Three sorts of oxide ions are found in the compounds produced:

O^{2-}	oxide ion	a single oxygen atom with two extra electrons
O_2^{2-}	peroxide	a pair of joined oxygen atoms with a total of two extra electrons
O_2^{-}	superoxide	a pair of joined oxygen atoms with one extra electron

The formulas for the oxides formed by group 1 and 2 metals when they react with oxygen in the air are shown in the table below.

Alkali metal oxides			Alkaline earth metal oxides	
Li_2O				
	Na_2O_2		MgO	
	K_2O_2	KO_2	CaO	
	Rb_2O_2	RbO_2	SrO	SrO_2
	Cs_2O_2	CsO_2	BaO	BaO_2

a) You already know that metal activity increases:

- from right to left across a period
- from top to bottom down a group made up of metals

so that the most active metal in the table above is ______________

Describe trends in the formulas of these metal oxides:

- across a period
- down a group?

____

____

____

b) Can you see a connection between the trends in formulas of these metal oxides and metal activity?

____

____

Exercise 2.2: Metal properties and uses

The table Metal properties in the *Appendix 2* lists the 19 metals in the metal activity series order and shows certain properties. Write the name under each element symbol then use information in the table to answer questions on the next page.

The headings used in the table are:

Metal	**Density ($g\ cm^{-3}$)**	**MP (°C)**	**Electrical conductivity ($MS\ m^{-1}$)**	**Thermal expansion coefficient ($10^6 K^{-1}$)**	**Toxic level in human (g)**

Density is measured in $g\ cm^{-3}$ at 25°C.

MP, Melting point is measured in °C.

Electrical conductivity is measured in megasiemens per metre at 25°C – the larger the value the better the electrical conductor.

Thermal expansion coefficient (K^{-1}) shows how much a piece of the metal expands in one direction when the temperature rises one kelvin (= one Celsius degree).

Toxic level in human shows the amount of the metal as element or compound that could poison but not necessarily kill the ‘average human’.

a) Which three metals would float on water?

b) Which two metals would sink in mercury?

c) List the five metals with the highest MPs in order from highest to lowest.

d) Which metal is the best electrical conductor?

e) Suggest a reason why Cu is the most commonly used electrical conductor.

f) What chemical property of Au makes it the preferred electrical conductor for connections between parts inside large computers?

g) Suggest two reasons why Al cables suspended from towers are used to carry high voltage electricity supply long distances.

h) Suggest a reason why Hg has the lowest electrical conductivity and the highest thermal expansion.

i) List the five most toxic metals in this table starting with the most toxic.

j) Fe, Co and Ni have a physical property that distinguishes them from the other metals. What is this distinguishing physical property?

Chemistry

Preliminary Course

Stage 6

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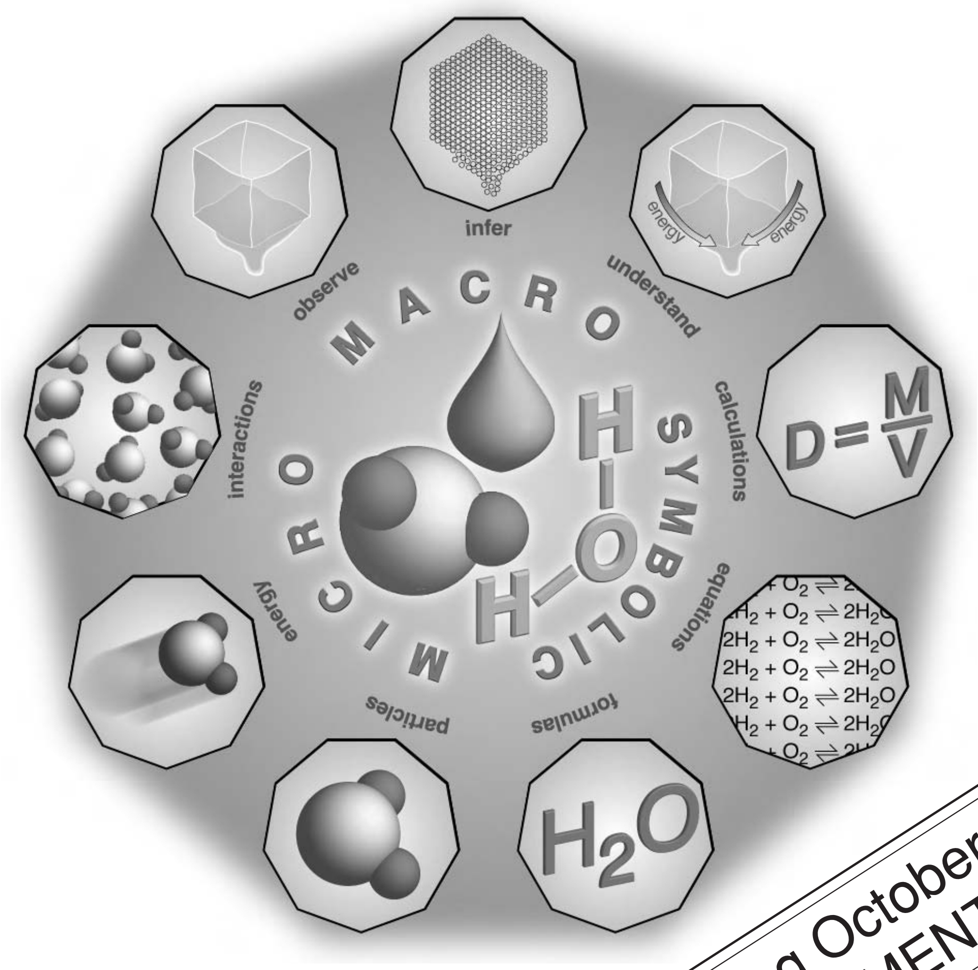
Metals

Part 3: The periodic table

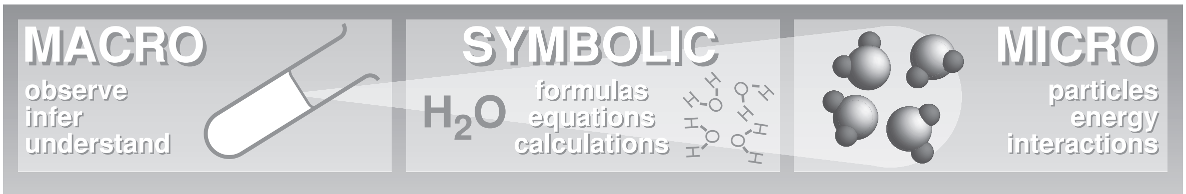


Incorporating October 2002 AMENDMENTS

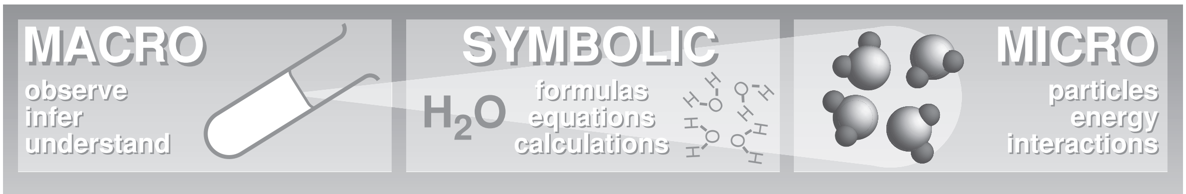
1 H 1.008 Hydrogen	Atomic number Symbol Atomic weight Name

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.39 Zinc	31 Ga 69.72 Gallium	32 Ge 72.61 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc [98.91] Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57-71 LANTHANIDES	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.8 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po [210.0] Polonium	85 At [210.0] Astatine	86 Rn [222.0] Radon
87 Fr [223.0] Francium	88 Ra [226.0] Radium	89-103 ACTINIDES	104 Rf [261.1] Rutherfordium	105 Db 262.1 Dubnium	106 Sg [263.1] Seaborgium	107 Bh [264.1] Bohrium	108 Hs [265.1] Hassium	109 Mt [268] Meitnerium	110 Uun – Ununnilium	111 Uuu – Unununium	112 Uub – Ununbium	113	114 Uuq – Ununquadium	115	116 Uuh – Ununhexium	117	118 Uuo – Ununoctium

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm [146.9] Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium
89 Ac [227.0] Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np [237.0] Neptunium	94 Pu [239.1] Plutonium	95 Am [241.1] Americium	96 Cm [244.1] Curium	97 Bk [249.1] Berkelium	98 Cf [252.1] Californium	99 Es [252.1] Einsteinium	100 Fm [257.1] Fermium	101 Md [258.1] Mendelevium	102 No [259.1] Nobelium	103 Lr [262.1] Lawrencium


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

Contents



Introduction

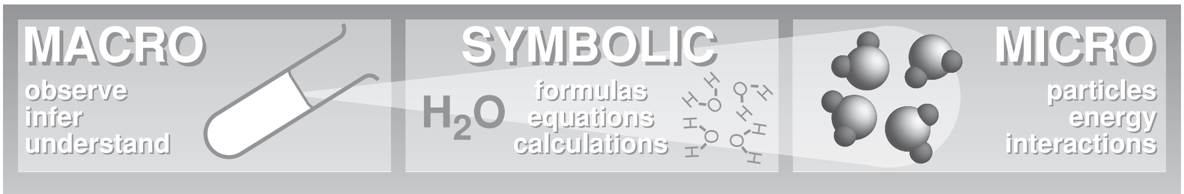
In Part 3 you will learn about how elements are organised into periodic tables that enable scientists to make predictions about elements.

In this part you will be given opportunities to learn to:

- identify an appropriate model that has been developed to describe atomic structure
- outline the history of the development of the Periodic Table including its origins, the original data used to construct it and the predictions made after its construction
- explain the relationship between the position of elements in the Periodic Table, and
  - electrical conductivity
  - ionisation energy
  - atomic radius
  - melting point
  - boiling point
  - combining power (valency)
  - electronegativity
  - reactivity.

In this part you will be given opportunities to:

- process information from secondary sources to develop a Periodic Table by recognising patterns and trends in the properties of elements and use available evidence to predict the characteristics of unknown elements both in groups and across periods
- use computer based technologies to produce a table and a graph of changes in one physical property across a period and down a group.



Developing a periodic table

Scientists have studied the properties of many elements, both metals and non–metals. They noticed similar properties for different elements. Could the similarities be used to organise the elements so that predictions could be made from the patterns?

Looking at the past

Read through the information below which has been extracted from a secondary source – NATCAP *The periodic table.* This will:

- give you experience in processing information from a secondary source
- prepare you for a send–in exercise on the history of the Periodic Table, its origins and the original data used to construct it.

What is the periodic table?

Have you used a table or chart today? Perhaps you looked at a bus, train or school timetable? Did you consult a television or radio program? Maybe you looked up a number in the phone book, or checked the share or produce prices in a newspaper?

Tables and charts are useful because they organise information so that we can find it more easily. This is one important function of the periodic table – to organise information about the chemical elements.

The periodic table has been designed so that the actual position of each element in the table conveys information. By the end of this unit, you should be able to predict lots of properties of elements and their compounds, just by using the positions of the elements in the periodic table.

Developing the periodic table

It took over one hundred years to develop the modern periodic table. In this section, we'll investigate some of the ideas scientists had about how the elements could be arranged into a periodic table.

Antoine Lavoisier was born in Paris, France in 1743. His chemical ability won him a position as an assistant at the Academy of Sciences. He studied the properties and reactions of substances, and established chemistry as a modern science.

One important advance he made was in the classification of substances. He began to group substances that we now call compounds separately from those we know as elements. He differentiated between elements that are metals and those that are not.

Thus, we can think of the earliest 'periodic table' showing two groups of elements, the **metals** and the **non–metals**.

In the Appendix there are descriptions of the properties or characteristics of twenty elements. Lavoisier would not have known about all of them, but you can still use his logic to organise them.

Remove the two pages from the Appendix, cut around the boxes and spread the element cards out on your desk. Classify the elements as metals or non–metals, and arrange the cards into a simple, two–columned table.

Record your arrangement of the element cards in the space below.

Check your answer.

In the early 1800s, the German chemist Dobereiner suggested that some elements could be placed into groups containing three elements. He called these groups **triads.**

The elements in a triad have very similar properties and the atomic mass of one element in a triad is approximately the average of the atomic masses of the other two elements in the triad.

John Newlands was a British chemist, born in 1838. He, too, noticed a relationship between the properties of elements and their atomic masses.

However, Newlands' work was initially ignored or rejected by other chemists. It's not unusual in science that a correct idea or hypothesis is not immediately accepted by other scientists. It takes time for a new idea to be tested and considered.

It's also not so strange that a new hypothesis might be ignored altogether. Scientists make many suggestions to explain their observations, and only some of these hypotheses turn out to be true.

By the time of his death in 1898, Newlands' hypothesis about the relationship between the properties of elements and their atomic masses had been modified and accepted.

Both Lothar Meyer and Dmitri Mendeleev investigated the periodic, or repeating, properties of the elements. Like Newlands, they were interested in the relationship between atomic masses and the properties of elements.

Meyer was born in Germany in 1830 and died in 1895. He developed a periodic table based on his study of elements. One strategy he used was to graph the properties of elements against their atomic masses.

Dmitri Mendeleev was born in Siberia in 1834. It is Mendeleev who is credited with the development of the modern periodic table. His observations of the properties of elements led him to the same hypothesis as Meyer – that there is a repeating pattern in the properties of elements when they are listed in order of increasing atomic mass.

But it is the way Mendeleev organised and used his periodic table that is so important. He used valency as an important feature of his table. And with his table, he predicted undiscovered elements and their properties with great accuracy. Many of the elements and their compounds that have been discovered in the twentieth century were first predicted from Mendeleev's periodic table. They were discovered only because scientist looked for them specifically.

Mendeleev's periodic table included all of the elements known in the mid 1800s. He published his first periodic table in 1869, but the table he presented in 1871 resembles the structure of the modern table more closely.

Now complete Exercise 3.1 about the historical development of a periodic table.

Atomic structure

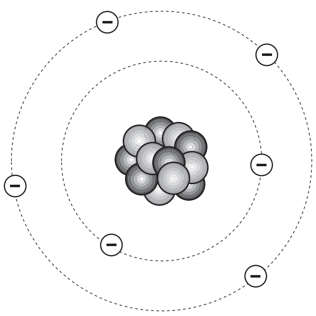
The most appropriate model of atomic structure for your course pictures protons and neutrons in a nucleus surrounded by electron shells.

Atomic mass and atomic weight

Remember that chemists usually think of mass and weight as being equivalent. So the terms atomic mass and atomic weight are often used interchangeably. However, there is a case for considering atomic mass and atomic weight to have different meanings.

The full correct term to describe the amount of substance in an atom is relative atomic mass. Relative indicates that atomic mass is compared to a standard. The standard for comparing atoms is the mass of an atom of carbon–12. What does carbon–12 mean?

Here is a diagram of an atom of carbon–12, or ^{12}C.



Key:

⊖ = electron = proton = neutron

Count the number of:

- protons ____________________
- electrons ____________________
- neutrons. ____________________

Remember that the **atomic number** for an element is the number of protons in the nucleus of the atom. For an uncharged atom, this is also the number of electrons. The symbol for atomic number is Z.

The atomic number of carbon is 6. All carbon atoms will have six protons (and six electrons). An atom with more or less protons would be a different element.

The **mass number** for an atom is the total number of protons and neutrons in the nucleus of the atom. Its symbol is A.

1 What is the mass number of the atom of carbon shown above? __

The number with the name, oxygen–16, and the superscript with the symbol, ^{16}O, indicate the mass number. From the mass number and the atomic number, you can calculate the number of neutrons in an atom.

2 How many neutrons will be in an atom of carbon–14, ^{14}C? ______

If you'd like to check your answer, do it now.

Why does it matter? Atoms of carbon–12 and carbon–14 will have different atomic masses even though they are the same element. They are called **isotopes** which means atoms of the same element with different atomic masses (or numbers of neutrons).

In a sample of carbon, there are billions of carbon atoms including several carbon isotopes. The average mass of a carbon atom in this sample takes account of the isotopes, and can be called the **atomic weight**.

If you look at a periodic table you'll see that carbon has an atomic mass of 12.01. It would be better to call 12.01 an atomic weight to identify it as an average weight of isotopes of carbon in nature.

Identifying isotopes

Isotopes can be identified by name, such as carbon–12 and carbon–14. The can also be identified by symbol, such as ^{12}C and ^{14}C.

A more detailed identifier can be written in the following form:

$^{A}_{Z}X$ where
A is the mass number
Z is the atomic number
X is the element's symbol.

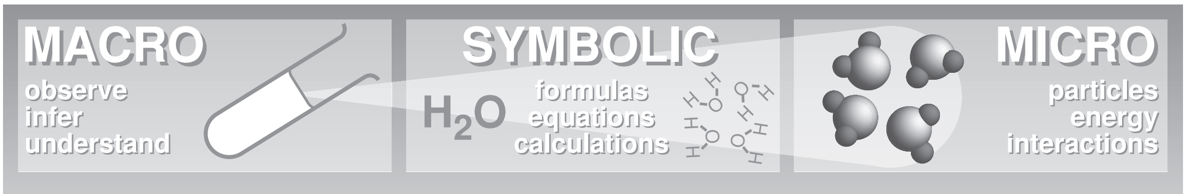
Use this form to show:

1 hydrogen–2 ____

2 iodine–131 ____

3 uranium–238 ____

Compare your solutions to those in the answer pages.



Predicting from a periodic table

The real value of a periodic table is that it can be used for predictions.

Predicting properties of elements

You've noticed that some elements in the periodic table have very similar properties. Similar elements are arranged into vertical columns in the modern periodic table.

Here are some of the properties of elements from the first two columns in the modern periodic table. You used the properties of some of these elements when you organised your element cards from the Appendix.

Li Lithium 1 • silver–white, light metal • melting point = 180˚C • reactive. Rapidly forms an oxide in air and reacts with water	**Be Beryllium** 2 • grey, hard, brittle metal usually covered with oxide coating • melting point = 1280˚C • burns when heated. Slow reaction with water and acid
Na Sodium 1 • silver–white, soft metal • melting point = 98°C • very reactive. Rapidly forms an oxide in air and reacts vigorously with water	**Mg Magnesium** 2 • silver–white, very light metal • melting point = 650˚C • burns when heated in air. Reacts very slowly with water

K Potassium 1 • silver–white, soft metal • melting point = 64°C • very reactive. Rapidly forms an oxide in air and reacts violently with water	**Ca Calcium** 2 • silver–white, soft metal • melting point = 838˚C • Reactive. Quickly forms an oxide in air and reacts steadily with water
Rb Rubidium • • •	**Sr Strontium** • • •
Cs Cesium 1 • silver metal • melting point = 29°C • extremely reactive. Reacts violently with water, oxygen and halogens	**Ba Barium** 2 • silver–white metal • melting point = 714°C • quickly forms an oxide in air and reacts vigorously with water
Fr Francium • radioactive metal • melting point = 27°C	**Ra Radium** 2 • silver–white, radioactive metal • melting point = 700°C • very reactive

Look at the properties of the elements in the first column then answer questions 1 to 8 below. These elements – lithium, sodium, potassium, rubidium, cesium and francium – are called the Group 1 or Group I elements or the alkali metals.

1. How are the elements in the first column similar? Write a general description of a Group 1 element.

   ____

   ____

   Of course you noticed that they were all metals, and silver or silver–white in colour. They have low melting points and are very reactive, with a valency of 1. So your general description should be something like this: "A Group I element is probably a silver–white metal with a low melting point and a valency of 1. It is very reactive."

2. There were no properties listed for rubidium.
   What properties would you predict?

   ____

   ____

   That was easy! Rubidium "is probably a silver–white metal with a low melting point and a valency of 1. It is very reactive."

   You can make more precise predictions than these by looking for patterns or trends in the properties of the elements in the column. You'll look at these trends in more detail later.

3. Look at the melting points of the alkali metals.
   What pattern do you see as you move down the column?

   ____

   Did you notice that the melting point of each element down the column was slightly lower than the one above it? We say that the melting point decreased down the group.

4. What melting point would you predict for rubidium?

   ____

   Following the pattern, it should be between 64°C and 29°C.
   The actual melting point of rubidium is 39°C.

   Now look at the reactivity of the elements in the first column. What pattern do you notice?

5. What reactivity would you predict for rubidium?

   ____

   The reactivity in the group increases down the column.
   You'd expect rubidium to be more reactive than potassium but less reaction than cesium. So its reactivity is between very reactive and extremely reactive.

6. Write a summary of the properties you have predicted for rubidium.

   ____

   ____

   Now look at the properties of the elements in the second column. These elements – beryllium, magnesium, calcium, strontium, barium and radium – come from the second column or group of the periodic table. They are called Group 2 or Group II elements or the alkaline earth metals.

7. Predict the properties of strontium. Be as detailed as you can.

____

____

Did you notice that the elements in the first two columns of the periodic table had similar properties? An element often shares some properties with the elements either side of it in a row.

8. The elements described in Group 1 and Group 2 can also be called the s–block elements. What properties do the elements in the s–block have in common?
(Or which properties are shared along each row?)

____

____

Please check your predictions for rubidium and strontium in the Answer pages. You'll also find a list of common properties of s–block elements.

You have been able to predict the properties of some s–block elements by looking at the properties of nearby elements.

Here are some columns from the right hand side of the periodic table. They come from the area of the periodic table called the p–block.

S Sulfur 2,4,6 • yellow non–metal • melting point = 119˚C • reactive. Forms compounds with most elements when heated	**Cl Chlorine** 1,3,7 • greenish yellow non–metal • melting point = –101˚C • very reactive. Forms compounds with most elements	**Ar Argon** • colourless non–metal • melting point = –189˚C • unreactive. Doesn't form compounds
Se Selenium 2,4 • red or grey metalloid • melting point = 217˚C • moderately reactive. Forms compounds with most elements when heated	**Br Bromine** • • •	**Kr Krypton** 2 • colourless non–metal • melting point = –157˚C • forms a very small number of compounds

Te Tellurium 2,4,6 • grey or grey–black metalloid • melting point = 450°C • combines readily with oxygen, halogens and metals	**I Iodine** 1,5,7 • black non–metal • melting point = 114°C • reacts with most metals and many other elements	**Xe Xenon** 2,4,6 • colourless non–metal • melting point = –112˚C • forms a small number of compounds
Po Polonium • • •	**At Astatine** 1,5 • metalloid • melting point = 302°C • forms some compounds	**Rn Radon** • • •

Study the section of the periodic table above.
Look for the similar properties in each column and in each row.
Compare each element with those that surround it.
Look for the trends that occur in each column.

Using the information about the elements shown from the p–block, predict three properties of:

a) polonium ____

____

____

b) bromine ____

____

____

c) radon ____

____

____

Check your answers.

Now complete Exercise 3.2

You can also use the periodic table to predict the properties of elements that have yet to be discovered. To do this, you need to know some of the patterns in the properties of elements. But before you do this, look at some different ways of presenting the periodic table.

Different types of periodic table

The periodic table you made using element cards and periodic tables you have seen in texts are not the only forms of the periodic table.

Here is the periodic table like the one you used in *The chemical earth*.

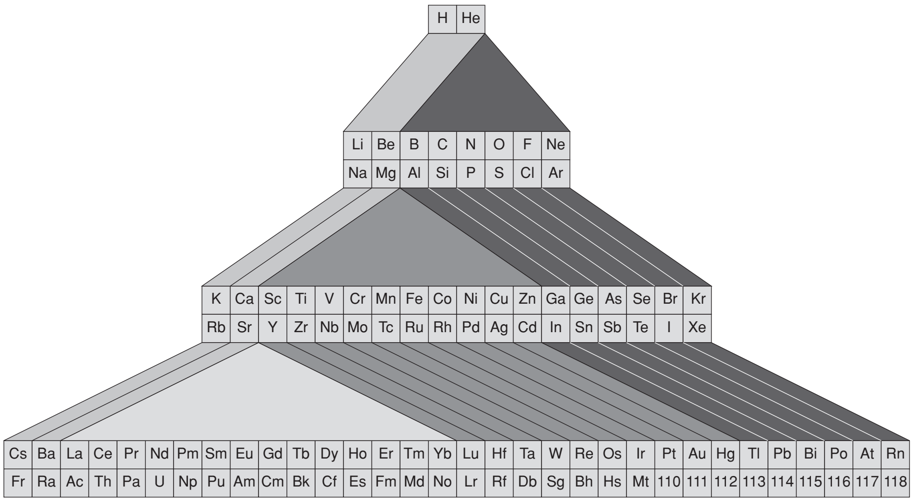
Key	
1 H Hydrogen	Atomic number Symbol Name

Group 1	Group 2	Group 3	4	5	6	7	8	9	10	11	12	Group 13	14	15	16	17	Group 18
1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57-71 LANTHANIDES	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89-103 ACTINIDES	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Uun Ununnilium	111 Uuu Unununium	112 Uub Ununbium	113	114 Uuq Ununquadium	115	116 Uuh Ununhexium	117	118 Uuo Ununoctium

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

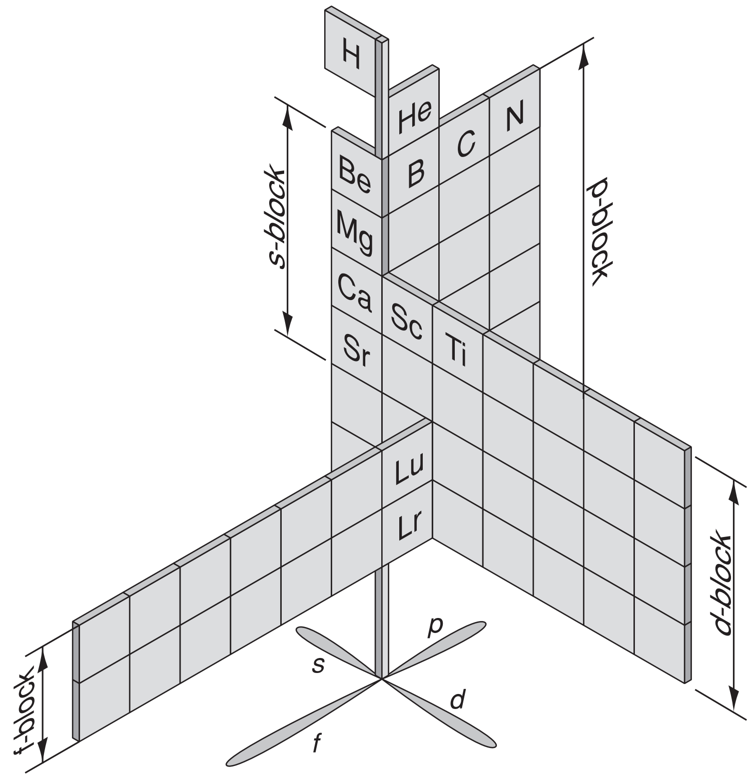
This periodic table includes the more recently discovered elements. Also notice that the groups are numbered from 1 to 18 across the table instead of from I to VIII. For example, Group V is now called Group 15.

There are also other ways to present a periodic table.

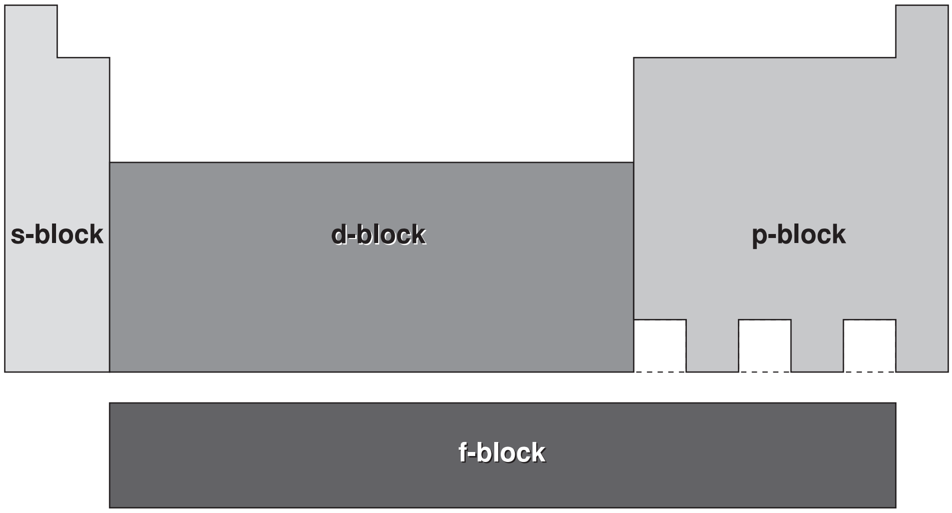


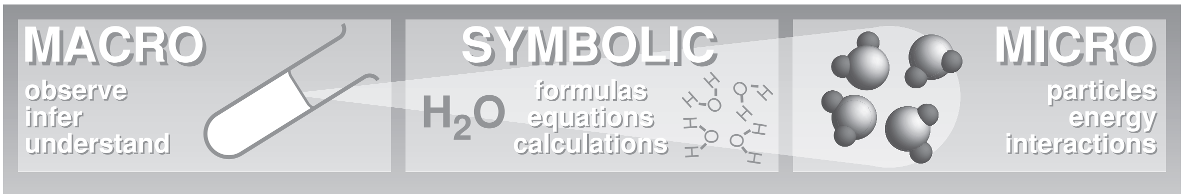
The pyramidal periodic table above was developed by William Jensen in the 1990s to show the balanced way that properties of elements repeat.

Periodic tables can also be built as three dimensional pyramids and on three dimensional axes such as the one by Paul Giguère below.



The s, p, d and f blocks are shown below for the type of periodic table you will use most of the time. The blocks are based on the arrangement of electrons in the s, p, d and f subshells of atoms of the elements.


s-block
d-block
p-block
f-block



Patterns in the periodic table

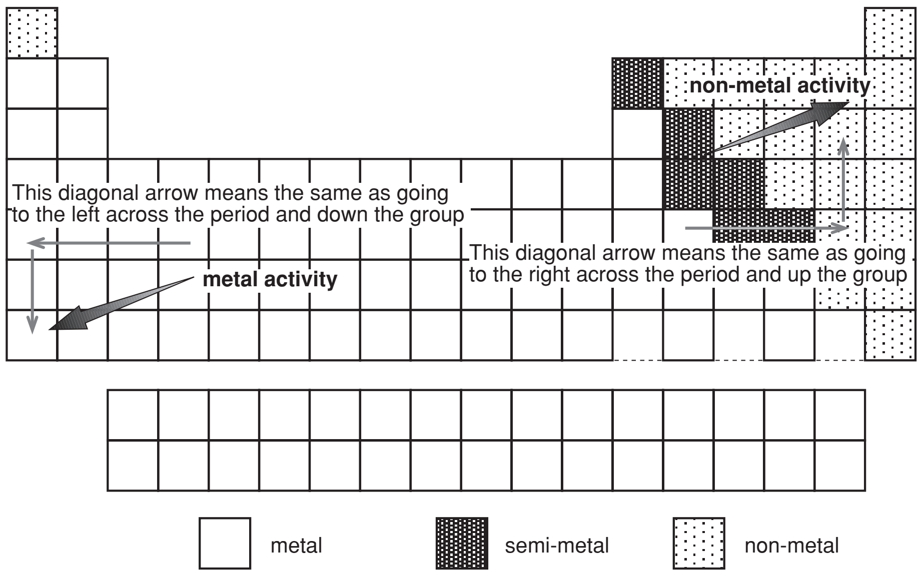
You have already noted some of the patterns in properties within the periodic table. In Part 2 of *The chemical earth*, you found patterns in the melting and boiling points of elements. In Part 2 of this module, *Metals*, you identified a pattern in the chemical reactivity of metals.

Turn to Exercise 3.3 where you will use computer–based technology to produce a table and a graph of changes in first ionisation energies across a period and down a group. Tables and graphs are useful ways of showing patterns.

Many important patterns in the periodic table relate to the metallic (and non–metallic) character of elements.

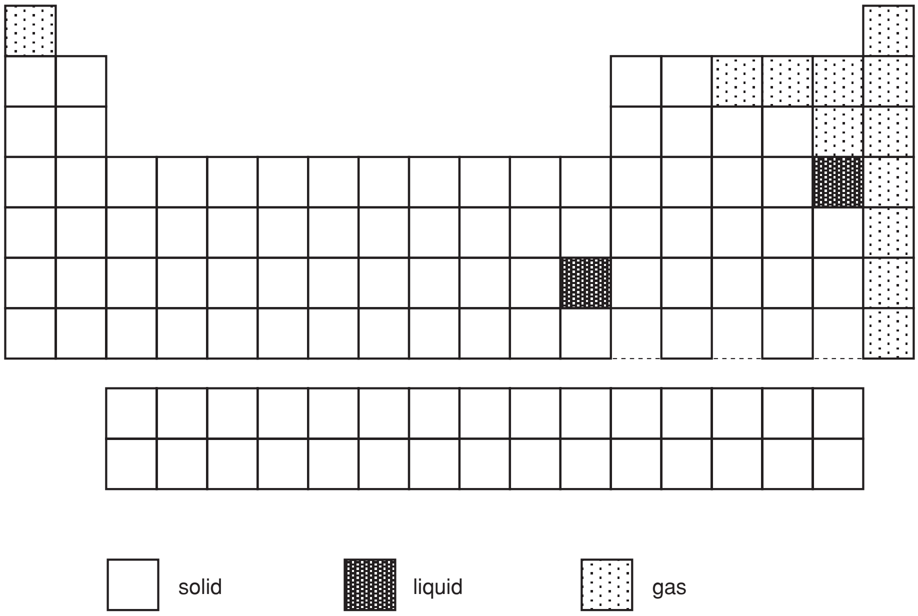
Metallic character

You can explain many patterns in the properties of elements by referring to the classification of elements as metals, semi–metals (metalloids) and non–metals.



Melting and boiling points

Melting and boiling points determine the states of elements. The states at 25°C and 101.3 kPa atmospheric pressure are shown on the periodic table below.



1 Write generalisations about the trends in melting and boiling points for elements in the periodic table.

____

____

____

____

____

2 Explain the patterns you have observed.

____

____

____

____

Check your answers.

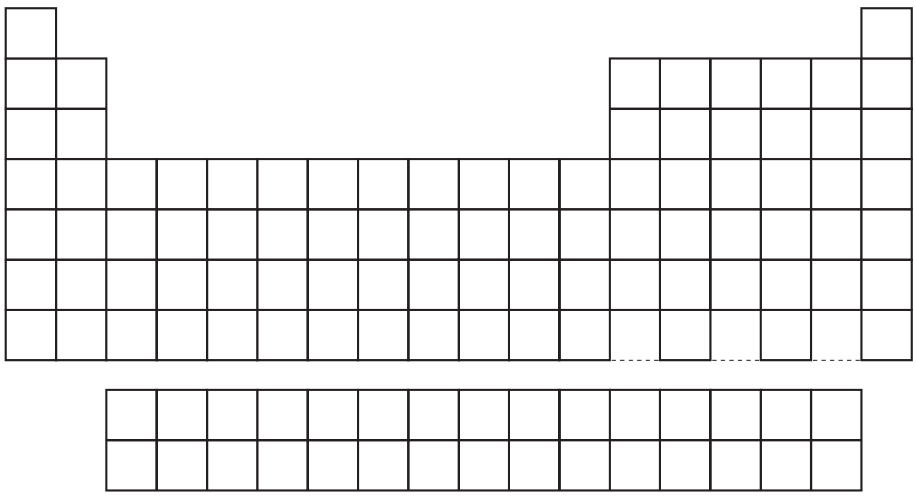
Electrical conductivity

Electrical conductivity is another property that can be readily explained by referring to changes in metallic character across the periodic table.

In Part 5 of *The chemical earth* you learnt about metallic bonding. Metals are good conductors of electricity because they form lattices in which outer (valence) electrons can move freely through the lattice.

In elements other than metals, atoms are covalently bonded and most electrons are shared between atoms. Electrons are not free to move and so these elements are unable to conduct electricity. The exceptions are semi–metals, such as silicon, and the unusual layered covalent lattice of the carbon allotrope, graphite. Graphite's unusual structure leaves some electrons free to move.

On the periodic table below, draw an arrow to show the way that electrical conductivity tends to increase in the periodic table.

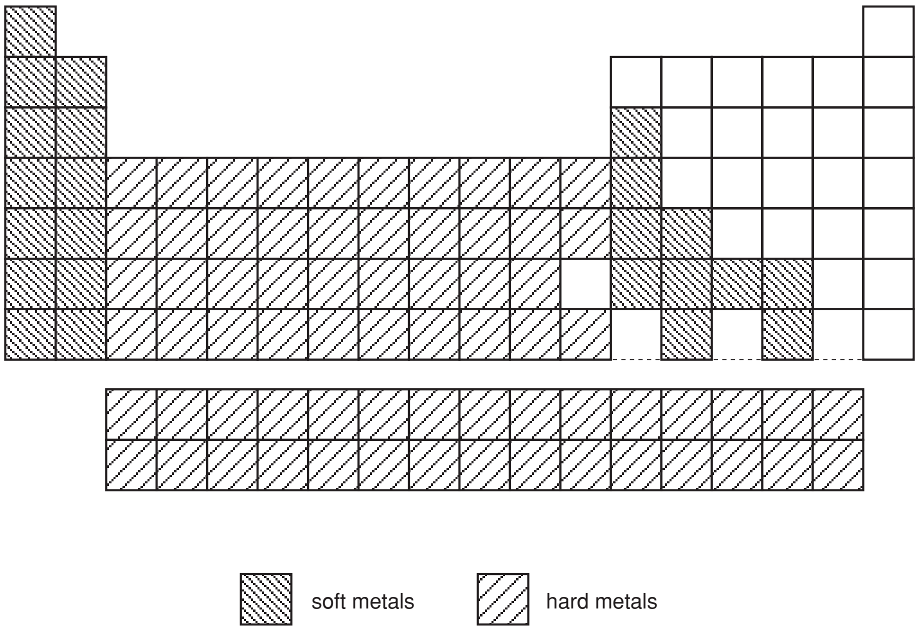


Check your answer now.

Hardness

How hard is a solid? Describing the hardness of elements usually applies to metals because most elements are metals and all but one are solid. There is little value in rating the hardness of non–metals that are liquids or gases. Non–metals that are solid are usually brittle and crack easily.

Metals can be classified as hard or soft. Hard metals are sometimes called engineering metals because of their uses in construction and machinery.



Write a generalisation about the pattern of hardness for metals in the periodic table.

____

____

____

Check your answer.

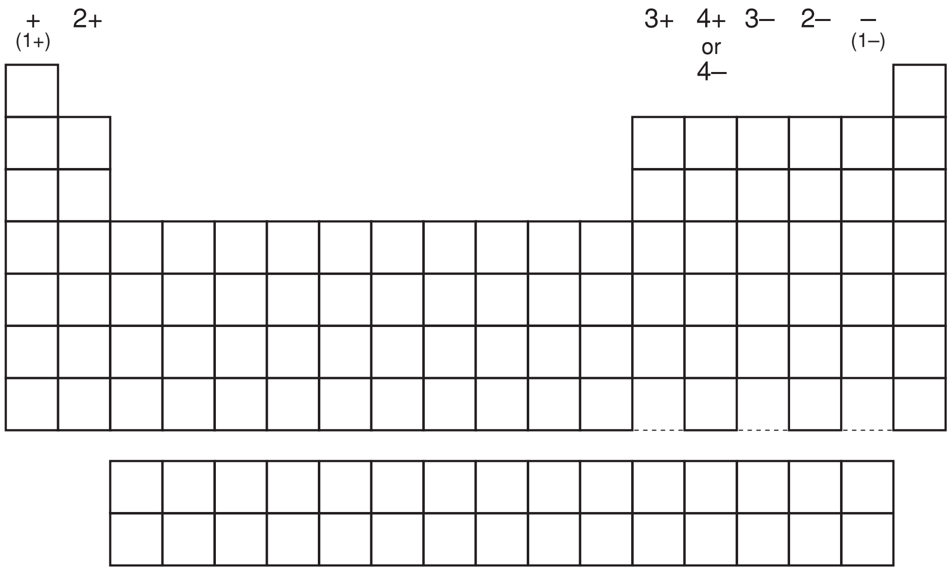
The properties you have considered so far – melting and boiling points, electrical conductivity and hardness – are readily testable for elements. There are other properties that are more difficult to test and measure that have patterns across the periodic table too. These include combining power, ionisation energy, atomic radius and electronegativity.

Combining power (valency)

When elements combine, they may gain, lose or share electrons. You've seen that atoms of metals lose electrons to form positive ions. However, non–metallic atoms tend to share electrons or gain them to become negatively charged.

The number of electrons that an atom typically gains or loses to become an ion is sometimes called the element's combining power, or valency. (A combining power is not usually given a positive or negative charge).

You considered the pattern in which ions are formed in Part 3 of *The chemical earth*.



The combining power, or valency, is the size of the charge on the ion.

1 When would you use these patterns in combining powers?

____

____

2 Why is there no ion listed for the last column (Group 18) of the table?

____

____

Check your answers.

Ionisation energy

Use the table and graphs from Exercise 3.3 to help complete this work:

1 Complete the sentences below about first ionisation energies.

- First ionisation energy is the amount of energy needed to remove one ………… from a ………… atom.
- First ionisation energy ………… down Group 1 since metallic character increases down the group
- However, first ionisation energy increases across a ………… as elements become less active as metals.

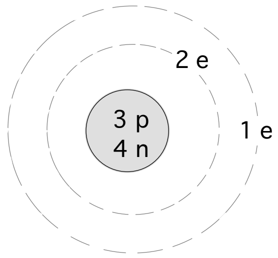
2 How easily will non–metals tend to lose electrons? Predict the trend in first ionisation energy for Group 17 (halogens).

Check your answers.

Atomic radius

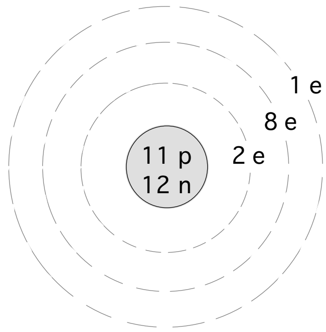
How does atomic size change down a group?

Examine the diagrams at the side which show the first three members of group 1. These diagrams show the relative size of the atoms as well as the electronic structure and nuclear structure.



lithium

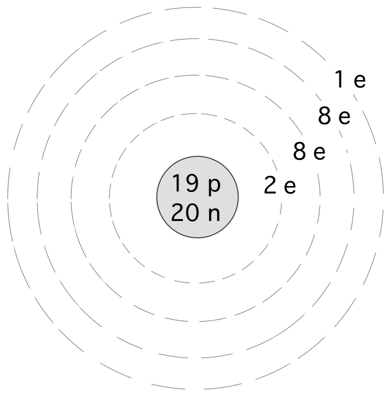
Note that as the number of electron shells increase so does the atomic size increase.



sodium

If you examined information for all groups you would see that atomic radius increases down each group because atoms become larger by having more electron shells.

You might guess that atoms will also become bigger as you move across a period, since as the atomic number increases, the atom gains more protons and electrons.



potassium

However, this is not what actually happens. To compare the sizes of atoms across a period, you need to consider how strongly the nucleus of each atom can attract its own electrons.

Think about first ionisation energies again.

____

____

Check your answers.

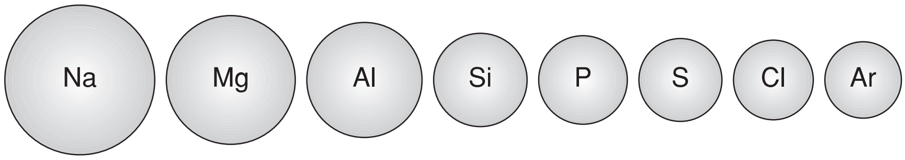
Across a period electrons are going into the same electron shell but the nuclear charge (number of protons) attracting them is increasing.

From these answers you might predict that noble gases will have smaller atoms because the electrons will be pulled strongly towards their nuclei.

And alkali metals will have larger atoms because electrons are held less tightly. Let's see if this is so.

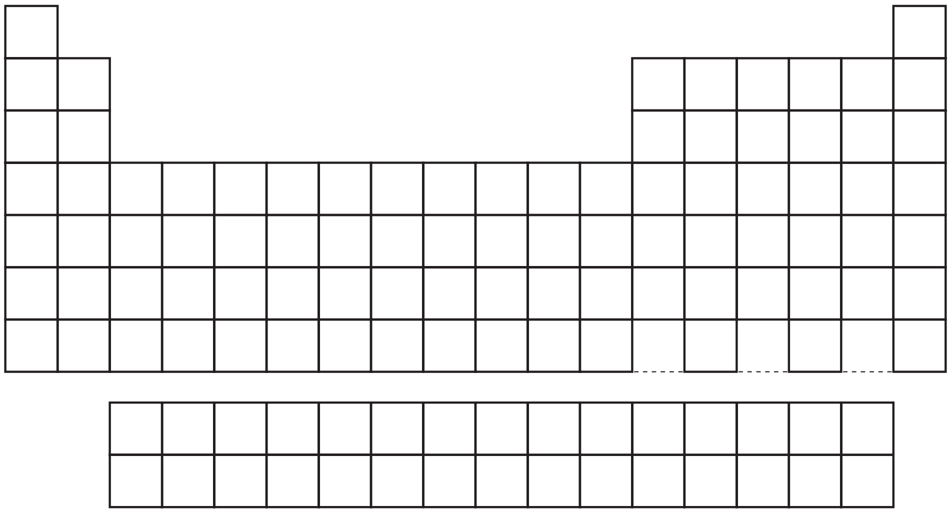
How does atomic size change across a period?

Compare the size of the atoms from sodium to argon in the third period of the periodic table:



You can see that non–metallic nuclei attract their outer electrons more strongly than metallic nuclei of the same period.

Summarise these two trends, down a group and across a period, by drawing an arrow onto the periodic table below. Label your arrow, increasing atomic radius.



There is a labelled arrow on the periodic table in the answer pages.

Electronegativity

Electronegativity is the ability of a neutral atom to attract extra electrons.

The alkali metals in Group 1 with low ionisation energies readily lose an electron. They have a low attraction for extra electrons and so are said to have low electronegativity.

The non–metal halogens in Group 17 do not readily lose electrons. They have a strong attraction for electrons, often forming negative ions. Thus halogens have high electronegativity.

The concept of electronegativity is not usually used with the noble gases of Group 18. These stable atoms have the highest ionisation energies but the concept of electronegativity is not usually applied to them as they hardly ever attract electrons or other atoms.

The periodic table below shows the increasing trend in electronegativity.

1 What is the trend in electronegativity in this periodic table?

____

____

2 Explain why this pattern occurs.

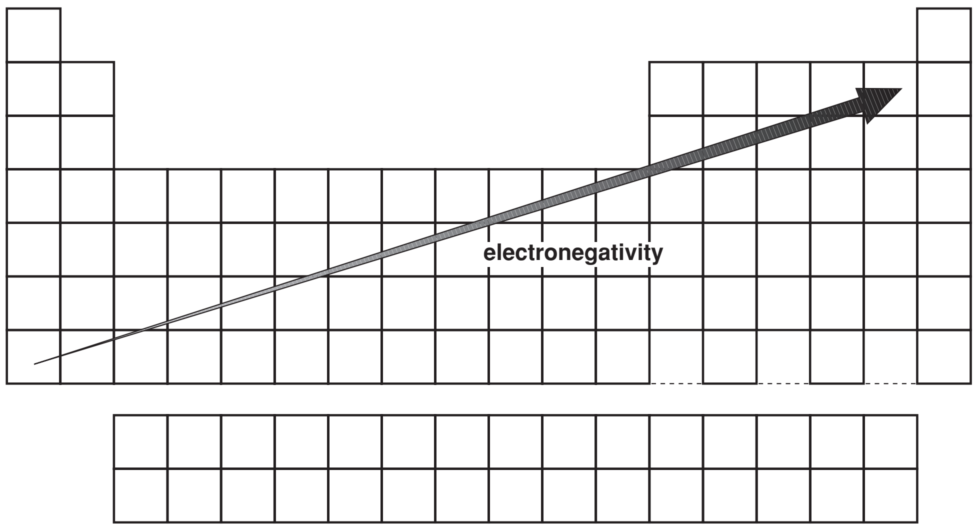
____

____

____

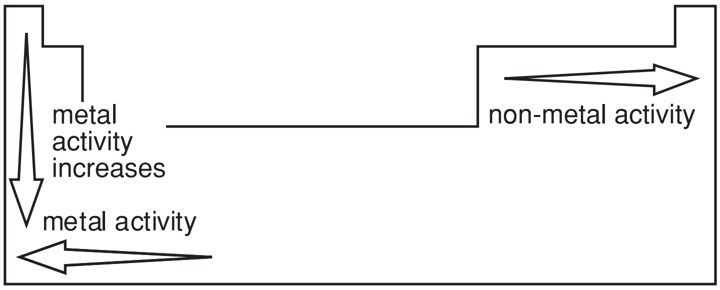
____

Check your answers before you continue.



Reactivity

In Part 2 you looked at trends in activity in the Periodic Table.



Trends in metal and non–metal activity

In a school chemistry context, activity and reactivity refer to the same thing. A metal of high activity from is said to be very reactive or have high reactivity. Similarly, a non–metal of high activity is said to be very reactive. Active elements readily react. Thus elements of high activity are said to have high reactivity.

Note that the noble gases of Group 18, in the last column of the Periodic Table, have extremely low activity. Some elements in this group have never formed any compound with any other elements.

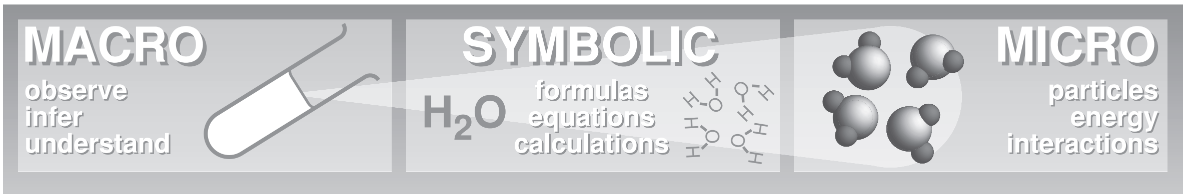
Complete the statements below by selecting one of the possibilities:

1 The Group of lowest reactivity is Group (1/2/12/13/18).

2 The most reactive metal is predicted to be (Fr/Li/Ra/Po).

3 The most reactive non–metal is predicted to be (He/F/At/Rn).

Throughout this section, you have been identifying and explaining trends in the properties of elements in the periodic table. Complete Exercise 3.4 now about some of these relationships.



Suggested answers

Developing the periodic table

The metals are lithium, beryllium, sodium, magnesium, aluminium, potassium and calcium.

The non–metals are hydrogen, helium, boron, carbon, nitrogen, oxygen, fluorine, neon, silicon, phosphorus, sulfur, chlorine and argon.

Lavoisier would not have known all the atomic masses and boiling points so he could not have used these to organise his table. Neither did he use the symbols for the elements as these were not developed until the early 1800s.

Atomic mass and atomic weight

1 The carbon atom shown has a mass number of 12. (It has 6 neutrons and 6 protons)

mass number = 6 protons + 6 neutrons = 12

2 Carbon–14, ^{14}C, has 14 – 6 = 8 neutrons.

Identifying isotopes

1 ${}^{2}_{1}H$

2 ${}^{131}_{53}I$

3 ${}^{238}_{92}U$

Predicting properties of elements

6. Rubidium is probably a silver–white metal with a valency of 1 and a melting point of about 50°C. It will be very reactive.

7. Strontium is probably a silver–white metal with a valency of 2 and a melting point of about 760°C. It will be very reactive, and will probably form an oxide in air and react vigorously with water.
8. They are all reactive and all metals. Except for beryllium which is grey and has a high MP of 1280°C they tend to be silver–white and have low MPs.

a) polonium
Predicted properties: A solid radioactive metal. Its MP is probably higher than 450°C and it is probably less reactive than tellurium.
Actual properties: A radioactive metal with a MP of 254°C. Forms a variety of compounds.

b) bromine
Predicted properties: A dark–coloured non–metal. Its MP is probably about 0°C, so it could be a liquid. It will form many compounds.
Actual properties: A dark red non–metal with a MP of –7°C, thus a liquid. It forms many compounds.

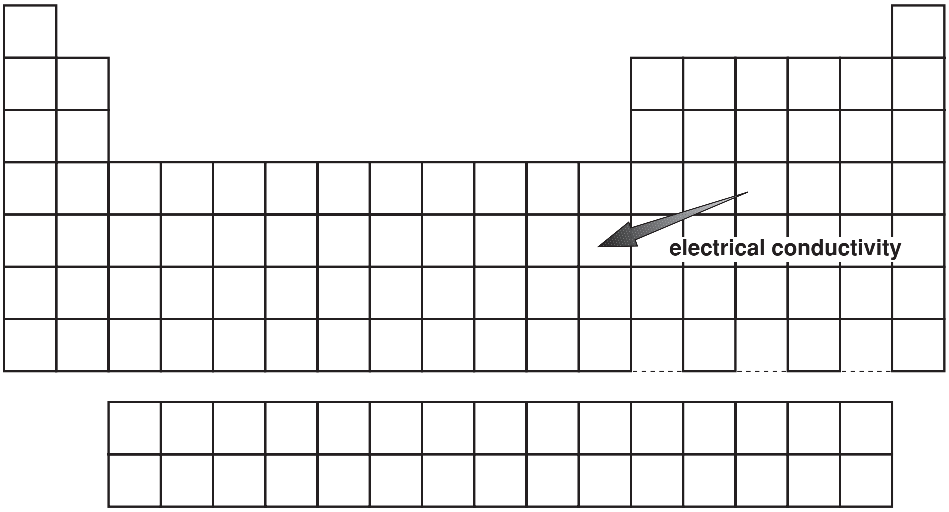
c) radon
Predicted properties: A radioactive non–metallic gas. It probably has a low MP of about –90°C. It probably forms many compounds.
Actual properties: A radioactive non–metallic gas with a MP of –71°C. It forms many compounds.

Melting and boiling points

1 Melting and boiling points tend to initially increase then decrease across a period. They usually increase down a group. However, there is considerable variation in the melting and boiling points of metals; most transition metals tend to have very high melting and boiling points. (See *The chemical earth*, Part 2 for values of melting and boiling points for most elements.)

2 Non–metals tend to have low melting and boiling points (as they typically form small molecules held together by weak intermolecular attractions); metals usually have higher melting and boiling points (because they have a lattice structure held together by strong metallic bonds).

Electrical conductivity



Hardness

Most transition metals (Groups 3 to 12) are hard but other metals tend to be soft.

Combining power (valency)

1 Patterns in combining powers are useful for writing the formulas of compounds.

2 The elements in Group 18 (He, Ne, Ar and so on) do not form ions. They seldom form compounds at all.

Ionisation energy

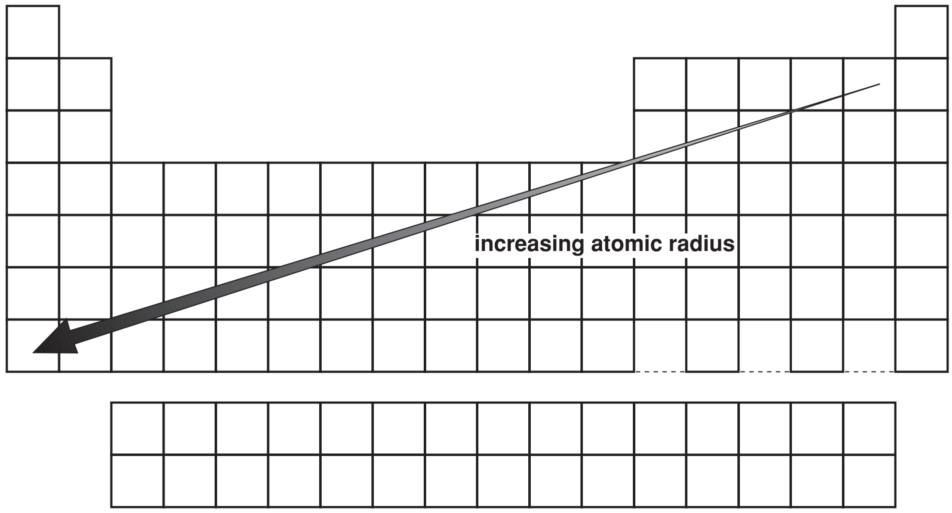
1
- First ionisation energy is the amount of energy needed to remove one *electron* from a *gaseous* atom.
- First ionisation energy *decreases* down Group 1 since metallic character increases down the group.
- However, first ionisation energy increases across a *period* as elements become less active as metals.

2 Non–metals form negative ions, not positive ions, so they do not readily lose electrons. Fluorine is the least like a metal in its group so it will be the hardest to ionise by removing an electron. Thus, you can generalise that ionisation energy decreases down Group 17.

Atomic radius

a) Group 18, the noble gases

b) Group 1, the alkali metals.



Electronegativity

1 Electronegativity decreases down a group but increases across a period.

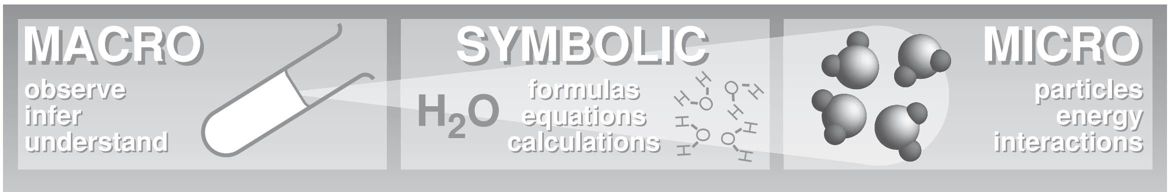
2 Elements increase in metal activity towards the bottom left corner of the periodic table. This means the ability to lose an electron increases and the ability to attract extra electrons decreases; hence a decrease in electronegativity. Elements decrease in metal activity towards fluorine, near the top right hand corner of the table. That is, they increase in non–metal behaviour. Non metal atoms are more likely to attract additional electrons to form negative ions.

Reactivity

1 The Group of lowest reactivity is Group 18

2 The most reactive metal is predicted to be Fr (Francium).

3 The most reactive non–metal is predicted to be F (Fluorine).



Appendix: Element cards

Al Aluminium 3

- silver–white, light solid
- boiling point = 2450˚C
- atomic mass = 26.98
- oxide layer prevents it from reacting rapidly in water or air. Reacts with acids

Ar Argon

- colourless gas
- boiling point = –186˚C
- atomic mass = 39.95
- unreactive. Doesn't form compounds

Be Beryllium 2

- grey, hard, brittle solid usually covered with oxide coating
- boiling point = 2480˚C
- atomic mass = 9.012
- burns when heated, slow reaction with water and acid

B Boron 3

- dark brown, hard and brittle solid
- boiling point = 3900˚C
- atomic mass = 10.81
- relatively unreactive. Burns in air and reacts with halogens.

C Carbon 4

- black or colourless solid
- boiling point = 4830˚C
- atomic mass = 12.01
- burns in air and reacts with halogens

Cl Chlorine 1,7

- greenish yellow gas
- boiling point = –35˚C
- atomic mass = 35.45
- very reactive. Forms compounds with most elements

F Fluorine 1

- light yellow gas
- boiling point = –188˚C
- atomic mass = 19.00
- very reactive. Forms compounds with most elements

He Helium

- colourless gas
- boiling point = –269˚C
- atomic mass = 4.003
- unreactive. Doesn't form compounds

Ca **Calcium** **2**

- silver–white, soft solid
- boiling point = 1490˚C
- atomic mass = 40.08
- very reactive. Quickly forms an oxide in air and reacts rapidly with water

H **Hydrogen** **1**

- colourless gas
- boiling point = –253˚C
- atomic mass = 1.008
- Very reactive. Explodes with oxygen and halogens. Forms compounds with most elements

Li **Lithium** **1**

- silver–white, light solid
- boiling point = 1330˚C
- atomic mass = 6.941
- reactive. Rapidly forms an oxide in air and reacts with water

P **Phosphorus** **3,5**

- white, red or black solid
- boiling point = 280˚C (white form)
- atomic mass = 30.97
- reactivity varies with different forms. Reacts with oxygen, sulfur and halogens.

Mg **Magnesium** **2**

- silver–white, very light solid
- boiling point = 1110˚C
- atomic mass = 24.31
- burns when heated in air, reacts very slowly with water

K **Potassium** **1**

- silver–white, soft solid
- boiling point = 760°C
- atomic mass = 39.10
- very reactive. Rapidly forms an oxide in air and reacts violently with water

Ne **Neon**

- colourless gas
- boiling point = –246˚C
- atomic mass = 20.18
- unreactive. Doesn't form compounds

Si **Silicon** **4**

- grey solid
- boiling point = 2680˚C
- atomic mass = 28.09
- reacts with oxygen and halogens when heated. In nature, always part of a compound

N	Nitrogen	3,5

- colourless gas
- boiling point = –196˚C
- atomic mass = 14.01
- fairly unreactive. When heated, reacts with metals. Also reacts with oxygen and hydrogen

Na	Sodium	1

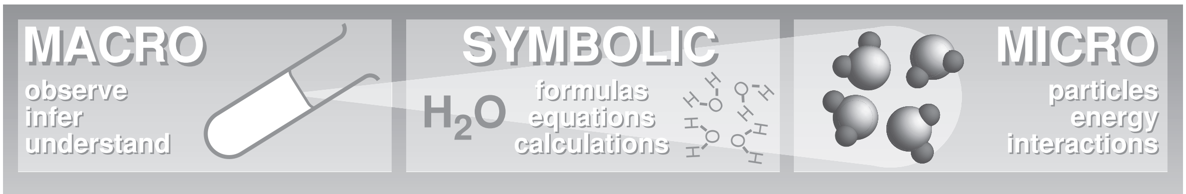
- silver–white, soft solid
- boiling point = 892°C
- atomic mass = 22.99
- very reactive. Rapidly forms an oxide in air and reacts vigorously with water

O	Oxygen	2

- colourless gas
- boiling point = –183˚C
- atomic mass = 16.00
- When heated, reacts with most elements

S	Sulfur	2,4

- yellow solid
- boiling point = 445˚C
- atomic mass = 32.06
- reactive. Forms compounds with most elements when heated



Exercises Part 3

Exercises 3.1 to 3.4 Name: ______________________________

Exercise 3.1: Developing a periodic table

Outline how the following scientists contributed to the development of the periodic table.

Lavoisier ______________________________

____

____

Döbereiner ______________________________

____

____

Newlands ______________________________

____

____

Meyer and Mendeleev ______________________________

____

____

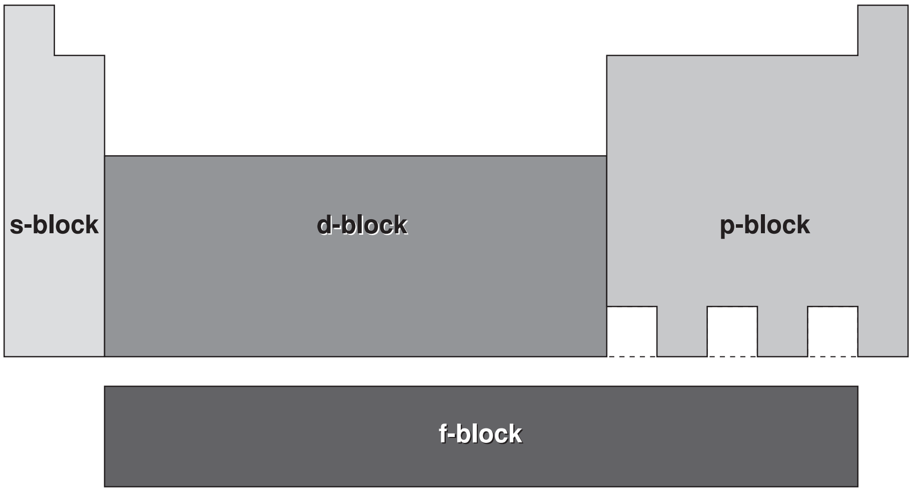
____

Exercise 3.2: Predicting from a periodic table

1 What prediction did Mendeleev make regarding elements from the periodic table he helped develop?

2 Why was the prediction of undiscovered elements made?

3 Make a prediction from the periodic table



for one of the recently made elements in the bottom, incomplete row, of the p–block.

(These elements have only been made a few atoms at a time. It may be decades, even centuries, before sufficient of these elements are made to confirm the many predictions that can be made using the periodic table).

Exercise 3.3: Using computer–based technologies

produce a Periodic table and graphs of first ionisation energies from the information in this table.

Atomic No.	First ionisation energy (kJ/mol)	Atomic No.	First ionisation energy (kJ/mol)	Atomic No.	First ionisation energy (kJ/mol)
1	1318	20	596	39	606
2	2379	21	637	40	666
3	526	22	664	41	670
4	906	23	656	42	691
5	807	24	659	43	708
6	1093	25	724	44	717
7	1407	26	766	45	726
8	1320	27	765	46	811
9	1687	28	743	47	737
10	2087	29	752	48	874
11	502	30	913	49	565
12	744	31	585	50	715
13	584	32	768	51	840
14	793	33	953	52	876
15	1018	34	947	53	1015
16	1006	35	1146	54	1177
17	1257	36	1357	55	382
18	1527	37	409		
19	425	38	556		

In Exercise 2.1 of *The chemical earth* module you should have accessed and used a spreadsheet program. Using a spreadsheet program and then printing out a table and graphs is using computer based technologies.

The instructions given below are general guidance only. If you know someone who has experience using spreadsheets they could assist you.

1 Access a spreadsheet program on a computer. Reduce the width of the cells so that you have at least 20 cells visible across the screen. You will now be able to see the whole of your periodic table at once.

2 Make sure you get the appearance of a periodic table by leaving some of the cells empty. Look at the top half of the Periodic Table grid at the start of exercise 3.4 to see the general shape of your table.

3 Enter numerical data from the table for Group 1. Use the Periodic Table on the inside cover of this part to check the position of atomic numbers 1, 3, 11, 19 and 37.

4 Next enter the numerical data for the period running from atomic number 19 to 36. You should find it easier now to enter the rest of the numerical data if you wish.

5 Save the spreadsheet you have created so far.

6 Highlight (darken on the screen) a rectangular shape that includes all the information for a period.

7 Go to the chart producing icon (called Chart Wizard if you are using an Excel spreadsheet). Choose a line chart (graph).

8 Produce a graph with appropriate labeling to show the change in first ionisation energy across a period.

9 Print out a copy of your graph.

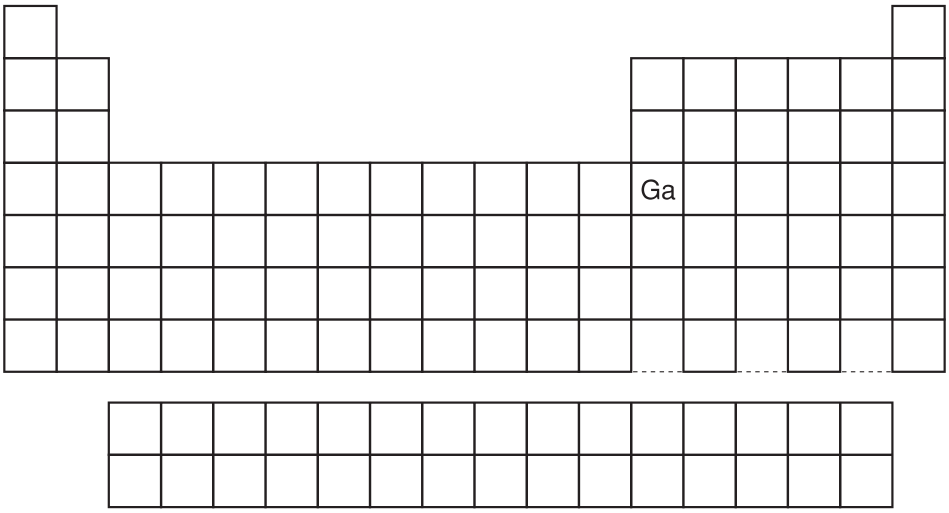
10 Repeat steps 6 to 9 using information for a vertical group instead of a horizontal period.

11 Add printed information to the spreadsheet saved in step 5 to produce an appropriately labeled periodic table. (Your periodic table will not be a full Periodic Table as you have only been provided with data for the first 55 elements or top half of the full Periodic Table.) Print a copy of your table.

12 Return a copy of your table, a period graph and a group graph with your send in exercises.

Exercise 3.4 : Patterns in the periodic table

Gallium has an atomic number of 31. Its position in the periodic table is shown below.



Using the patterns that you have learnt about in this part, predict the properties listed below for gallium. Explain why you make each prediction – you may need to refer to the properties of other elements to make your answers clear.

1 **electrical conductivity** ______________________________

Why? ______________________________

____

____

2 **ionisation energy** ______________________________

Why? ______________________________

____

____

3 **atomic radius** ______________________________

Why? ______________________________

____

____

4 **melting point** ______________________________

Why? ______________________________

____

____

5 **boiling point** ______________________________

Why? ______________________________

____

____

6 **combining power (valency)** ______________________________

Why? ______________________________

____

____

7 **electronegativity** ______________________________

Why? ______________________________

____

____

8 **reactivity** ______________________________

Why? ______________________________

____

____

Chemistry

Preliminary Course
Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING
TAFE NSW
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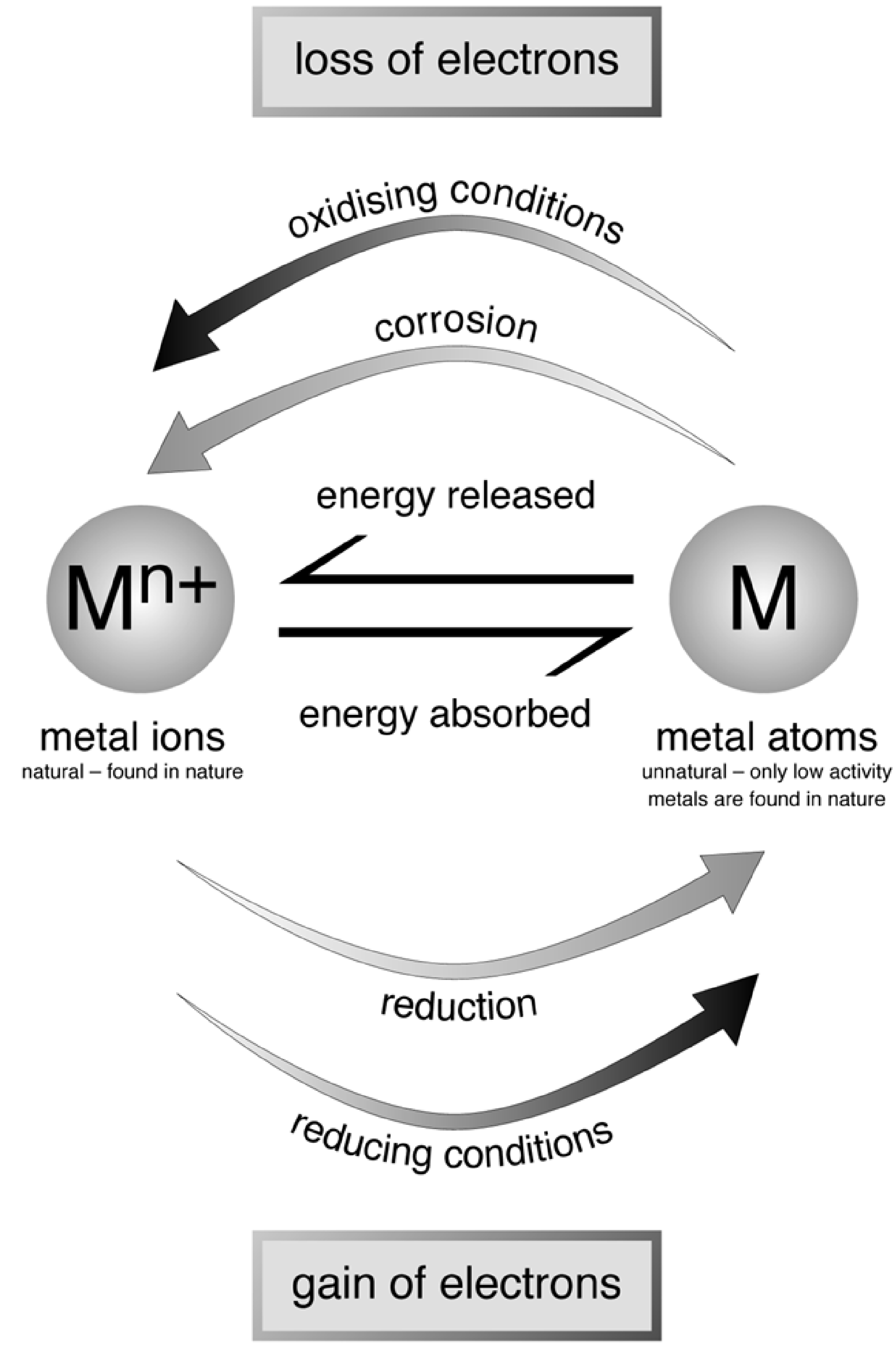
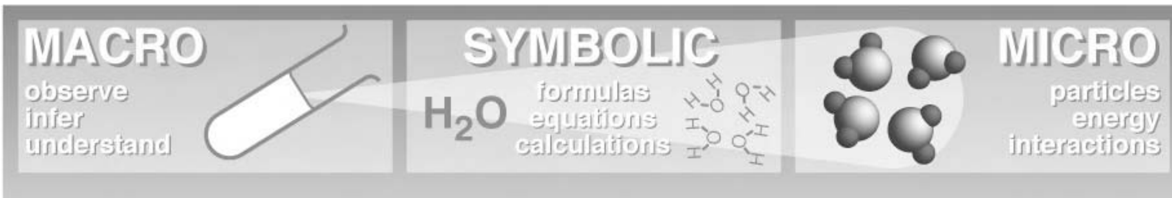
Metals

Part 4: Metal extraction from ores

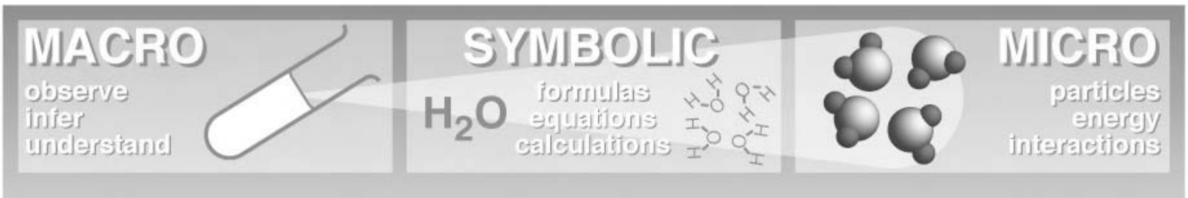
Incorporating October 2002 AMENDMENTS



loss of electrons
oxidising conditions
corrosion
energy released
M^{n+}
M
energy absorbed
metal ions
natural – found in nature
metal atoms
unnatural – only low activity metals are found in nature
reduction
reducing conditions
gain of electrons


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

Contents



Introduction

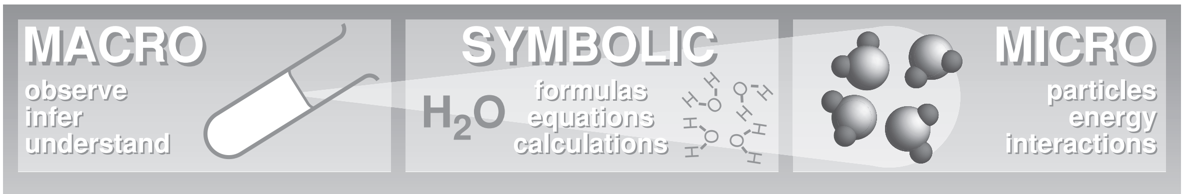
In Part 4 you will study how the type and amount of energy required to extract metals and how relative abundance of ores influences the value and breadth of use of metals in the community.

In this part you will be given opportunities to learn to:

- define the terms mineral and ore with reference to economic and non–economic deposits of natural resources
- describe the relationship between the commercial prices of common metals, their actual abundances and relative costs of production
- explain why ores are non–renewable resources
- describe the separation processes, chemical reactions and energy considerations involved in the extraction of copper from one of its ores
- recount the steps taken to recycle aluminium.

In this part you will be given opportunities to:

- justify the increased recycling of metals in our society and across the world
- analyse information to compare the cost and energy expenditure involved in the extraction of aluminium from its ore and the recycling of aluminium.



Minerals and ores

In the first module, *The chemical earth*, a mineral was defined as a useful element or compound from the earth. A mineral could be found in the biosphere, lithosphere, hydrosphere or atmosphere.

1 A number of useful elements or compounds include alumina, iron(III) oxide, oxygen, carbon (charcoal and diamond), copper carbonate and sodium chloride. Complete the table below showing the sphere from which these minerals are mostly extracted.

Mineral	**Element/ compound**	**Formula**	**Sphere**
alumina		Al_2O_3	
	element		biosphere
copper carbonate		$CuCO_3$	
diamond			
iron(III) oxide		Fe_2O_3	
			atmosphere
		NaCl	

2 Which sphere is the main source of minerals?

____

3 From which part of this sphere are most minerals extracted?

____

Check your answers.

For websites that show how applied science is trying to discover hidden minerals refer to the chemistry web page: http://www.lmpc.edu.au/science

Only the very low activity metals such as gold and platinum are found in nature as the metal. Even then they are often not in pure metal form but alloyed with other metals such as silver or palladium.

Silver, mercury and copper are occasionally found in the metal form but mostly as sulfide compounds. Apart from meteorite iron (typically containing 10–15% nickel) all the other metals are found combined with non–metals in their minerals. Chemical reactions and considerable energy is required to separate the metal from non–metals in mineral compounds.

The common form in which the metal is mined is shown below in this metal activity series:

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

← Chl →Sate Carb ← Ox→ Side← Oxides →← Sides → free

Chl=chloride Sate=sulfate Carb=carbonate Ox=oxide Side=sulfide free=uncombined

In the first module an ore was defined as matter from the earth worth extracting a mineral from. Bauxite is an example of an ore worth extracting alumina mineral from Aluminosilicates (clays) although they contain aluminium are not ores – there is no economic way of extracting the aluminium. A bauxite deposit suitable for mining has high levels of Al_2O_3 and low levels of Fe_2O_3 and SiO_2.

Not all economic (financially profitable) mineral deposits in Australia are being mined. Environmental and political considerations can determine which deposits are mined. Uranium mining and mineral sands mining are two economically attractive activities that have been affected by environmental and political considerations.

Bauxite mining

Consider the mining of bauxite ore at Weipa in North Queensland and transport to Gladstone on the central Queensland coast for the separation of alumina mineral. Listed below are eleven activities in this process. Place a number from 1 to 11 to show the sequence (order) of these activities:

- topsoil above the bauxite stripped by scrapers and stored for reuse
- vegetation cleared
- grinding of bauxite and mixing with sodium hydroxide solution
- explosives used to break up hard deposits of bauxite

- bauxite transported to ship
- bauxite transported at sea
- screening of bauxite at Weipa to separate unwanted material
- washing and drying of bauxite
- alumina solution filtered, concentrated, cooled to form crystals
- alumina crystals dried in gas fired kilns
- front end loaders collect bauxite

Check your answers.

Decisions affecting mining

It is virtually impossible to pass a day in modern society without using a metal or eating or drinking a product that has come in contact with metal. Metal minerals are a major export earner for Australia.

Production varies from year to year. The approximate annual production from Australia mines is shown in the table below.

Mineral or metal product	Production per year (t)
iron ore	170 000 000
bauxite	50 000 000
ilmenite	1 500 000
zinc	1 300 000
lead	1 000 000
copper	600 000
rutile	500 000
zircon	350 000
nickel	150 000
uranium	5 000
gold	250

There are three main steps in producing metal:

1 Mining of the ore.

2 Beneficiation of the mineral – concentration and purification processes that improve desirable physical properties.

3 Metal extraction in a smelter involving chemical changes.

A single company may carry out all three steps. Small companies may just carry out mining or beneficiation near the ore body and pay a smelter to extract the metal.

Planning a mine project can take many years and can involve considerations such as:

- Government legislation eg in the past Australia has had restrictions on the number of operational uranium mines
- Effect on nearby communities. If at an isolated location, will a new town need to be built? Will employees want to live there or live elsewhere and travel to and from the mine site?
- Environmental impact and cost of pollution control and rehabilitation of the mine site
- Concentration and amount of ore – for how long will the mine be economic?
- Predictions of the price of metal when the mine is operating. Changes occurring elsewhere in the world can affect this.
- Transport costs for supplies and product.

Can you think of another consideration involving the amount of energy needed to extract the metal?

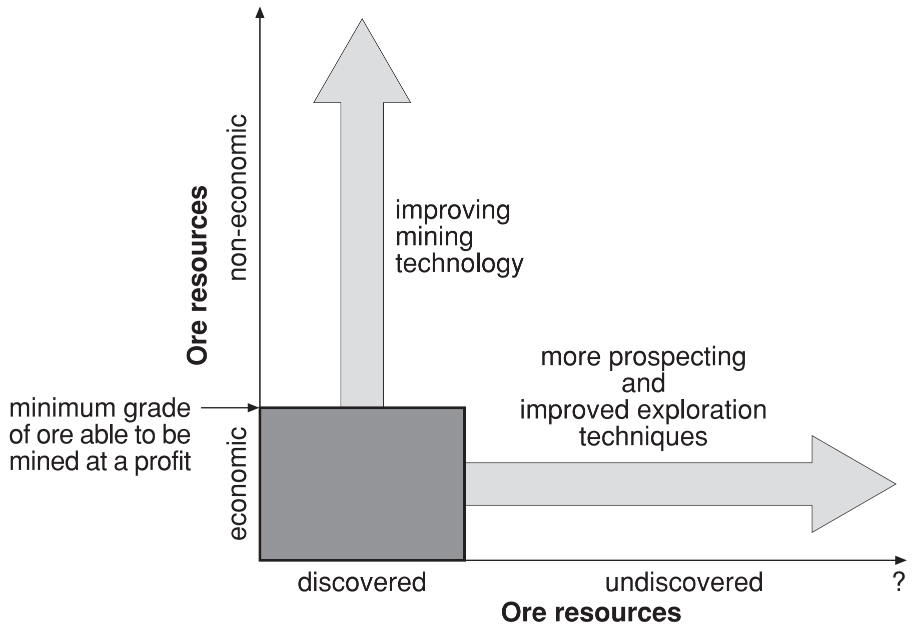
____

____

Check your answer.

Ores are classified as non–renewable resources. The rate at which ores are used by humans are many millions of times greater than the rates at which ores deposit as sediments or form near volcanoes.

Examine the graph on the next page which illustrates factors that can affect availability of an ore and hence the metal.



Factors affecting ore availability.

When there is a world shortage of a metal or the price rises there is incentive to invest in:

- improving mining technology
- ____
- ____

Check your answers.

At the present rate of world consumption the discovered ore resources (also called known reserves) will last less than 100 years for zinc, tin, lead, copper, silver, mercury and tungsten. Fortunately the ores of the two metals used in largest amounts, aluminium and iron, are available in enormous quantities, adequate for many hundreds of years.

The table below compares prices of selected metals and steel alloys. Use this information to answer the questions that follow.

1 Describe trend involving the minimum % of metal in the ore and the cost of the metal.

____

2 a) Can you see a metal that does not fit in with this trend?

____

b) How active is this metal compared with other metals costing similar amounts?

____

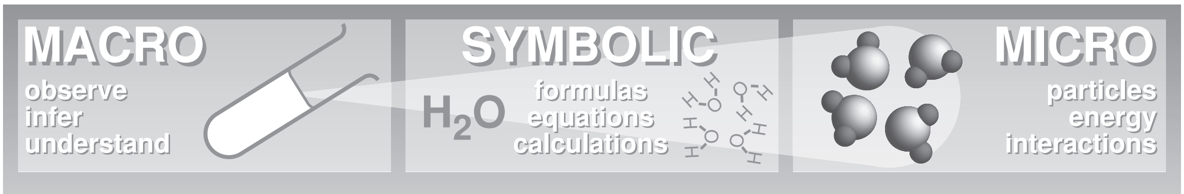
c) The ore of this metal is relatively easy to mine. Why is this metal so costly to extract? Refer to the energy used to extract this metal from the mineral in your answer.

____

____

Check your answers.

Material	**Minimum % by mass of metal in ore to mine economically**	**AUS$/kg (1994)**
platinum	0.0003	30 000
gold	0.0001	12 000
silver	0.006	1 000
stainless steel, tool steel	–	4
copper	0.5	3
aluminium	25	2
zinc	2	2
lead	3	2
mild steel, cast iron	30	1



Copper mining and extraction

The main copper ores mined in Australia are chalcopyrite $CuFeS_2$ and chalcocite Cu_2S. Near the Earth's surface the action of oxygen, carbon dioxide and water from the atmosphere change copper sulfide ores to green malachite $CuCO_3.Cu(OH)_2$ and blue azurite $2CuCO_3.Cu(OH)_2$.

The mining operation may be carried out in two stages. The first stage processes the greenish blue surface deposits while the second, longer stage processes the darker, deeper sulfide deposits.

Copper metal from copper carbonate

In this section you will carry out a practical activity to extract copper from copper carbonate. Then you will learn about and analyse the separation processes, chemical reactions, environmental and energy considerations in the extraction of copper from copper sulfides.

What you will need:

- copper (II) carbonate
- a burner (gas Bunsen burner/methylated spirit burner/pencil torch burner/candle) and matches
- small heat resistant test tube or ignition tube
- wooden peg or test tube holder
- 'white vinegar' that is colourless
- glass beaker or transparent plastic container
- iron/steel wool

Note: If you are using a candle flame you will need a paper towel or rag folded over on itself twice. Use this to clean soot (carbon) from the outside of the heated tube. You will then be able to see what is happening inside the tube.

What you will do:

1 Place about 5 to 10 rice grains volume of copper carbonate in a heating tube.

2 Light the burner then gradually heat the bottom of the heating tube.

3 Heat the green copper (II) carbonate until it has completely decomposed to black copper (II) oxide.

4 Allow the heating tube to cool in air for at least a minute then turn it upside down over the beaker. Gently tap the wooden peg/test tube holder against the edge of the beaker so that most of the black oxide falls out of the tube and into the beaker.

5 Cover the black oxide with at least 1 cm depth of vinegar (acetic acid, CH_3COOH, solution).

6 Observe what happens in the solution for five minutes. Are there any signs of reaction occurring?

   – is a gas released?
   – does a colour change occur?
   – does the beaker change temperature?

7 When most of the black oxide has reacted with the acetic acid solution place a length of iron wool in the solution leaving at least half of the iron wool out of the solution.

   Are there any signs of reaction occurring?

   – is a gas released?
   – does a colour change occur?
   – does the beaker change temperature?

After a few minutes lift the iron wool out of the solution and compare the parts that were below and above the solution.

Draw the appearance of the iron wool that has been in the copper acetate solution.

Explaining your observations:

1 Match the three observations a, b and c with the three equations by writing the equation after the observation.

$Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$

$CuCO_3 \rightarrow CuO + CO_2$

$CuO + 2CH_3COOH \rightarrow Cu(CH_3COO)_2 + H_2O$

a) green copper carbonate turned black on heating

b) black copper (II) oxide reacted with acetic acid forming soluble copper acetate and water

c) the more active metal iron displaced the less active metal copper from its solution

Match the equation descriptions with the equations by writing the equation letter (X, Y or Z) next to the equation.

X thermal decomposition equation

Y ionic equation

Z neutralisation of acid equation

2 Was energy absorbed or released in extracting copper form copper carbonate? Give reasons in your answer.

Check your answers.

Copper from sulfide ore

Copper ores contain much lower concentrations of metal than bauxite and haematite. The energy needed to extract a metal from an ore requires energy expenditure in mining, crushing and concentrating the ore, transporting minerals as well as energy to operate the smelter and refine the metal to a useable purity.

Metal	**Metal by mass of Earth's crust (%)**	**Typical ore**	**Typical metal by mass in ore (%)**	**Mineral**	**Metal by mass in mineral (%)**	**Energy to extract metal from ore (MJ/t)**
Al	8.2	bauxite	25	alumina	50	280 000
Fe	4.1	banded iron formation	30	haematite	70	55 000
Cu	0.00005	mixed copper sulfides	0.5 – 5	chalcopyrite, chalcocite	35–80	140 000 to 300 000

Analyse (identify components and the relationship between them; draw out and relate implications) the information in the table. Why do you think the energy to extract copper varies whereas the aluminium and iron figures are relatively fixed?

____

____

Check your answer.

A description of the process

The diagrams in the *Appendix* illustrate the extraction of copper in Australia. Two features of this process – **froth flotation** and stainless steel cathodes – were developed first in the Australian mining industry and are now applied world–wide.

Read the notes that follow to help you understand the two page diagram. After reading all of this information you must analyse the information and answer questions.

The ball mill contains hard steel balls which are lifted up as the ball mill rotates. The balls fall down on lumps of copper ore breaking them into smaller pieces.

Froth flotation uses the different surface properties of sulfide minerals and **gangue** (waste) minerals. The flotation chemicals added are complex organic molecules called collectors and frothers.

The collectors adhere to the surface of the sulfide mineral grains and prevent them from being wetted by the water. The frothers act like detergents and produce stable bubbles which float up to the surface.

The collectors are not attracted to water and cause the sulfide mineral grains to collect in the rising air bubbles. Although the sulfide mineral grains are denser than the water they rise because they are attached to low density air bubbles and concentrate in the froth which overflows from the tank.

After drying the copper sulfides are heated in contact with air and SiO_2 in the smelter. The iron oxide formed by heating in air forms a slag with SiO_2. The copper **matte** (pronounced mat) is a mixture of molten Cu_2S and Cu_2O.

In the converter sulfur and oxygen react to form bubbles of SO_2 gas which mostly escape. As the converted copper cools, some bubbles of SO_2 at the surface are trapped when the copper solidifies, giving a blistered appearance.

The blister copper is cast into anode shapes and sent to an **electrolytic refinery** that could be near the smelter or at a distant installation with cheaper electricity.

Answer the questions below. They are based on the information you have just read and analysed for the conversion of Cu_2S and $CuFeS_2$ to blister copper. You will study the purification process in the electrolytic refinery in more detail later.

1 Four chemicals are major reactants. Two of them are the minerals Cu_2S and $CuFeS_2$. Give the formula and name the other two. (One is a solid found in the form of sand, the other is a gas.)

2 Three chemicals are major products. One of them is copper. Give the formula and name the other two. (One is a solid that can be used as road aggregate, the other is a gas.)

3 Two chemicals in the equations are intermediate reactants. Intermediate reactants are not present at the start. They form during a series of reactions then react to form final products. Both the intermediate reactants are oxides. Give their formulas and names.

____

____

4 Sulfur dioxide, SO_2, is a highly irritating and toxic gas. Asthmatics can be at particular risk when exposed to it. Smelters releasing SO_2 need high exhaust stacks and may have to close down when the wind takes the gas towards population centres. Some smelters have sulfuric acid plants that make sulfuric acid from SO_2 using the following reactions.

Write balanced equations in symbols under these two word equations.

sulfur dioxide + oxygen $\rightarrow$ sulfur trioxide

____

sulfur trioxide + water $\rightarrow$ sulfuric acid

____

5 Both of the reactions carried out to form sulfuric acid release energy, that is they are **exothermic**. The heat energy released can be used to produce high pressure steam, turn turbines and generate electrical energy. If a sulfuric acid plant adjoined a smelter and converter how could the electrical energy be used in operating the smelter and converter?

____

____

____

6 How can tailings dams cause environmental problems?

____

____

____

Check your answers.

Electrolytic refining of copper

Blister copper contains up to 2% of other metals such as zinc, iron, silver, platinum and gold. The blister copper casts and stainless steel sheets are inserted in a bath of acidified copper sulfate solution. A potential difference (voltage) is applied between the blister copper and stainless steel electrodes.

The low voltage is carefully adjusted so that copper and more active metal atoms such as zinc and iron lose electrons. $Cu \rightarrow Cu^{2+} + 2e^{-}$. The copper ions produced dissolve in the copper sulfate solution around the blister copper.

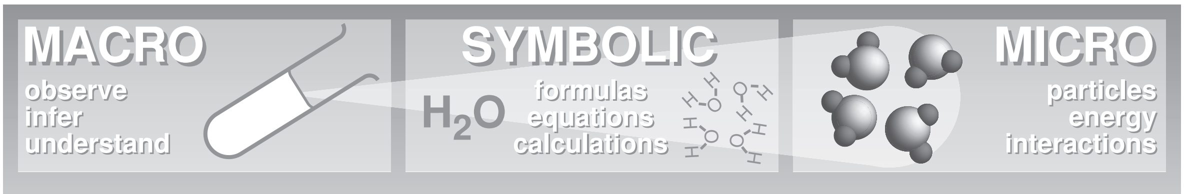
The electrode where loss of electrons (oxidation) occurs is called the anode. Metal atoms less active than copper cannot undergo oxidation at this low voltage. As the copper atoms change to copper ions and dissolve the unreactive metal atoms fall to the bottom of the bath and collect as a solid insoluble deposit.

Positive copper ions are attracted to the negative stainless steel electrode. These ions gain electrons (reduction) at the electrode called the cathode. $Cu^{2+} + 2e^{-} \rightarrow Cu$. The voltage is not great enough to reduce zinc or iron ions which remain in the solution. Thus, the copper deposited on the stainless steel electrode surface can be extremely pure. The more carefully the voltage is controlled, the purer the copper deposited.

Copper ions produced by oxidation at the anode travel through the electrolyte solution to be reduced at the cathode. The overall effect is that copper atoms in a 98% pure anode become copper atoms in an up to 99.999% pure cathode coating. The high purity copper is stripped from the stainless steel surface by special stripping equipment.

Suppose the blister copper was contaminated with some nickel. Where would the nickel be found at the end of the electrolysis? Use the metal activity series to explain your answer.

Check your answer.



Iron and aluminium

In Part 5 of *The chemical earth* you studied the modern era extraction of iron and aluminium from their ores. In this module you studied the historical use of iron and aluminium in Part 1 and the different reactivities in Part 2.

In this section you will be completing notes that link these different parts. You may like to read the information again before attempting the questions. Complete the notes below using the words *iron* or *aluminium*.

Of the two metals, iron and aluminium, ______________ was the first to be used by ancient societies. Both of these metals occur in large amounts in the Earth's crust as oxide minerals. The metal______________ is less active than _______________ and so easier to extract from the oxide.

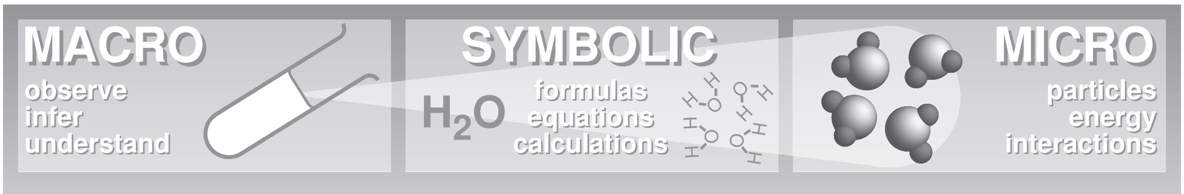
Extraction of both these metals from their oxides requires carbon to react with the oxygen in the compound.

In the case of ______________ the oxide is heated with carbon and oxygen in a blast furnace. The carbon monoxide reduces the _______________ oxide to iron and carbon dioxide gas is released.

_______________ oxide has a very high melting point and has to be mixed with a molten mineral cryolite Na_3AlF_6 to melt below 1000°C. Electrical energy then has to be used to extract the ________________ from its oxide. The oxide ions formed in the electrolysis react with carbon electrodes so that carbon dioxide gas is released.

________________ has been extracted from its oxide by humans for about the last 3500 years. Large scale production started after the Industrial Revolution just over 200 years ago.

________________ has only been extracted from its oxide on a large scale for the last 100 years. This extraction process depends on the availability of large amounts of electrical energy. Since the 1950s the amount of electrical energy required to make one kilogram of ________________ from alumina has dropped from 21 kWh to 14 kWh. (1kWh = 1 kilowatt/hour = 3.6×10^6 J = 3.6 MJ).



Recycling of metals

Recycling is the re–use of waste materials.

The most recycled metal of all is gold. Practically all the gold that has ever been mined is still available to humans. Why is this so? Humans put a high value on gold and have used it as the basis of money for long periods of time. Gold’s lack of chemical reactivity avoids tarnishing and its distinctive colour make it attractive especially in jewellery.

The increasing concentration of humans into urban centres makes recycling more economic by reducing transport costs. Recycling also reduces waste disposal costs especially for urban centres where waste has to be transported out of the city.

The bulk of recycled metal is **ferrous** (iron–containing) and can easily be separated from other waste using powerful magnets. The other metals, called non–ferrous, require careful separation, sometimes by hand.

Demand for metal extraction from metal ores, a **non–renewable** resource, can reduce as recycling increases.

Apart from precious metals such as gold, platinum and silver, aluminium would be one of the most recycled metals.

Aluminium has been called ‘solid electricity’ and an ‘energy bank’. About 55% of the world’s aluminium is made using the renewable energy hydro–electricity. Recycling one kilogram of aluminium saves about 14 kilowatt hours of electrical energy. The energy needed to recycle aluminium is just over 5% of that needed to make aluminium from bauxite. One recycled kilogram of aluminium also saves the energy needed to mine 4 kg of bauxite and processing requiring 4 kg of chemical reactants.

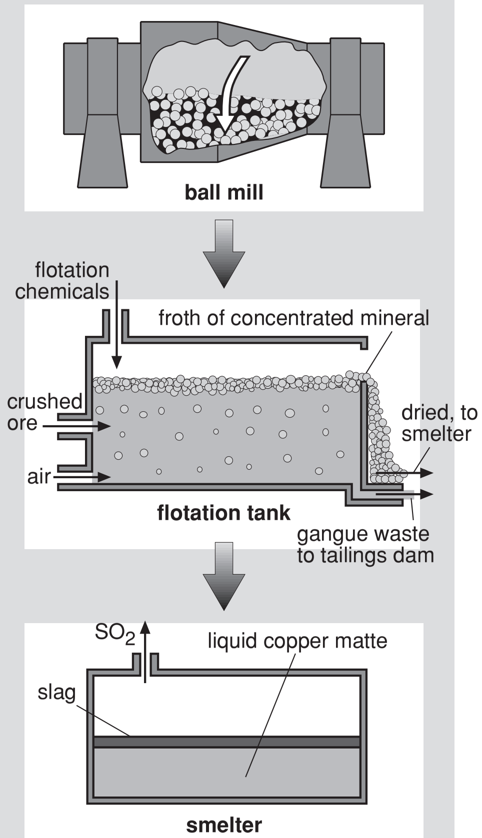
In Australia over 60% of aluminium cans are recycled and normally back on the supermarket shelf as new cans within a few months of collection. Aluminium is one of the most effectively recycled packaging materials. Sweden (92%) and Switzerland (88%) have the best aluminium can recycling records. How can you help improve Australia’s figure of 60%?

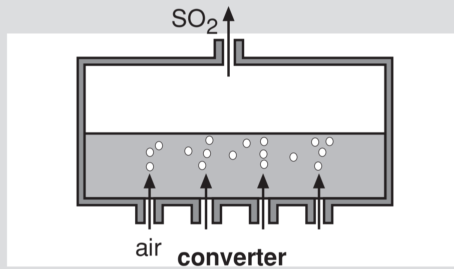
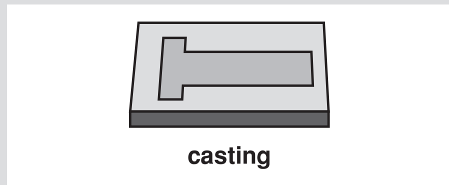
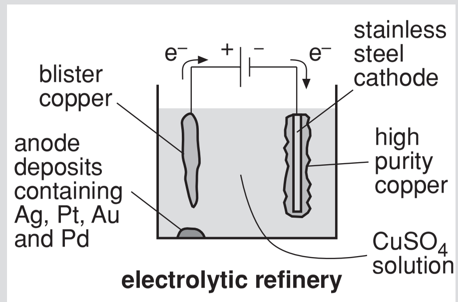
New cars are being designed to make recycling of the metal components easier. The amount of energy used in moving a car around during its lifetime is often about equal to the amount of energy that went into mining, extracting and processing the materials that make up the car.

Justify (support an argument or conclusion) the increased recycling of metals in our society and across the world.

Appendix

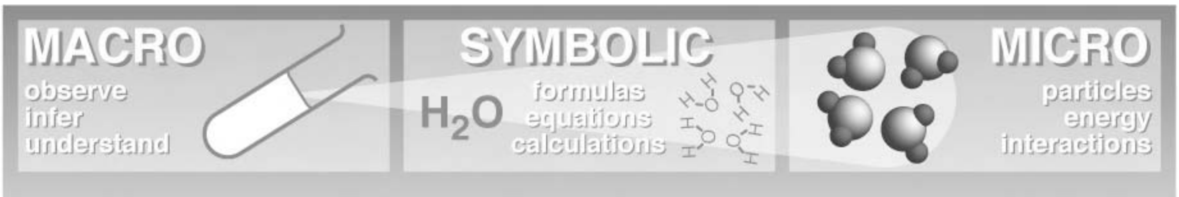
Copper composition by mass	Process	Equipment	
0.5–5%	copper ore crushed in ball mill	ball mill	Cu_2S and $CuFeS_2$ mixed with other minerals
25–57%	copper sulfides concentrated by froth flotation	flotation tank	
	concentrates heated with SiO_2 to remove iron	smelter	**Reactions** $FeO + SiO_2 \longrightarrow \underset{\text{slag}}{FeSiO_3}$ $2Cu_2S_{(l)} + 3O_{2(g)} \longrightarrow 2Cu_2O_{(l)} + 2SO_{2(g)}$



Copper composition by mass	Process	Equipment	Reactions
	air injected into molten material to remove sulfur		$2Cu_2O_{(l)} + Cu_2S_{(l)} \longrightarrow 6Cu_{(l)} + SO_{2(g)}$
98%	blister copper cast		
up to 99.999%	electrolytic refining		anode $Cu \longrightarrow Cu^{2+} + 2e^-$ cathode $Cu^{2+} + 2e^- \longrightarrow Cu$

Metal	Density (g cm^{-3})	MP (°C)	Electrical conductivity (MS m^{-1})	Thermal expansion coefficient ($10^6 K^{-1}$)	Toxic level in human (g)
K	0.86	63	14	83	6
Na	0.97	98	21	71	non–toxic
Li	0.53	180	11	56	0.1
Ba	3.50	725	3	20	0.2
Ca	1.55	842	29	22	non–toxic
Mg	1.74	650	22	26	non–toxic
Al	2.70	660	37	23	5
Cr	7.19	1857	8	6	0.2
Zn	7.14	420	17	25	0.15
Fe	7.86	1535	10	12	0.2
Co	8.90	1495	16	13	0.5
Ni	8.90	1455	14	13	0.05
Sn	7.30	232	9	21	2
Pb	11.3	327	5	29	0.001
Cu	8.96	1085	58	16	0.25
Hg	13.5	–39	1	180	0.0004
Ag	10.5	962	63	19	0.06
Pt	21.4	1772	9	9	?
Au	19.3	1064	44	14	non–toxic

Some properties of a number of metals.



Suggested answers

Minerals and ores

1

Mineral	Element/ compound	Formula	Sphere
alumina	compound	Al_2O_3	lithosphere
charcoal	element	C	biosphere
copper carbonate	compound	$CuCO_3$	lithosphere
diamond	element	C	lithosphere
iron(III) oxide	compound	Fe_2O_3	lithosphere
oxygen	element	O_2	atmosphere
sodium chloride	compound	NaCl	hydrosphere

2 The main source of minerals is in the lithosphere.

3 Most minerals are extracted from the top part of the Earth's crust.

Bauxite mining

2 topsoil above the bauxite stripped by scrapers and stored for reuse

1 vegetation cleared

9 grinding of bauxite and mixing with sodium hydroxide solution

3 explosives used to break up hard deposits of bauxite

7 bauxite transported to ship

8 bauxite transported at sea

5 screening of bauxite at Weipa to separate unwanted material

6 washing and drying of bauxite

10 alumina solution filtered, concentrated, cooled to form crystals

11 alumina crystals dried in gas fired kilns

4 front end loaders collect bauxite

Decisions affecting mining

Energy costs eg. for electrical energy can be a major factor in extracting active metals from their minerals.

- improving prospecting
- more prospecting
- improving exploration techniques

1 The lower the minimum % of metal in the ore the higher the cost of the metal

2 a) Aluminium.

b) Aluminium is more active than the other metals.

c) Active metals form more stable compounds that require more energy to be decomposed.

Copper metal from copper carbonate

1 a) green copper carbonate turned black on heating

$CuCO_3 \rightarrow CuO + CO_2$ X

b) black copper (II) oxide reacted with acetic acid forming soluble copper acetate and water

$CuO + 2CH_3COOH \rightarrow Cu(CH_3COO)_2 + H_2O$ Z

c) the more active metal iron displaced the less active metal copper from its solution

$Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$ Y

2 Energy was absorbed in extracting copper from copper carbonate. A large amount of heat energy had to be supplied by the flame to change the green copper carbonate to black copper oxide. You may have noticed slight warming when the black copper oxide reacted with the acetic acid and when the copper appeared on the iron wool. The amount of heat released in these slight warmings was less than the amount of heat absorbed in decomposing the copper carbonate.

Copper from sulfide ore

Higher energy levels (300 000 MJ/t) would be required to extract copper from lower grade ores (0.5% copper).

1 SiO_2 silicon dioxide and O_2 oxygen.

2 $FeSiO_3$ iron silicate and SO_2 sulfur dioxide.

3 FeO iron (II) oxide and Cu_2O copper (I) oxide

4 $2SO_2 + O_2 \rightarrow 2SO_3$

$SO_3 + H_2O \rightarrow H_2SO_4$

5 Electrical energy can be use to produce heat, move pump motors to inject air and operate exhaust fans.

6 If the tailings dam overflows from heavy rain or a wall collapses toxic chemicals could be released.

Electrolytic refining of copper

Nickel is a more active metal than copper and so nickel, like the more active iron and zinc, will undergo oxidation and form ions in solution.

Iron and aluminium

Of the two metals, iron and aluminium, *iron* was the first to be used by ancient societies. Both of these metals occur in large amounts in the Earth's crust as oxide minerals. The metal *iron* is less active than *aluminium* and so easier to extract from the oxide.

Extraction of both these metals from their oxides requires carbon to react with the oxygen in the compound.

In the case of *iron* the oxide is heated with carbon and oxygen in a blast furnace. The carbon monoxide reduces the *iron* oxide to iron and carbon dioxide gas is released.

Aluminium oxide has a very high melting point and has to be mixed with a molten mineral cryolite Na_3AlF_6 to melt below 1000°C. Electrical energy then has to be used to extract the *aluminium* from its oxide. The oxide ions formed in the electrolysis react with carbon electrodes so that carbon dioxide gas is released.

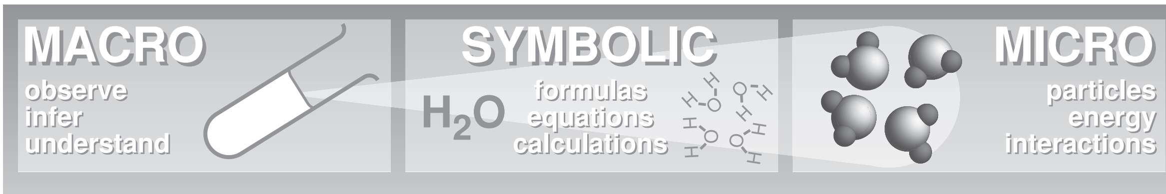
Iron has been extracted from its oxide by humans for about the last 3500 years. Large scale production started after the Industrial Revolution just over 200 years ago.

Aluminium has only been extracted from its oxide on a large scale for the last 100 years. This extraction process depends on the availability of large amounts of electrical energy. Since the 1950s the amount of electrical energy required to make one kilogram of *aluminium* from alumina has dropped from 21 kWh to 14 kWh.

Recycling of metals

Metal recycling:

- reduces the need to mine ores which are non–renewable resources
- reduces the energy needed to obtain metal and thus reduces cost
- makes users of metals more conscious of the environmental, social and economic cost of what they use
- reduces waste and litter.



Exercises – Part 4

Exercises 4.1 to 4.2 Name: ________________________________

Exercise 4.1: Identifying metals

As well as the iron, aluminium and copper you have studied in this unit zinc, lead, nickel and gold are important metal exports from Australia.

a) Arrange these seven metals into a vertical metal activity series with the most active metal on top.

b) Using your knowledge of the activity of zinc, lead, nickel and gold label these descriptions of the extraction of these metals.

- __________ is mostly found as a sulfide or an oxide. The sulfide is smelted to produce the oxide which is reduced with carbon. The metal is electrolytically refined.
- __________ is mostly found as small particles of the free metal. These small particles are extracted by reaction with poisonous cyanide solution or by formation of an amalgam with mercury. Careless disposal of the cyanide and mercury have caused environmental problems.
- __________ is mostly found as the sulfide. Froth flotation is followed by smelting of the concentrates. Purified by blasts of air which remove more active metal impurities as oxides. About half of this metal is recycled mostly from car batteries.
- __________ is mostly found as the sulfide. Froth flotation is followed by smelting of the concentrates. Low boiling point

allows metal purification by distillation. Used for galvanising iron as it is more reactive than iron.

Exercise 4.2: Comparing extraction of aluminium from its ore and the recycling of aluminium

Compare means show how things are similar or different.

Compare the cost and energy expenditure involved in the extraction of aluminium form its ore and the recycling of aluminium.

Chemistry
Preliminary Course
Stage 6

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

Metals

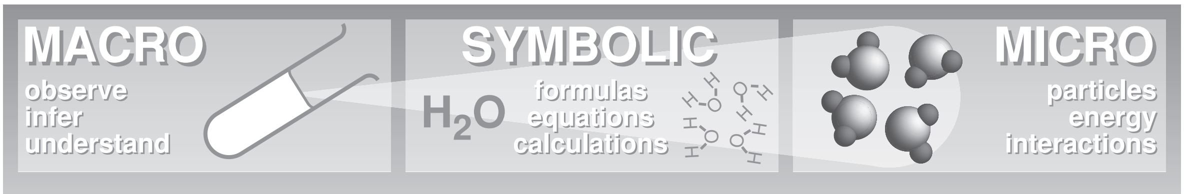
Part 5: The mole concept

Incorporating October 2002
AMENDMENTS

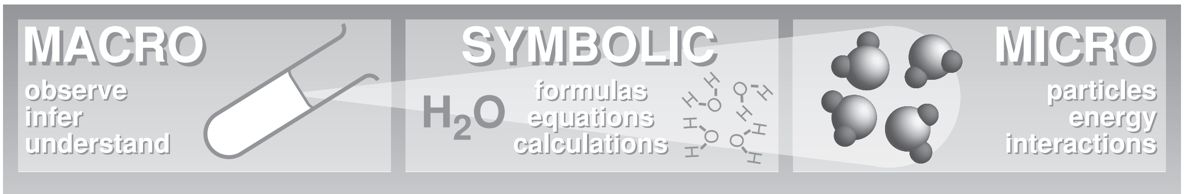
1 H 1.008 Hydrogen	
Atomic number Symbol Atomic weight Name	

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.39 Zinc	31 Ga 69.72 Gallium	32 Ge 72.61 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc [98.91] Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57-71 LANTHANIDES	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.8 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po [210.0] Polonium	85 At [210.0] Astatine	86 Rn [222.0] Radon
87 Fr [223.0] Francium	88 Ra [226.0] Radium	89-103 ACTINIDES	104 Rf [261.1] Rutherfordium	105 Db 262.1 Dubnium	106 Sg [263.1] Seaborgium	107 Bh [264.1] Bohrium	108 Hs [265.1] Hassium	109 Mt [268] Meitnerium	110 Uun – Ununnilium	111 Uuu – Unununium	112 Uub – Ununbium	113	114 Uuq – Ununquadium	115	116 Uuh – Ununhexium	117	118 Uuo – Ununoctium

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm [146.9] Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium
89 Ac [227.0] Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np [237.0] Neptunium	94 Pu [239.1] Plutonium	95 Am [241.1] Americium	96 Cm [244.1] Curium	97 Bk [249.1] Berkelium	98 Cf [252.1] Californium	99 Es [252.1] Einsteinium	100 Fm [257.1] Fermium	101 Md [258.1] Mendelevium	102 No [259.1] Nobelium	103 Lr [262.1] Lawrencium


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

Contents



Introduction

The mole concept in chemistry is an important symbolic concept. It links the quantities of chemicals that you handle in a laboratory situation to ideas about the atoms, molecules and ions that make up matter.

The word mole has many meanings and how you use it depends on the context (situation). Mole can mean different things to people discussing skin or furry blind animals or spies. If you come across the word mole in a chemistry context then mole refers to amounts of chemicals.

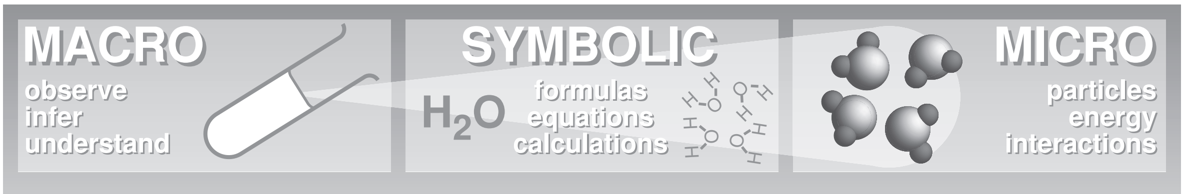
In this part you will be given opportunities to learn to:

- define the mole as the number of atoms in exactly 12 g of carbon–12 (Avogadro's number)
- compare mass changes in samples of metals when they combine with oxygen
- describe the contribution of Gay Lussac to the understanding of gaseous reactions and apply this to an understanding of the mole concept
- recount Avogadro's law and describe its importance in developing the mole concept
- distinguish between empirical formulas and molecular formulas

In this part you will be given opportunities to:

- process information from secondary sources to interpret balanced chemical equations in terms of mole ratios
- perform a first–hand investigation to measure and identify the mass ratios of metal to non–metal(s) in a common compound and calculate its empirical formula
- solve problems and analyse information from secondary sources to perform calculations involving Avogadro's number, number of moles present in reactants and products using: $n = \dfrac{m}{M}$

- process information from secondary sources to investigate the relationship between the volumes of gases involved in reactions involving a metal and relate this to an understanding of the mole
- discuss the importance of predicting yield in the identification, mining and extraction of commercial ore deposits.



The mole

The tiny packages that matter comes in – atoms, ions and molecules – are so small that you cannot see them. A lot of chemists' time is spent on stoichiometry – calculating quantitative relationships in chemical reactions. In making measurements of quantities of atoms, ions and molecules chemists must be able to count out these particles no matter how small they are. The counting unit used by chemists is the mole.

Match each occupation, each counting unit name and each number in these jumbled lists.

egg supplier	mole	12
printer	dozen	500
chemist	pair	6×10^{23}
bootmaker	ream	2

Check your answers.

The word mole probably comes from the Latin word *moles* meaning a heap or pile. A mole is defined as the number of atoms in exactly 12 g of carbon–12. This number is called Avogadro's number and is approximately 6×10^{23}.

How big is 6×10^{23}? You can say it's six hundred thousand million million million or write the number in full as 600 000 000 000 000 000 000 000. Alternatively you could imagine the continent of Australia covered with 6×10^{23} sand grains. The whole of Australia would be covered to a depth of about one metre with sand grains!

How small are atoms, molecules and ions? If you arrange an average human hand into a cup shape it would hold about:

- one mole of carbon atoms in the form of charcoal C
- one mole of water molecules in a handful of water H_2O
- one mole of sodium ions and one mole of chloride ions in a handful of table salt NaCl.

The mole is one of the seven basic units of the Systeme International (SI) of measurement endorsed by IUPAC. The mole is the SI unit for measuring amount of substance. The unit, mole has the symbol mol.

Very accurate measurements give a value of 6.0221367×10^{23} for Avogadro's number. For your calculations use 6.02×10^{23}.

Molar mass

The most practical way of measuring out a mole is by mass in grams.

atomic | atoms
1 mole = {molecular} mass in g for a substance made up of{molecules}.
formula | ions

Most elements can be considered to be made up of atoms rather than molecules. For most elements one mole is the atomic weight in grams.

When you are dealing with elements that form diatomic molecules (H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2 and At_2) one mole is the molecular weight in grams.

Remember how you learnt in the first module that compounds could be divided into two main types?

Compounds

Covalent	Ionic
• nonconductors of electricity when liquid or dissolved in water • usually gas, solid or low melting point solid.	• conductors of electricity when liquid or dissolved in water • usually high melting point solid.

Covalent compounds are made up of molecules so the formula used is the molecular formula. This shows the actual number of each type of atom in a molecule eg. H_2O for water, $C_6H_{12}O_6$ for glucose.

The formula written for an ionic compound is the empirical formula. An empirical formula shows the simplest whole number ratio of ions in the ionic compound eg. NaCl for sodium chloride, NaOH for sodium hydroxide, $CuSO_4$ for copper (II) sulfate.

Some ionic compounds, called hydrated salts, contain water molecules attracted to ions in their ionic lattice eg. blue copper (II) sulfate $CuSO_4.5H_2O$.

It doesn't matter what type of compound you are asked to calculate one mole for. You simply take the formula, and add up the atomic weights for all the atoms shown in the formula, then express the formula weight in grams.

Note that the '.' in a hydrated salt formula is not a multiplication sign; '.' simply separates the ionic part from the water molecules.

Compound	**Formula**	**Calculation**	**One mole (g)**
water	H_2O	2 x 1.008 + 16.00 = 18.016	18.02
glucose	$C_6H_{12}O_6$	6 x 12.01 + 12 x 1.008 + 6 x 16.00 =180.216	180.22
sodium chloride	NaCl	22.99 + 35.45 = 58.44	58.44
sodium hydroxide	NaOH	22.99 + 16.00 + 1.008 = 39.998	40.00
copper(II) sulfate	$CuSO_4$	63.55 + 32.06 + 4 x 16.00 =159.61	159.61
blue copper(II) sulfate	$CuSO_4.5H_2O$	159.61 + 5 x 18.016 = 249.69	249.69

In calculations of the mole use atomic weight values in the periodic table. (There is one supplied on the inside cover of this part.)

Weighing equipment in school laboratories can usually measure to the nearest 0.01g. The calculation answers have been rounded off to the nearest 0.01 g in the last column of the table.

The mass of one mole is called the molar mass. Molar mass is usually expressed in grams because the gram is the most common weighing unit used by laboratory chemists.

You now know how to weigh out a certain number of atoms, ions or molecules of an element or compound. In a school laboratory situation you would normally handle about 10^{22} to 10^{24} particles at a time!

Complete Exercise 5.1 by calculating the molar mass of various elements and compounds now.

Number of moles

To calculate 0.5 or 5 mole you simply multiply one mole by 0.5 or 5.

There are two formulas that you will find useful for calculating the number of moles n:. These are shown below.

$n = \frac{N}{N_A}$ where N = the number of atoms, molecules or of formula units
N_A = Avogadro's number 6.02×10^{23}

$n = \frac{m}{M}$ where m = mass of element or compound
M = molar mass of the element or compound.

The quantities, m and M, must be measured in the same unit eg. both in g or both in kg. The units normally used are grams, g because
M = atomic/molecular/formula mass in g.

Combining these two equations you can see how the number of moles n is a link between the mass of chemicals you handle and ideas about the particles making up chemicals:

mass of chemicals m $\Leftrightarrow$ number of moles $\Leftrightarrow$ particles in chemicals N

$$\frac{m}{M} = n = \frac{N}{N_A}$$

Examples:

1 A cup of water H_2O contains 250 mL = 250 g of water.

a) How many moles of water are in the cup?

$n = ?$

$m = 250$ g

M = molar mass of water = 2 x 1.008 + 16.00 = 18.02 g

$$n = \frac{m}{M} = \frac{250}{18.02} = 13.9 \text{ mol}$$

b) How many H_2O molecules are in the glass of water?

$N = ?$

$n = 13.9$ mol

$N_A = 6.02 \times 10^{23}$

$n = \frac{N}{N_A}$ therefore $N = n \times N_A$
$= 13.9 \times 6.02 \times 10^{23}$
$= 83.7 \times 10^{23} = 8.37 \times 10^{24}$ molecules!

2 The average person absorbs one mole of oxygen per hour to keep alive. What weight of oxygen is absorbed into the blood per hour?

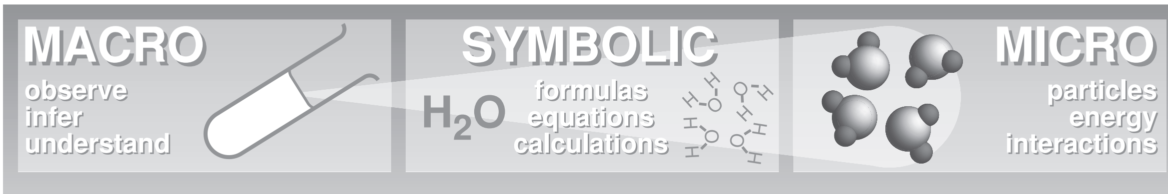
m = ?

n = 1

M = 2 x 16.00 = 32.00 g for O_2 molecules.

$n = \frac{m}{M}$ therefore m = n x M
= 1 x 32.00 g = 32.00 g of oxygen.

Complete Exercise 5.2 using $\frac{m}{M} = n = \frac{N}{N_A}$.



Development of modern chemistry

Lavoisier, a French tax agent who was guillotined in 1794 during the French Revolution, is often regarded as the founder of modern quantitative chemistry.

His achievements included:

- establishing the idea that solid, liquid and gas could be different forms of the same chemical substance eg. water
- establishing the concepts of elements and compounds
- explaining the differences between chemical and physical changes
- proving that burning involved reaction with oxygen of the air
- demonstrating the law of conservation of mass – in a reaction the total mass of reactants equals the total mass of products.

All of these ideas were covered in the first chemistry module.
This illustrates the importance of Lavoisier's ideas as a foundation for understanding chemistry.

In 1808 an English schoolteacher, John Dalton, published a book called *A New System of Chemical Philosophy.* He put forward the theory that:

- matter was made up of indivisible atoms
- each element consists of identical atoms with the same atomic weight.

Dalton explained the law of conservation of mass by pointing out that in a reaction atoms are just rearranged – no atoms are created or destroyed. Other scientists had written similar ideas but Dalton was a good teacher who communicated his ideas very effectively, in a manner which others could understand. His ideas spread rapidly amongst chemists.

Unfortunately another of Dalton's ideas caused confusion about atomic weights for half a century. Dalton thought that water was made up of one hydrogen atom and one oxygen atom. Measurements demonstrated that water contains oxygen and hydrogen in a mass ratio of about 8:1.

Scientists early in the 1800s thought oxygen had an atomic weight about eight times that of hydrogen.

The atomic weights of many new elements were worked out from their reactions with oxygen. Because the atomic weight value for oxygen was wrong these new atomic weight values were often wrong.

When mercury was heated in air below 500°C it slowly converted to orange mercury oxide. When mercury oxide was heated above 500°C it decomposed to mercury and oxygen. The ratio of the mass of mercury to the mass of oxygen released was found to be 12:1.

1 Assume mercury oxide contains mercury and oxygen in the ratio 1:1. Mercury oxide has 12 times the mass of mercury compared to oxygen. Calculate the atomic weight of mercury if oxygen is assumed to have an atomic weight of 8.

2 When 1.00 g of copper is heated slowly in air it converts to 1.25 g of black copper oxide.

Assume copper oxide contains copper and oxygen in the ratio 1:1 Using the weight figures above calculate the atomic weight of copper if oxygen is assumed to have an atomic weight of 8.

Check your answer.

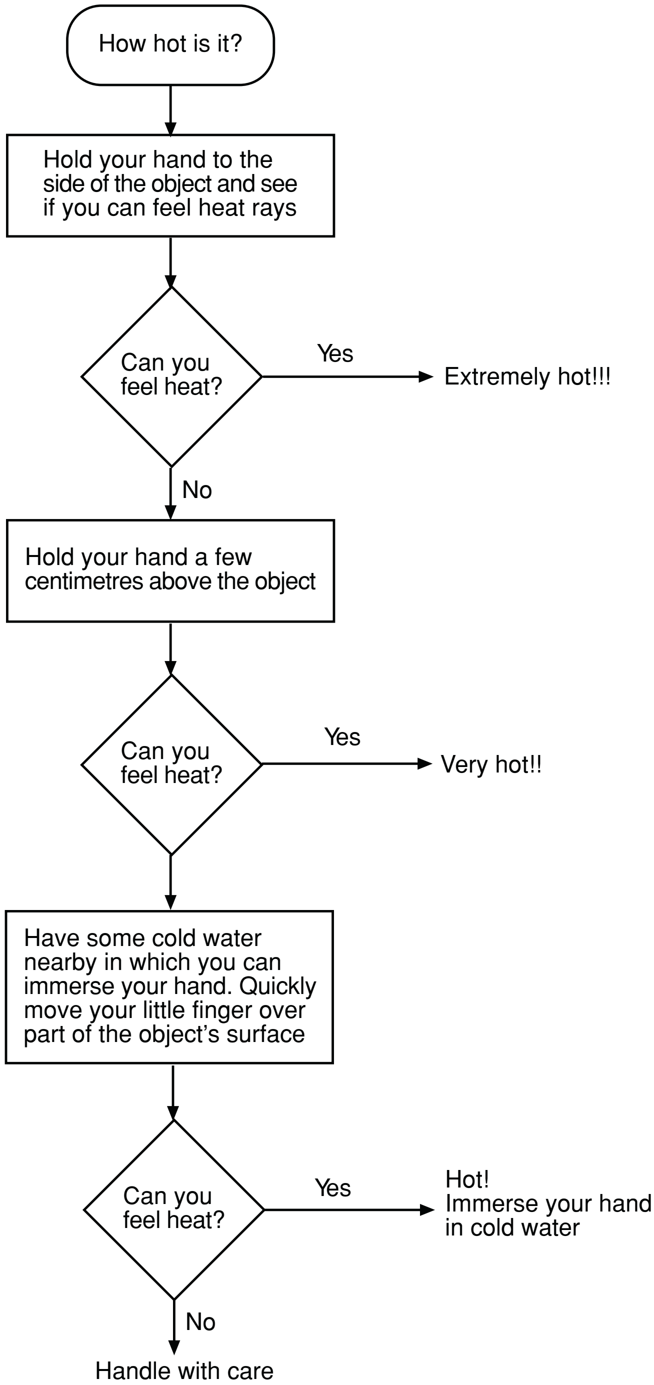
The First International Chemical Congress held in 1860 led to an agreed list of corrected atomic weights. Only then could chemists have confidence in their calculated formulas. No new elements were discovered in the 1850s. Confidence in the atomic weights and formulas chemists used from 1860 helped in the discovery of 24 new elements in the next forty years.

Measuring the mass ratio

In this activity you will be measuring the mass ratio of metal: non–metal in a common compound magnesium oxide. You will need to test if an object is hot. This is described below.

- Do not touch! Hold your hand to the side of the object and see if you can feel heat rays.

- Hold your hand a few cm above the object. Can you feel heated air rising from the object?
- Make sure you have some cold water nearby in which you can immerse your hand. Quickly move your little finger over part of the objects surface to see if you can feel heat. If the object was hot immediately immerse your finger in the cold water for minutes to prevent skin damage.



In this activity you measure the masses of equipment containing magnesium and magnesium oxide formed from the magnesium.

You are required to use school science laboratory equipment such as a balance measuring to 0.01 g. If you do not have access to this equipment then use the measurements A = 25.17 g, B = 26.15 g, C = 26.83 g.

From your measurements you will identify the mass ratio of magnesium:oxygen and calculate the empirical formula of magnesium oxide. This calculation requires a knowledge of correct atomic weights – something chemists did not have access to until 1860.

Magnesium oxide is a common compound that is used as a refractory. A refractory is a material whose physical and chemical properties do not change at high temperatures. Magnesium oxide is use to make bricks for lining high temperature kilns and furnaces. The high temperature you use in this activity cannot break down the magnesium oxide. Magnesium oxide has a MP of 2852°C.

You will need:

- 20 cm length of magnesium ribbon
- iron wool or emery paper to clean the magnesium surface
- a balance weighing to 0.01 g
- a porcelain crucible and lid
- tongs for holding the crucible
- pipeclay triangle to fit the crucible
- tripod
- burner (Bunsen or pencil torch) and matches

Note: The pencil torch burner has a hot concentrated flame. Move the flame around the object when you first heat it. This will gradually heat up the object. Once the object is very hot you may be able to leave the pencil torch flame in one position.

Method:

1 Heat the clean dry crucible and lid and allow to cool.

2 Clean the magnesium surface on both sides until shiny.

3 When the crucible + lid are cool enough for you to touch use the tongs to transfer them to a balance. Record the total weight A.

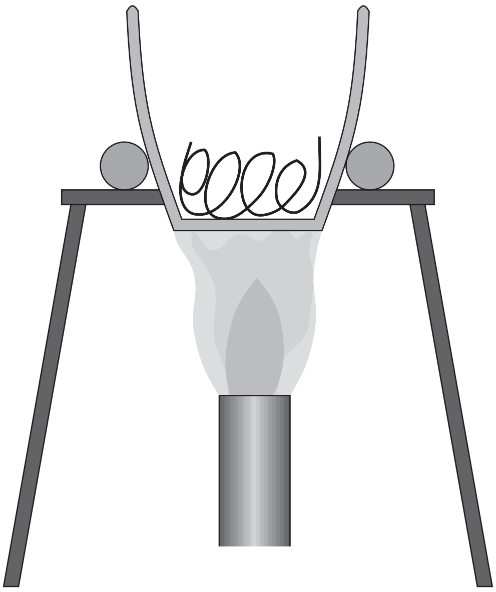
A = ______________________________

Make sure there are no cracks in the crucible or lid. If there are, replace the cracked object and start again.

4 Coil the magnesium ribbon so that it fits into the crucible. Weigh the crucible + lid + magnesium. Record the total weight B.

B = ____

5 Set up the equipment as shown in the diagram.



Gently heat the crucible without the lid. As soon as the magnesium begins to burn and glow place the lid on top using the tongs. Continue heating. Lift the lid on occasions to let oxygen in for the magnesium to react.

6 When no more magnesium appears to react, heat the crucible strongly without the lid. If any smoke (white ash) is released put the lid back on and heat strongly for a minute before removing the lid again. When there are no further signs of reaction (white glowing of magnesium or release of white smoke) turn off the burner. Let the crucible, lid and magnesium oxide cool.

7 While the equipment is cooling work your way through the results.

8 When the crucible + lid + magnesium oxide are cool enough for you to touch use the tongs to transfer them to a balance. Record the total weight C.

C = ____

Results:

1 Use weight A from step 3 and weight B from step 4 to calculate the amount of magnesium used. Call this result 1.

Result 1 = ____

2 Use weight A from step 3 and weight C from step 8 to calculate the amount of magnesium oxide that formed. Call this result 2.

Result 2 = ____

3 Use result 1 and result 2 to find the mass of oxygen that reacted with your strip of magnesium. Call this result 3.

Result 3 = ____

4 The mass ratio of metal to non–metal in magnesium oxide is ____:____

5 Using atomic weights of 24 for magnesium and 16 for oxygen calculate the empirical formula for magnesium oxide. If you are not sure what to do below then revise *Why an ionic formula is empirical* in Part 3 of the first module, *The chemical earth*.

	magnesium	:	oxygen
mass ratio		:	
particle ratio		:	
mole ratio	=		=
that is		:	
empirical formula			

6 Justify the empirical formula you have written for magnesium oxide.

____

____

7 At the beginning of this section, five of Lavoisier's achievements /ideas were listed. Describe three of his ideas you have used in doing this practical activity.

____

____

____

____

____

____

Check your answers.

Gay–Lussac's Law and Avogadro's Law

In the first half of the 1800s chemists measured the masses of chemicals that reacted and were produced for many reactions. Not many simple mass ratios could be found. The situation was very different for gas volumes.

In 1808 a Frenchman, Gay–Lussac, reported that, in reactions involving gases, the volumes involved were always in simple whole number ratios. This is known as the law of combining gas volumes.
Measurements were made at the same temperature and pressure as both of these conditions can affect gas volume. Gay Lussac found that:

2 vol. hydrogen + 1 vol. of oxygen → 2 vol. of water

1 vol. of hydrogen + 1 vol. of chlorine → 2 vol. of hydrogen chloride

1 vol. of nitrogen + 3 vol. of hydrogen → 2 vol. of ammonia

2 vol. of carbon monoxide + 1 vol. of oxygen → 2 vol. of carbon dioxide

(Note: vol. = volumes)

Throughout his life Gay–Lussac showed great interest in gases. Whilst studying the gases of the atmosphere from a balloon he set a world altitude record of over 7 km that stood for half a century!

In 1811 an Italian lawyer and scientist, Avogadro, put forward a hypothesis: equal volumes of gases, at the same temperature and pressure, contain the same number of molecules. Avogadro also introduced the idea that elements could consist of molecules containing an even number of atoms. These two ideas together could explain Gay–Lussac's law of combining gas volumes.

2 vol. hydrogen + 1 vol. of oxygen → 2 vol. of water

□ □ + □ → □ □

H_2 H_2 + O_2 → H_2O H_2O

2 H_2 + O_2 → $2H_2O$

1 vol. of hydrogen + 1 vol. of chlorine → 2 vol. of hydrogen chloride

□ + □ → □ □

H_2 + Cl_2 → HCl HCl

H_2 + Cl_2 → 2HCl

You can use Avogadro's ideas to write balanced equations for the reactions forming ammonia NH_3 and carbon dioxide CO_2.

$N_2 \quad + \quad 3\ H_2 \quad \rightarrow \quad 2\ NH_3$

$2CO \quad + \quad O_2 \quad \rightarrow \quad 2\ CO_2$

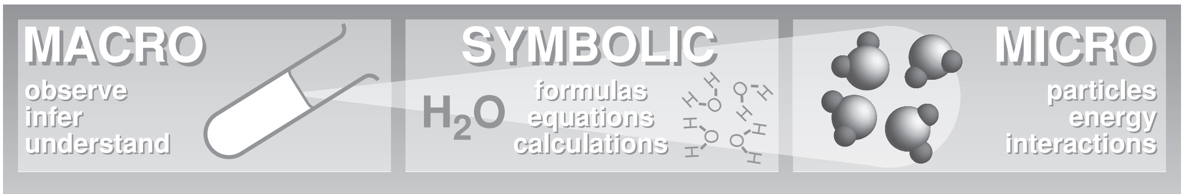
Unfortunately, Avogadro's ideas were not clearly communicated and did not become widely known amongst chemists.

In 1860 the First International Chemical Congress was held in Germany. Here Avogadro's hypothesis was widely appreciated as a way of overcoming much confusion about atomic weights. Avogadro's hypothesis became known as Avogadro's Law.

From this congress and application of Avogadro's Law chemists agreed on a list of atomic weights.

The agreed list of atomic weights helped Meyer and Mendeleev construct periodic tables. It also helped to develop the mole concept.

These ideas and connections are summarised in the *Appendix*.



Using the mole concept

The concept of a mole developed over 100 years ago. The term mole has only been used in chemistry textbooks for about 50 years.
Today chemists calculating amounts of reactants and products constantly work and think in terms of moles.

You have learnt:

- one mole can be thought of as Avogadro's number of anything (usually atoms, molecules or formula units)
- the most common way to measure in moles is to use mass in grams since one mole = the formula mass in grams
- you need to specify the element or compound or type of particles you are measuring in moles.

One mole of oxygen would be assumed to be one mole of oxygen molecules O_2 = 2 x 16.00 = 32.00 g. One mole of oxygen atoms O would be 16.00 g.

The amount of oxygen in one mole of ionic magnesium oxide MgO would be one mole of oxide ions O^{2-} = 16.00 g. When you calculate the mass of a mole of ions you ignore the extra weight of electrons in anions and the loss of weight of electrons in cations. The mass of an electron is about one two–thousandth that of a proton or a neutron and so is ignored in mole calculations that you do.

Note: You do not normally measure mixtures in moles. But you can state the ratio of substances in a mixture by mole ratio eg. a mixture made up of 1 mol of salt to 9 mol of water. In the next module *Water* you will learn how to use molar concentration in moles per litre for solutions.

Chemists use moles because one mole of any substance contains the same number of particles. In the reaction $A + 2B \rightarrow AB_2$

A	+	2B	$\rightarrow$	AB_2
1 particle of A	+	2 particles of B	$\rightarrow$	1 particle of AB_2
thus, N_A of A	+	2 N_A of B	$\rightarrow$	N_A of AB_2
that is 1 mol of A	+	2 mol of B	$\rightarrow$	1 mol of AB_2

If a chemist wants to react one mol of A they will need 2 mol of B and expect to form 1 mol of AB_2 if the reaction goes to completion.
The mole ratio for this reaction is $1:2 \rightarrow 1$.

Molar volume

Molar volume is the space occupied by one mole of a substance.

The molar volumes of solids and liquid chemicals vary. The molar volume of gold is 7 mL while the molar volume of mercury is 15 mL. The molar volume of magnesium oxide is 11 mL while the molar volume of water is 18 mL.

The molar volumes of gases do not vary provided the gases are measured at the same temperature and pressure. Measurements are usually made at a temperature of $0^{o}C$ (273 K) or $25^{o}C$ (298 K) and a pressure of 100kPa (1bar) or 101.3kPa (1atmosphere).

Molar volume in litres for all gases:

	100 kPa (1 bar)	101.3 kPa (1 atm)
$0^{o}C$ (273 K)	22.7	22.4
$25^{o}C$ (298 K)	24.8	24.5

Note that:

- higher temperature causes expansion of gases and gives a larger volume
- higher pressure causes compression of gases and gives a smaller volume.

The number of moles at these temperatures and pressures can be calculated using the following formulas.

$$n = \frac{V}{V_{mol}}$$ where V = volume of gas and V_{mol} = volume of one mol

Both V and V_{mol} must be measured at the same temperature and pressure.

Complete Exercise 5.3 by calculating the molar mass and molar volume now.

Interpreting equations for reactions in solution

The steps use the example of the reaction of 10.6 g of sodium carbonate with excess hydrochloric acid. What weight of sodium chloride and volume of carbon dioxide gas (at 25°C and 100 kPa) are produced?

Because the hydrochloric acid is in excess the amount of sodium carbonate determines the amounts of sodium chloride and carbon dioxide produced.

1 Make sure the formulas are correct.

$Na_2CO_3 + HCl \rightarrow NaCl + H_2O + CO_2$

2 Check that the equation is balanced

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$

3 Underline the formula of any chemical with a known amount.

$\underline{Na_2CO_3} + 2HCl \rightarrow 2NaCl + H_2O + CO_2$

4 Underline the formula of any chemical of unknown amount you are asked to find. Place '?' under each formula.

$\underline{Na_2CO_3} + 2HCl \rightarrow \underset{?}{\underline{2NaCl}} + H_2O + \underset{?}{\underline{CO_2}}$

5 Use the mole ratio in the equation to construct a proportionality involving the known amount and an unknown amount.

$$\frac{molNa_2CO_3}{molNaCl} = \frac{1}{2} \qquad \frac{molNa_2CO_3}{molCO_2} = \frac{1}{1}$$

6 Rearrange the proportionality so that the unknown amount is on one side and all the known amounts are on the other side.

$molNaCl = 2 \text{ x } molNa_2CO_3 \qquad molCO_2 = mol\ Na_2CO_3$

7 Change known quantity to moles.

Formula mass of Na_2CO_3 = 2 x 22.99 + 12.01 + 3 x 16.00 = 106.0

10.6 g of Na_2CO_3 = 10.6/106.0 = 0.100 mol
Thus $molNa_2CO_3 = 0.100$

8 Calculate mol of unknown quantities.

$molNaCl = 2 \text{ x } 0.100 = 0.200 \qquad molCO_2 = 0.100$

9 Convert moles to grams or litres.

$NaCl$ = O.200 x (22.99 + 35.45) = 11.7g
CO_2 = 0.100 x 24.8 L = 2.48 L

Interpreting equations for reactions involving gases

The volume of a gaseous product or reactant can be used to calculate the amount of another gaseous product or reactant in a reaction.
This type of calculation applies Gay–Lussac's law of gas volumes and Avogadro's Law.

Example 1:

Methane gas CH_4 in natural gas burns in a Bunsen burner when the airhole is open to form carbon dioxide gas and gaseous water.
Suppose that 1 L of gaseous methane is burnt. How many litres of oxygen are used and how many litres of gaseous CO_2 and water H_2O are produced? (All gas volumes are measured at the same temperature and pressure.)

CH_4	+	O_2	→	CO_2	+	H_2O
CH_4	+	$2\ O_2$	→	CO_2	+	$2\ H_2O$
$\underline{CH_4}$	+	$\underline{2\ O_2}$	→	$\underline{CO_2}$	+	$\underline{2\ H_2O}$
1 L		?		?		?
1 L		2 L	→	1 L		2 L

Example 2:

The butane gas C_4H_{10} burnt in a pencil torch forms carbon dioxide gas and gaseous water. Suppose that 1 mL of gaseous butane is burnt.
How many millilitres of oxygen are used and how many millilitres of gaseous CO_2 and water H_2O are produced? All gas volumes are measured at the same temperature and pressure.

C_4H_{10}	+	O_2	→	CO_2	+	H_2O
C_4H_{10}	+	$13/2\ O_2$	→	$4\ CO_2$	+	$5\ H_2O$
$2\ C_4H_{10}$	+	$13\ O_2$	→	$8\ CO_2$	+	$10\ H_2O$
$\underline{2\ C_4H_{10}}$	+	$\underline{13\ O_2}$	→	$\underline{8\ CO_2}$	+	$\underline{10\ H_2O}$
1 mL		?		?		?
1 mL		13/2		8/2		10/2
that is		6.5 mL		4 mL		5 mL

Example 3:

Oxyacetylene torches burn acetylene C_2H_2 and oxygen gases. When the acetylene gas is first lit it burns with a smoky carbon rich flame.
When oxygen is added to the acetylene gas the oxyacetylene mixture

burns at a very high temperature producing carbon dioxide gas and gaseous water.

Write a balanced equation for the reaction that produces the very high temperature oxyacetylene flame. Calculate the volume of oxygen required to burn one volume of acetylene.

Check your answer.

Yield of chemical reactions

When a chemical reaction product is collected and the quantity measured a yield can be calculated for the reaction. The yield is usually calculated as a percentage.

$$\% yield = \frac{actual}{theoretical} \times \frac{100}{1} \%$$

The calculation of the theoretical amount that could be produced by the reaction practically always uses the mole concept.

For chemical reactions involving inorganic chemicals, such as ionic reactions producing a precipitate, the actual amount is close to the theoretical amount and yields can be close to 100%.

Why is a yield of over 100% unsatisfactory for a chemical reaction?

For chemical reactions involving carbon compounds there are usually a number of possible reactions and a number of possible products.
It is difficult to get yields close to 100% in carbon chemistry reactions.

Calculations in the mining industry

The mole unit is rarely used in mining industry reports outside of laboratories.

Parts per million (ppm) by mass or g/t are usually used to report concentrations. These are equivalent units: 1 ppm = 1 gram/tonne.

The term yield is frequently used in exploration, mining and extraction reports for ore deposits. Whereas reporting on yield of a chemical reaction is often as a %, reporting on mining yields can be in ppm, g/t, tonnes at a certain % of metal or tonnes at so many g/t.

Decisions on whether to mine an ore deposit commercially depends on:

- yields identified in samples taken in the exploration phase
- yield achieved from trialling the mining process
- yield achieved in extracting the desired material from mined material.

Discuss the importance of predicting yield in the identification, mining and extraction of commercial ore deposits.

Gold

A gold ore might be reported as economic to mine at 2 ppm. The gold deposit could vary in concentration in different parts. Easily accessible parts above 2 ppm would probably be mined first. If the market price of gold rose significantly it may become economic to mine parts below 2 ppm. Alternatively if the market price dropped significantly mining could be suspended partly or totally.

Aluminium

Ore bodies containing less valuable metals such as aluminium or iron could be reported in percentage by mass terms.

The Al content of a bauxite deposit would always be below the % of Al in Al_2O_3 because the alumina mineral is mixed with water, silica and iron oxides in bauxite.

The maximum percentage of Al in Al_2O_3 is calculated as follows:

$2Al/Al_2O_3 = 2 \times 26.98/\ 2 \times 26.98 + 3 \times 16.00 = 53.96/101.96 = 0.5292$

Therefore, maximum % of Al = 53%

In Australia bauxites are mined with about 25% Al by mass.

Iron

Calculate the maximum percentage of iron in haematite Fe_2O_3.
How does your answer compare with a typical Australian ore figure of 30% Fe by mass?

Check your answer.

Copper

Copper ore bodies are mined between 0.5 and 5% copper by mass in Australia. An operation mining 5% Cu would probably continue even if the market price of copper slumped dramatically. An operation mining 0.5 % Cu would probably be closed down temporarily or permanently.

Sometimes a by–product makes the mine economic. Mount Isa Mines in Queensland gains considerable economic benefit from silver extracted as a by–product from the lead. Yield until June 1981 was reported as:

79 834 803 tonnes at 3.25% copper

52 438 457 tonnes at 185 g/t Ag, 7.5% Pb, 6.5% Zn.

Although the mole unit is not commonly used in reporting by mining companies it can be useful in estimating large quantities.

Example: Suppose a mining company has smelted 80 000 000 tonnes of 3.25% copper ore. Assume the copper is all present as copper (I) sulfide Cu_2S.

How much sulfur dioxide would have been released into the atmosphere?

3.25% of 80 000 000 tonnes = (3.25/100) x 80 000 000

= 24 750 000 tonnes of Cu_2S

Copper (I) sulfide reacts with oxygen to produce copper and sulfur dioxide: $Cu_2S + O_2 \rightarrow 2Cu + SO_2$.

When you studied the extraction of copper in a smelter and a converter this was shown as a two stage reaction:

smelter: $2Cu_2S(l) + 3O_2(g) \rightarrow 2Cu_2O(l) + 2SO_2(g)$

converter $2Cu_2O(l) + Cu_2S(l) \rightarrow 6Cu(l) + SO_2(g)$

Adding the left hand sides and right hand sides together and cancelling the intermediate compound $2Cu_2O(l)$, the overall reaction is:
$3Cu_2S(l) + 3O_2(g) \rightarrow 6Cu(l) + 3SO_2(g)$

Simplifying to $Cu_2S(l) + O_2(g) \rightarrow 2Cu(l) + SO_2(g)$ this is the same overall equation.

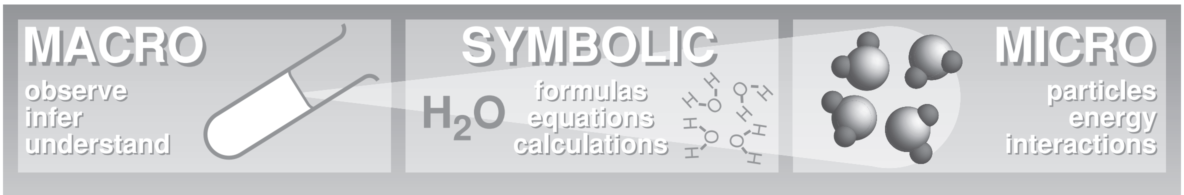
From the balanced equation $Cu_2S + O_2 \rightarrow 2Cu + SO_2$ you can see that each mole of Cu_2S produces a mole of SO_2.

$$\frac{molCu_2S}{molSO_2} = \frac{2 \times 63.55 + 32.07}{32.07 + 2 \times 16.00} = \frac{159.17}{64.07} = \frac{24,750,000}{?}$$

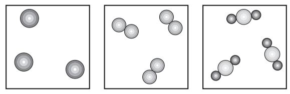
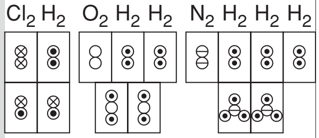
$$? = \frac{24,750,000 \times 64.07}{159.17} = 9\ 963\ 000 \text{ tonnes of } SO_2 \text{ gas released}$$

In an iron blast furnace Fe_2O_3 is reduced by CO which is changed to CO_2. Calculate the amount of carbon dioxide gas released to the atmosphere for every tonne of iron produced by this reaction.

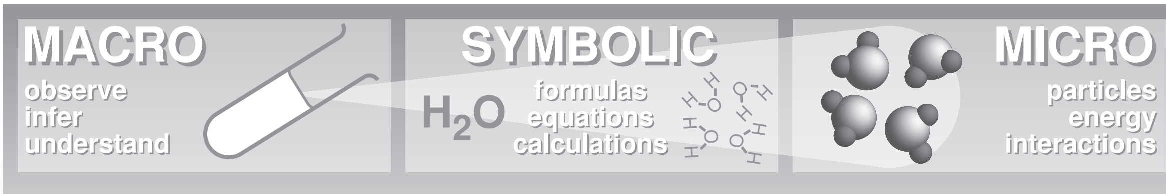
Check your answer.



Appendix

late 1700's	**Lavoisier**	• concept of element • metal + oxygen → metal oxide • law of conservation of mass	Relative gas density measurements • comparison of the masses of equal volumes of different gases
1803	**Dalton**	• atomic theory proposed	
1808	**Dalton**	• atomic theory communicated effectively in his book Incorrect list of atomic weights	**Gay-Lussac** • law of combining gas volumes
1811	*uncertainty about formulas* *confusion about atomic weight*		**Avogadro** • hypothesis, equal volumes of gases contain the same number of molecules  • elements made up of diatomic molecules 
1860			First International Chemical Congress became aware of methods for determining atomic weights using Avogadro's hypothesis
1865	**Loschmidt**	• first estimate of atomic size • first estimate of Avogadro's number $N_A = 2.5 \times 10^{23}$*	
1869	**Mendeleev and Meyer**		correct atomic weights
1880		*technological advances* $N_A = 5 \times 10^{23}$	correct formula weights
1909		$N_A = 7.2 \times 10^{23}$	correctly balanced equations
1911		$N_A = 6.1 \times 10^{23}$	Avogadro's hypothesis *becomes* Avogadro's Law
1917		$N_A = 6.07 \times 10^{23}$	
1963		$N_A = 6.0225 \times 10^{23}$	* Avogadro's number is called Loschmidt's number "L" in German speaking countries. Avogadro never estimated or wrote about N_A. Loschmidt made the first experimental estimate of this number.
limit of current technology		$N_A = 6.0221367 \times 10^{23}$	

Key: long term trend; A leads to B; based on experiments



Suggested answers

The mole

egg supplier	dozen	12
printer	ream	500
chemist	mole	6×10^{23}
bootmaker	pair	2

Development of modern chemistry

1 Mercury would be expected to have an atomic weight of 12 x 8 = 96 if oxygen had an atomic weight of 8. The actual atomic weight of mercury is 200.6.

2 1.00 g of copper is combined with 0.25 g of oxygen in black copper oxide. Assuming copper: oxygen is 1:1 each copper atom must weigh 1.00/0.25 = 4 times the weight of an oxygen atom. If oxygen had an atomic weight of 8 copper would be expected to have an atomic weight of 4 x 8 = 32 The actual atomic weight of copper is 63.55.

Measuring the mass ratio

Results (using A = 25.17 g, B = 26.15 g, C = 26.83 g)

1 Result 1 = 26.15 – 25.17 = 0.98 g

2 Result 2 = weight C – weight A = 26.83 – 25.17 = 1.66g

3 Result 3 = result 2 – result 1 = 1.66 – 0.98 = 0.68 g

4 The mass ratio of metal to non–metal in magnesium oxide is 0.98 : 0.68

5

	magnesium	:	oxygen
mass ratio	0.98	:	0.68
particle ratio	0.98/24	:	0.68/16
mole ratio	= 0.041		= 0.043
that is	1	:	1
empirical formula		MgO	

6 The magnesium and oxygen reacted in a mass ratio of about 1.5: 1. The atomic weight of magnesium is about 1.5 times as great as the atomic weight of oxygen. Therefore the magnesium and oxygen combine in a 1:1 ratio

7 Magnesium oxide is a compound made up of magnesium element and oxygen element

Magnesium reacts with oxygen of the air to form magnesium oxide

The total mass of magnesium oxide formed equals the total mass of magnesium and oxygen that reacted.

Interpreting equations

$C_2H_2 + O_2 \rightarrow CO_2 + H_2O$

$C_2H_2 + 5/2\ O_2 \rightarrow 2\ CO_2 + H_2O$

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

1 vol. 5/2 vol.

Volume of oxygen required is 5/2 times the volume of acetylene.

Note: The gases in the oxygen and acetylene cylinders are under pressure. If the oxygen cylinder gas was kept under a pressure 5/2 times the pressure in an acetylene cylinder of the same size both gas supplies would run out at about the same time.

Yield of chemical reactions

A yield of over 100% indicates that the product could be contaminated with impurities or has not been dried properly.

Calculations in the mining industry

The decision on whether to proceed with a mine could depend on the yield of samples being high enough, mining being able to access sufficient ore and cost of extraction being manageable.

$2Fe/Fe_2O_3 = 2 \times 55.85 / 2 \times 55.85 + 3 \times 16.00 = 111.7/159.7 = 0.6994$

$0.6994 = 69.94\%$

A typical Australian haematite ore contains less than half the iron of the pure mineral Fe_2O_3.

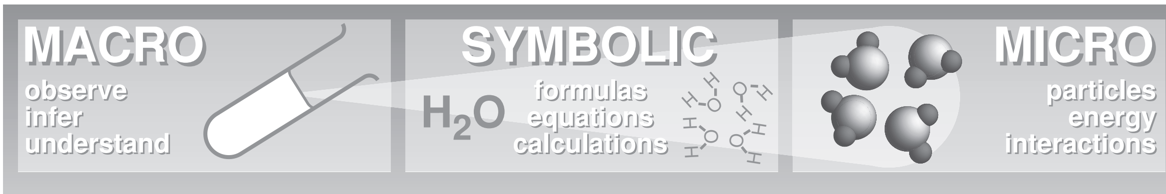
$Fe_2O_3 + CO \rightarrow Fe + CO_2$

$Fe_2O_3 + 3\,CO \rightarrow 2\,\underline{Fe} + 3\,\underline{CO_2}$

$CO_2 / Fe = 3 \times 44.01 / 2 \times 55.85 = 132.03 / 111.70 = 1.182$

1.182 tonnes of carbon dioxide are released for every tonne of iron produced by this reaction.

The amount of carbon dioxide released for every tonne of iron will actually be much greater. Carbon dioxide is produced by direct burning of coke to raise the temperature of the blast furnace, by the burning of fossil fuels in transporting materials to the blast furnace.



Exercise – Part 5

Exercises 5.1 to 5.4 Name: ______________________________

Exercise 5.1: Calculating molar mass

Substance	Formula	Calculation	One mole (g)
diamond			
helium			
hydrogen			
acetic acid	CH_3COOH		
magnesium sulfate			
calcium chloride			

Exercise 5.2: Using $\frac{m}{M} = n = \frac{N}{N_A}$

a) Calculate the number of moles in:

A large diamond weighing 0.3 g in a ring

____

____

100 g of pure acetic acid

____

____

1000 g of sodium chloride

____

____

b) Calculate the number of molecules in two moles of ozone O_3

____

____

c) How many moles is 6.02×10^{24} molecules of diatomic oxygen?

____

____

d) How many ions in ten moles of sodium chloride NaCl?
[Hint: How many ions are represented in the formula NaCl?]

____

____

Exercise 5.3: Molar mass and molar volume

Complete the statements below:

24.8 L of H_2 gas at 25°C and 100 kPa = 1.00 mol = 2.02 g

2.48 L of H_2 gas at 25°C and 100 kPa = 2.48/24.8 mol = _____ g

44.01 g of CO_2 gas at 25°C and 100 kPa = 1.00 mol = _____ L

440 g of CO_2 gas at 25°C and 100 kPa = _____ mol = _____ L

Exercise 5.4: Determining one mole of a metal

The diagrams below show four steps in an activity carried out in a school laboratory:

a) Describe in your own words how you would carry out this activity:

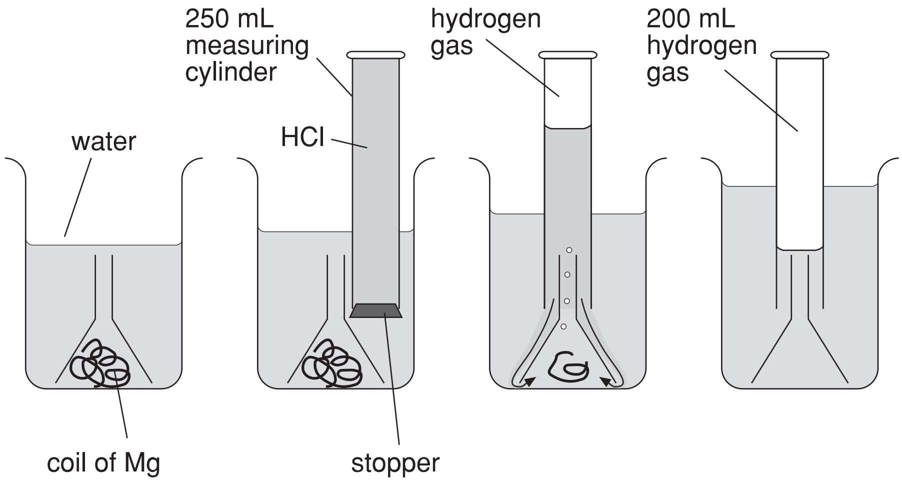
____

____

____

____

____



b) The 200 mL of hydrogen gas resulted from this reaction

$Mg + 2HCl \rightarrow MgCl_2 + H_2$

The balanced equation shows that the magnesium Mg : hydrogen H_2 mole ratio is __ : __

If the hydrogen gas was collected at 25°C and 100 kPa calculate the number of moles of hydrogen gas collected using $n = \frac{V}{V_{mol}}$.

c) How many moles of magnesium would be required to make the moles of hydrogen gas collected?

e) The coil of magnesium weighed 0.20 g. Calculate the number of moles of magnesium this is without using the atomic weight of magnesium. Explain your reasoning.

Chemistry
Preliminary Course
Stage 6

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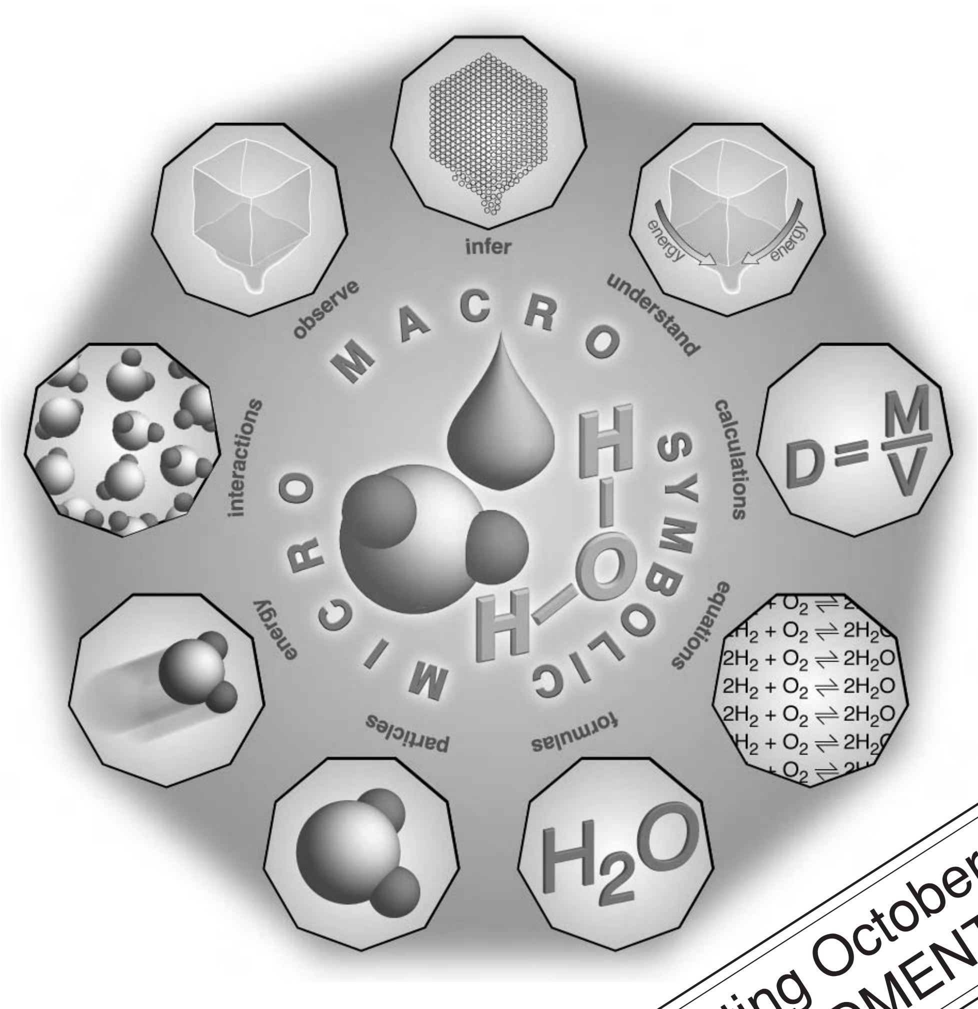
Metals

Part 6: Metals and society

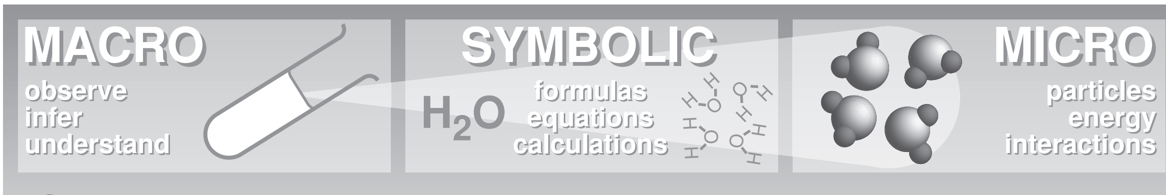


Incorporating October 2002 AMENDMENTS

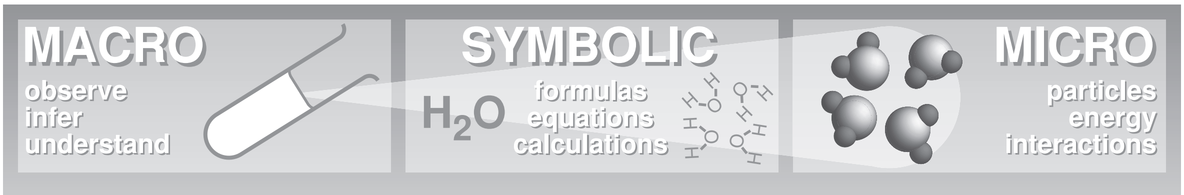
1 H 1.008 Hydrogen	Atomic number Symbol Atomic weight Name

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.39 Zinc	31 Ga 69.72 Gallium	32 Ge 72.61 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc [98.91] Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57-71 LANTHANIDES	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.8 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po [210.0] Polonium	85 At [210.0] Astatine	86 Rn [222.0] Radon
87 Fr [223.0] Francium	88 Ra [226.0] Radium	89-103 ACTINIDES	104 Rf [261.1] Rutherfordium	105 Db 262.1 Dubnium	106 Sg [263.1] Seaborgium	107 Bh [264.1] Bohrium	108 Hs [265.1] Hassium	109 Mt [268] Meitnerium	110 Uun – Ununnilium	111 Uuu – Unununium	112 Uub – Ununbium	113	114 Uuq – Ununquadium	115	116 Uuh – Ununhexium	117	118 Uuo – Ununoctium

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm [146.9] Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium
89 Ac [227.0] Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np [237.0] Neptunium	94 Pu [239.1] Plutonium	95 Am [241.1] Americium	96 Cm [244.1] Curium	97 Bk [249.1] Berkelium	98 Cf [252.1] Californium	99 Es [252.1] Einsteinium	100 Fm [257.1] Fermium	101 Md [258.1] Mendelevium	102 No [259.1] Nobelium	103 Lr [262.1] Lawrencium


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

Contents



Introduction

In this part you will listen to an audio recording that includes discussions with experts in:

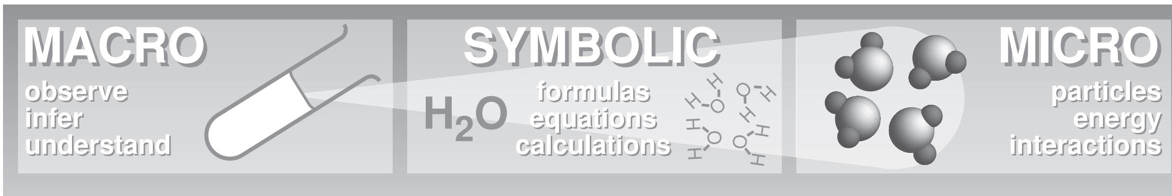
- ancient cultures: Mr Graham Joyner, Emeritus Curator Museum of Ancient Cultures, Macquarie University
- iron and steel making: Dr Veena Sahajwalla, Senior Lecturer School of Materials Science and Engineering, University of NSW
- modern metal uses: Dr Alan Crosky, Associate Professor School of Materials Science and Engineering, University of NSW
- acid making plants and sulfide mining: Mr Ian Knapp, Chemical Engineer
- archaeology and materials conservation: Dr Richard Thomas, Senior Lecturer Materials Conservation, University of Western Sydney Nepean.

The recording is available on audio–cassette tape (Chemistry – Metals 41519) or from the Learning Materials Production Centre web site (www.lmpc.edu.au/science, go to chemistry, go to metals, go to interviews).

After listening to the recording you will be required to answer questions based on the discussions.

You can then assess your knowledge and understanding as well as review key ideas in Parts 1 to 5 by answering true/false statements.

The exercises to be returned for this part can cover material from one part of this module or a number of parts.



Metals on tape / internet audio files

Listen to the audio (or web site interviews) on the *Metals and Society* cassette tape or web site audio file. Side 1 (30 minutes) or the first two internet audio files covers the Museum of Ancient Cultures (interview with Graham Joyner) and blacksmithing at Redfern Railway Locomotive Workshops. After listening, answer the questions that follow.

Side 1/first two internet audio files

1 How was metal recycling carried out on Bronze Age battlefields?

2 Give two uses where iron would have significant advantages over bronze.

3 The first metal tools were probably made from native (free) copper. How was the copper hardened?

4 How does folding hot iron over itself and beating it with a hammer change the composition?

5 Why is steel quenched?

Check your answers.

Side 2/rest of the web site interviews

Then listen to Side 2 (30 minutes) or the rest of the web site interviews involving discussions with four experts. Answer the questions. Check your answers with those supplied in the suggested answers.

1 The concentrations of various elements in iron can have a significant impact on the properties of steel. List three non–metals which can affect the properties of steel.

2 Until recently practically all Australian steel was produced in large scale integrated iron and steelworks such as those at Port Kembla near Wollongong. Now steel minimills have been established in Australian cities to produce steel. Give three advantages of minimills over integrated iron and steelworks.

3 Why is the main metal used in aircraft body construction aluminium alloy rather than steel?

4 Why are fan blades in jet engines made of titanium alloy?

5 Surface engineering includes modifying the surface properties of metals by implanting non–metals. Name three non–metals that are used in surface engineering.

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6 Give three possible reasons for building a sulfuric acid plant next to a metal sulfide smelter.

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7 Explain why the surface coating on copper in Sydney is mostly copper hydroxy chloride whilst in country areas the coating is mostly copper hydroxy carbonate.

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8 Multiple choice question – choose the best answer of the four alternatives. Laser Ablation Inductively Cooled Plasma Emission Mass Spectroscopy is a technique that can measure metals down to:

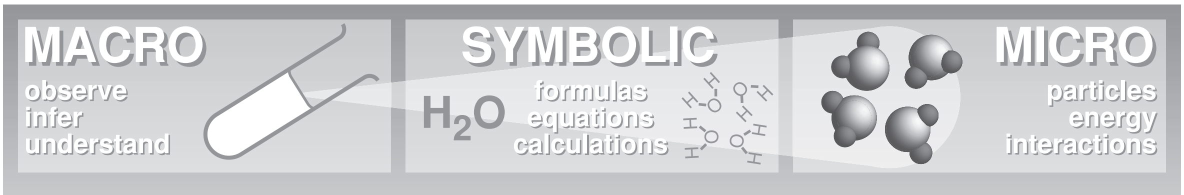
a) parts per hundred (%)

b) parts per thousand (ppt)

c) parts per million (ppm)

d) parts per billion (ppb).

Check your answers.



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.

Metal extraction and uses

- Stone tools are brittle and rarely recycled.
- Metal tools are malleable and easily recycled.
- Coke from coal was used before charcoal from wood to produce reducing conditions.
- Alloys never contain any non–metal.
- Bronze is an alloy of copper and zinc.
- An alloy is usually not as hard as the pure metals that make up the alloy.
- Alchemists found ways to change baser metals such as lead into gold.
- An amalgam is an alloy that must contain mercury.
- Electrons are needed to change metal combined in a mineral to the pure metal.
- Oxidising conditions in a kiln require the kiln to be blocked up so that the inside is filled with CO gas.

Metal reactivity

- Metals that react with dilute acid usually release hydrogen gas.
- When an acid reacts with a metal electrons transfer from the hydrogen ions to the metal atoms.
- Metals that react with water usually release hydrogen gas.
- The most reactive metals are found as the free element in nature.
- When a metal reacts with oxygen, water or acid the metal undergoes ionisation.
- The majority of metals react in cold water.
- The combining power of all metals never vary.
- There is no connection between metal activity and periodic table position.
- The most reactive metals in a periodic table group have the lowest ionisation energies
- An active metal reacts with most acids to form a salt and hydrogen.

The periodic table

- In ${}^{A}_{Z}X$ A represents the number of protons.
- In ${}^{A}_{Z}X$ X represents the element's symbol.
- ${}^{12}_{6}C$ can represent a carbon–12 atom.
- The gaseous elements are all non–metals.
- Atomic radius decreases down a group of the periodic table.
- Atomic radius increases from left to right across a period.
- Fluorine has the lowest electronegativity of all the elements.
- First ionisation energy is the energy required to remove an electron from a gaseous atom.
- Noble gases are the elements with the highest first ionisation energies.
- The most metallic elements are in the bottom left hand corner of the periodic table.

Metal extraction from ores

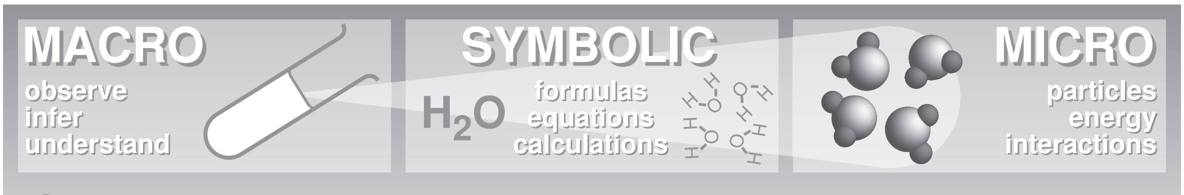
- Beneficiation of a mineral involves concentration and purification to improve desirable physical properties.
- Ores are non–renewable resources.
- The higher the concentration of a metal in an ore the higher the price of the metal.
- In an copper ore body you would expect to find sulfides at the surface and malachite and azurite well below the surface.
- Sulfur dioxide dissolves in water to form sulfuric acid.
- Froth flotation is a beneficiation technique first developed in Australia.
- Iron metal is sometimes called 'solid electricity' or the 'energy bank'.
- In a copper electrolytic refinery the copper ions are attracted to positive electrode.
- In a copper smelter SiO_2 is added to remove iron from the copper as slag.
- Gangue is the most useful part of an ore.

The mole concept

- Avogadro's number is approximately 6.02 x $10^{-23.}$
- The molar mass of oxygen gas is 16.00 g.
- Lavoisier is often regarded as the founder of modern quantitative chemistry.
- The best way to see if an object is hot is to touch it.
- Magnesium oxide has a low MP.
- The molar volume of any gas is 24.8 L at any temperature and pressure.
- One mole of any element is its atomic weight in grams.
- Your body contains more than N_A of atoms.
- Technological advances have improved the accuracy of calculated values of Avogadro's number.
- Avogadro's hypothesis is so well established it is now called a law.

Check your answers.

Do Exercises 6.1 to 6.5 now to complete your work on this module.



Suggested answers

Side 1/first two internet audio files

1 Metals were recycled in the Bronze Age in the following ways: bronze arrowheads were collected, melted and poured into moulds to cast new arrowheads; lead sling bullets were collected and either reused or melted and reshaped.

2 Iron was better than bronze when used as weapons such as swords and farming tools such as plough blades.

3 The copper used in the first metal tools was hardened by hammering.

4 Surface layers of oxide form on the outside of heated iron. Folding this over itself brings the oxide in contact with carbon. Reaction occurs and carbon combines with oxide to form carbon oxide gases which escape. This reduces the amount of carbon and changes the properties of iron. The iron can be changed to steel (stronger, harder, more corrosion resistant)

5 Steel is quenched to cool and change the properties of steel eg. by making the steel tougher.

Side 2/rest of the web site interviews

1 Three non–metals which can affect the properties of steel are carbon, phosphorus and sulfur.

2 One advantage of minimills is that there is no preprocessing of iron ore or coke. (Coke and sintered iron ore is used to give mechanical strength for packing in the blast furnace.)

Minimills do not use coke ovens which require extensive pollution control.

Minimills use recycled scrap steel.

3 Aluminium alloys have less than half the density of steel and therefore a lighter weight.

4 Titanium alloy is resistant to high temperatures and corrosion, hard and is resistant to wear.

5 Carbon, nitrogen and boron are used in surface engineering.

6 Sulfur dioxide gas SO_2 can be used to make sulfuric acid, otherwise it is a pollutant.

Sulfuric acid can be used to leach (dissolve) metals from some ores.

Heat energy released by smelting can be used to generate electricity to run the plant (electric motors, pumps, heating).

7 The salt spray in the air around Sydney provides the chloride component of the copper coating. In country areas there is less salt in the air. The carbonate in the coating comes from carbon dioxide in the air while water supplies the hydroxy component.

8 Laser Ablation Inductively Cooled Plasma Emission Mass Spectroscopy is a technique that can measure metals down to (d) parts per billion (ppb)

Metal extraction and uses

- Stone tools are brittle and rarely recycled. T
- Metal tools are malleable and easily recycled. T
- Coke from coal was used before charcoal from wood to produce reducing conditions. F

  Charcoal has been made from wood for thousands of years while coke has only been made from coal since the industrial revolution less than 300 years ago.
- Alloys never contain any non–metal. F

  Steel is an alloy of iron and the non–metal carbon.
- Bronze is an alloy of copper and zinc. F

  Bronze is an alloy of copper and tin or copper and arsenic.
- An alloy is usually not as hard as the pure metals that make up the alloy. F

  An alloy is harder than pure metals because it is harder for layers to move over layers containing atoms of different size.
- Alchemists found ways to change baser metals such as lead into gold. F

  There is no chemical way of changing atoms of an element into atoms of gold.
- An amalgam is an alloy that must contain mercury. T
- Electrons are needed to change metal combined in a mineral to the pure metal. T
- Oxidising conditions in a kiln require the kiln to be blocked up so that the inside is filled with CO gas. F

Oxidising conditions in a kiln involve increasing the supply of air or oxygen. CO gas produces reducing conditions.

Metal reactivity

- Metals that react with dilute acid usually release hydrogen gas. T
- When an acid reacts with a metal electrons transfer from the hydrogen ions to the metal atoms. F

  Electrons transfer from the metal atoms to the hydrogen ions producing hydrogen atoms then molecules which escape as gas.
- Metals that react with water usually release hydrogen gas. T
- The most reactive metals are found as the free element in nature. F

  The most reactive metals react quickly forming stable compounds; they are never found as the free element in nature.
- When a metal reacts with oxygen, water or acid the metal undergoes ionisation. T
- The majority of metals react in cold water. F

  Only group 1 metals and group 2 metals below Mg react with cold water.
- The combining power of all metals never vary. F

  Some metals have more than one combining power eg. copper 1 0r 2, iron 2 or 3.
- There is no connection between metal activity and periodic table position. F

  Metal activity decreases from the bottom left hand corner towards the most active non–metal fluorine.
- The most reactive metals in a periodic table group have the lowest ionisation energies. T
- An active metal reacts with most acids to form a salt and hydrogen. T

The periodic table

- In $^{A}_{Z}X$ *A* represents the number of protons. F

  It represent the number of protons and neutrons.
- In $^{A}_{Z}X$ X represents the element's symbol. T
- $^{12}_{6}C$ can represent a carbon–12 atom. T
- The gaseous elements are all non–metals. T
- Atomic radius decreases down a group of the periodic table. F

Atomic radius increases down a group as atoms become larger by adding more electron shells.

- Atomic radius increases from left to right across a period. F

  Atomic radius decreases as nuclei have increasing charge and attract their outer electrons more strongly.

- Fluorine has the lowest electronegativity of all the elements. F

  Fluorine has the highest electronegativity of all the elements.

- First ionisation energy is the energy required to remove an electron from a gaseous atom. T
- Noble gases are the elements with the highest first ionisation energies. T
- The most metallic elements are in the bottom left hand corner of the periodic table. T

Metal extraction from ores

- Beneficiation of a mineral involves concentration and purification to improve desirable physical properties. T
- Ores are non–renewable resources. T
- The higher the concentration of a metal in an ore the higher the price of the metal. F

  A high concentration of ore requires less effort and energy to separate from gangue so the price is lower.

- In an copper ore body you would expect to find sulfides at the surface and malachite and azurite well below the surface. F

  Sulfides react with oxygen, water and carbon dioxide at the surface to form malachite and azurite.

- Sulfur dioxide dissolves in water to form sulfuric acid. F

  Sulfur dioxide needs to be oxidised first to sulfur trioxide before dissolving in water $SO_2 \rightarrow SO_3 \rightarrow H_2SO_4$

- Froth flotation is a beneficiation technique first developed in Australia. T
- Iron metal is sometimes called ‘solid electricity’ or the ‘energy bank’. F

  These names are used to describe aluminium because of the large amount of electrical energy needed to extract aluminium from alumina.

- In a copper electrolytic refinery the copper ions are attracted to positive electrode. F

Copper ions are positive and therefore attracted to the negative electrode.

- In a copper smelter SiO_2 is added to remove iron from the copper as slag. T
- Gangue is the most useful part of an ore. F

  Gangue is the unwanted part of the ore.

The mole concept

- Avogadro's number is approximately 6.02 x 10^{-23} F *6.02* x *10^{23}*
- The molar mass of oxygen gas is 16.00 g. F

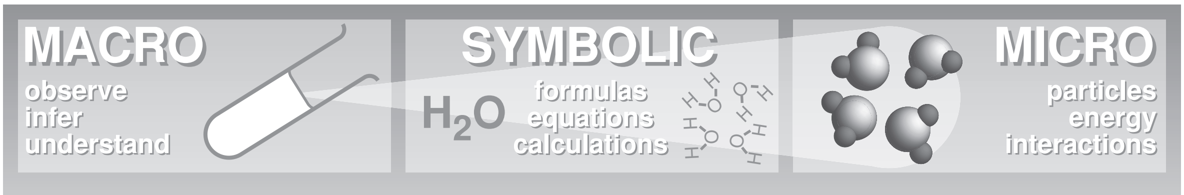
  Oxygen gas consists of O_2 molecules so the molar mass is the mass of O_2 in g = 32.00 g.
- Lavoisier is often regarded as the founder of modern quantitative chemistry. T
- The best way to see if an object is hot is to touch it. F

  See the flowchart How hot is it? in Part 5 for safe procedure.
- Magnesium oxide has a low MP. F

  MgO has a high MP and is used in refractories (high temperature kilns and furnaces).
- The molar volume of any gas is 24.8 L at any temperature and pressure. F

  This volume applies to 25°C and 100 kPa.
- One mole of any element is its atomic weight in grams. F

  One mole of diatomic elements is the molecular weight in grams.
- Your body contains more than N_A of atoms. T
- Technological advances have improved the accuracy of calculated values of Avogadro's number. T
- Avogadro's hypothesis is so well established it is now called a law. T



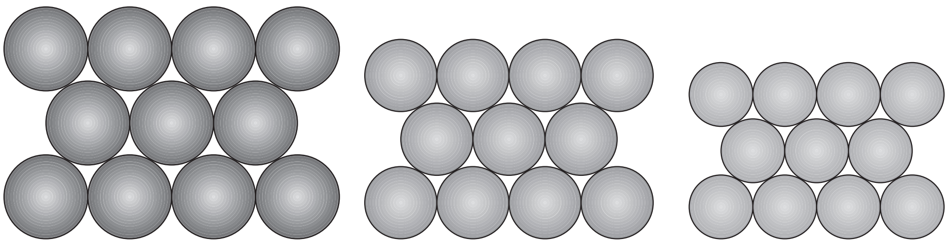
Exercises – Part 6

Exercises 6.1 to 6.5 Name: ________________________________

Exercise 6.1: Periodic table trends and models

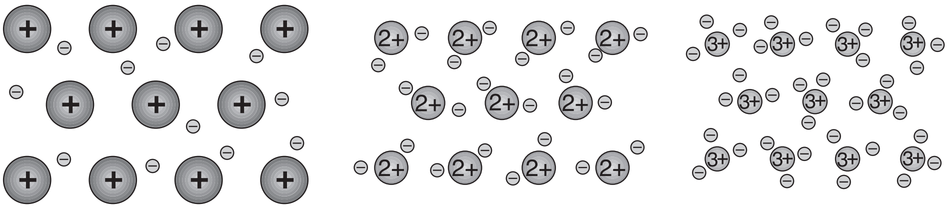
Two models are shown below for the first three members of a period. All three elements are metals and so can be represented by the metallic lattice model or the metallic bond model.

Metallic lattice model



Na 186 pm Mg 160 pm Al 143 pm

Metallic bond model



Na^+ 102 pm Mg^{2+} 72 pm Al^{3+} 53 pm

⊖ delocalised electron ⊖⊖ delocalised electrons ⊖⊖⊖ delocalised electrons

1 a) Use the diagrams to describe the trend across the period in atomic radius

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ionic radius

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b) One of these two trends is maintained until the end of the period while the other is not. Explain why.

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2 a) Use the diagrams to predict the trend in densities for Na Mg Al.

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b) Explain how you used the diagram(s) to predict the trend in densities.

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c) Now turn to the table *Metal properties* in the *Appendix* of Part 2. Does your prediction match the listed values for density?

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3 Use the table of ionisation energies on the next page to list the first ionisation energies of:

Na ………………. Mg ………………. Al ……………….

When scientists find a trend that is unexpected they investigate more thoroughly. Write the ionisation energies for the first three members of the period above Na Mg Al, that is, Li Be B.

Li ………………. Be ………………. B ……………….

.

Atomic No.	First ionisation energy (kJ/mol)	Atomic No.	First ionisation energy (kJ/mol)	Atomic No.	First ionisation energy (kJ/mol)
1	1318	20	596	39	606
2	2379	21	637	40	666
3	526	22	664	41	670
4	906	23	656	42	691
5	807	24	659	43	708
6	1093	25	724	44	717
7	1407	26	766	45	726
8	1320	27	765	46	811
9	1687	28	743	47	737
10	2087	29	752	48	874
11	502	30	913	49	565
12	744	31	585	50	715
13	584	32	768	51	840
14	793	33	953	52	876
15	1018	34	947	53	1015
16	1006	35	1146	54	1177
17	1257	36	1357	55	382
18	1527	37	409		
19	425	38	556		

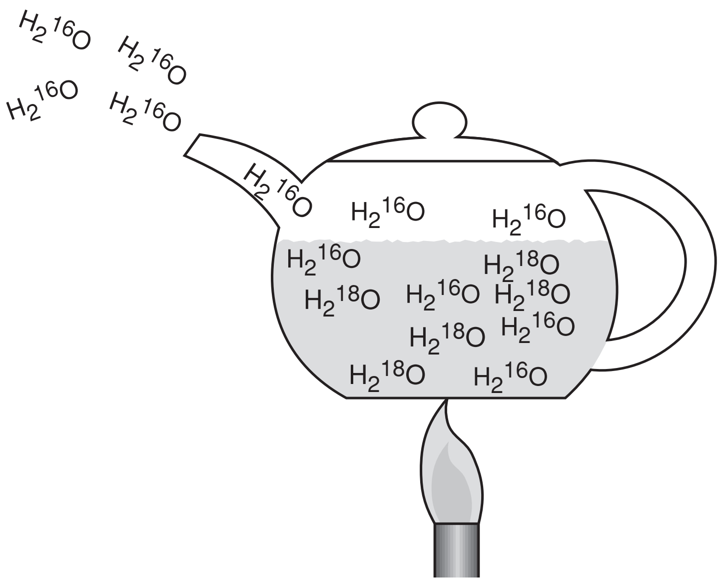
By looking at the ionisation energies for the whole of the two periods (Na → Ar and Li → Ne) or can you see any other similarities? Describe or draw any similarities.

Discrepant (unexpected) results like this can lead to scientists to develop more detailed and powerful models. From observations of trends in ionisation energy scientists have developed more sophisticated models of electron arrangement in shells involving *s, p, d* and *f* subshells.

Exercise 6.2: Separating isotopes

In the word isotope 'iso' means equal and 'p' can stand for protons. Isotopes are atoms with equal numbers of protons but different numbers of neutrons. Isotopes of an element have different masses and so differ in physical properties that depend on mass such as boiling point BP. The different masses of isotopes can also affect the physical properties of compounds that contain them.

In nature oxygen consists of mostly ^{16}O and a small number of ^{18}O atoms. Water in nature contains $H_2{}^{16}O$ molecules and the heavier $H_2{}^{18}O$ molecules. If you boil a kettle of water the lighter $H_2{}^{16}O$ molecules boil off at a lower temperature than the $H_2{}^{18}O$ molecules. Lighter molecules need less energy than heavier molecules to move from the liquid phase to the gas phase. Repeated boiling of your kettle at home, making sure that you always leave some water in the kettle, will increase the proportion of heavy $H_2{}^{18}O$ molecules in your kettle.



1 There is another type of heavy water molecule that contains only ^{16}O but ^{2}H atoms. Write the formula for an additional type of heavy water molecule.

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2 Most nuclear reactors need uranium isotope enrichment of fuel from the natural level of 0.7% U–235 to 3.5% U–235. Can you find out how enrichment of the level of U–235 is carried out? Books, encyclopaedias or the internet could be suitable sources. List the source(s) you used below your information.

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3 A mass spectrometer is a scientific instrument that sorts particles out according to their mass. Some of the most sophisticated chemical analysis equipment in the world is based on the mass spectrometer. Can you find out how a mass spectrometer works? Include the word *ionise* or *ionisation* in your answer and list the source(s) of your information.

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Exercise 6.3: Measuring the metal:oxygen mass ratio

In the activity on burning magnesium to magnesium oxide very high temperatures can be reached. This can cause some of the magnesium to react with nitrogen in the air forming magnesium nitride Mg_3N_2.

Any yellow–green Mg_3N_2 formed amongst the white MgO residue can be decomposed by carefully adding a few drops of water to the residue then reheating.

1 Addition of water H_2O to Mg_3N_2 forms magnesium hydroxide $Mg(OH)_2$ and ammonia gas NH_3. Write a balanced equation for this reaction.

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2 The reheating decomposes the magnesium hydroxide to magnesium oxide and water. Write a balanced equation for this change.

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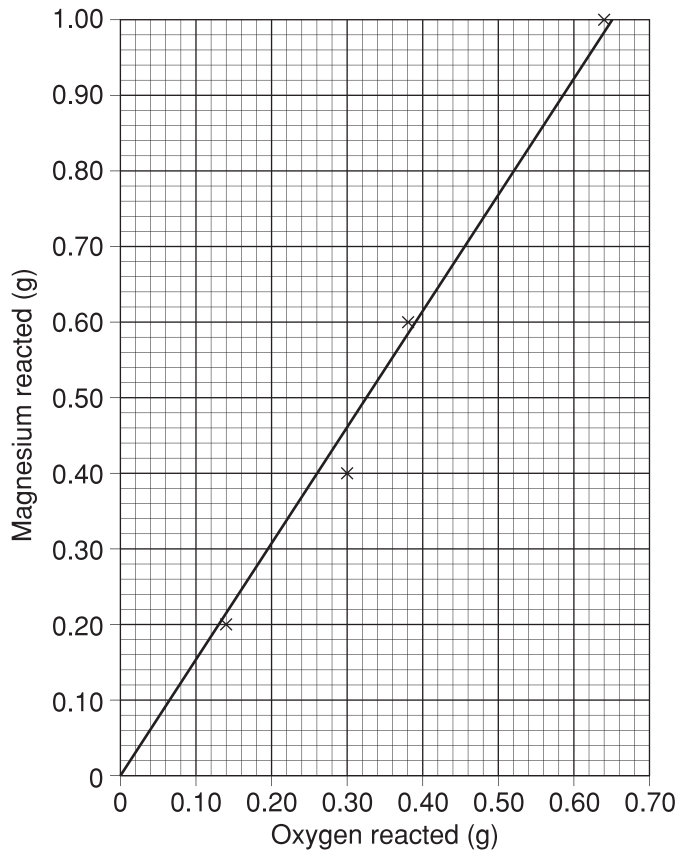
3 The graph below shows the results that four students obtained for this activity. The graph was not extrapolated (extended) above the

largest result (1.00 g of Mg) but was extrapolated below the lowest (0.20 g).



a) What additional point could be used in drawing this straight line graph below 0.20 g of Mg? [If you are not sure then think about how much oxygen would react with 0.00 g of Mg].

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b) If a student carried out this experiment using 0.75 g of magnesium use the graph to determine the amount of oxygen gas that would have reacted.

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c) If a student carried out this experiment using 0.34 g of magnesium use the graph and a calculation to determine the mass of magnesium oxide formed.

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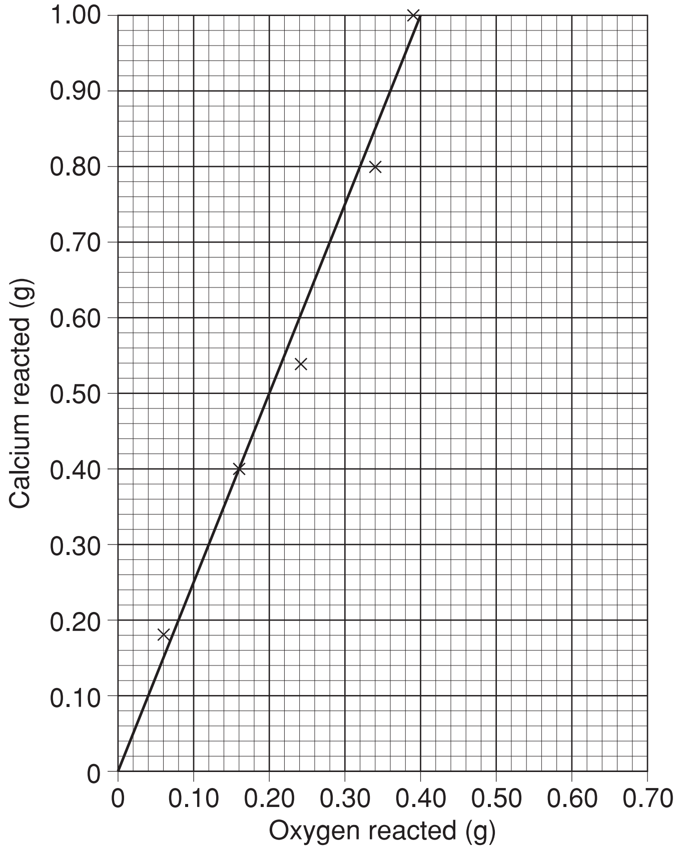
4 Another group of students carried out a similar experiment using calcium metal instead of magnesium metal. The results they obtained are shown below:



a) Write a balanced equation for the reaction of calcium with oxygen to form calcium oxide.

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b) Why is the graph for calcium steeper than the graph for magnesium? Try to use the term *mole* in your answer.

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c) If you wanted to make 1.05 g of calcium oxide use the graph and a calculation to work out how much calcium you would need to use.

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Exercise 6.4: Using the mole concept in calculations

In the smelting of copper(I) sulfide the following reaction occurs.

a) Complete the mole stoichiometry.

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

2 mol +___mol $\rightarrow$ ___mol + ___mol

b) If 1 t (= 1 000 kg = 1 000 000 g) of copper (I) sulfide is smelted calculate the number of moles.

____

____

c) Using the mole stoichiometry calculate how many moles of oxygen gas will be required to react with the 1 t of copper (I) sulfide.

____

d) Change the moles of oxygen required to grams and then tonnes.

____

____

e) How many litres of oxygen gas is this at 25°C and 101.3 kPa? The molar volume of any gas at 25°C and 101.3 kPa is 24.5 L.

____

____

f) How many moles of sulfur dioxide gas are produced by the oxidation of 1 tonne of copper(I) sulfide?

____

____

g) Change the moles of sulfur dioxide produced to grams and then tonnes.

____

____

h) How many tonnes of sulfuric acid could be made from this amount of sulfur dioxide byproduct?
1 mol $SO_2 \rightarrow$ 1 mol $SO_3 \rightarrow$ 1 mol H_2SO_4

____

Exercise 6.5: Electronegativity and the periodic table

The US chemist Linus Pauling was awarded the 1954 Nobel Prize in Chemistry for his work on bonding. In 1962 he became the first person to be awarded a second Nobel Prize when he received the Nobel Peace Prize for his nuclear test ban treaty campaign. He also devised ways to calculate electronegativity (EN).

H 2.20																	
Li 0.98	Be 1.57						H 2.20	Symbol Electronegativity (EN)				B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	
Na 0.93	Mg 1.31											Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	
K 0.82	Ca 1.00	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.90	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96	
Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16		Ru 2.2	Rh 2.28	Pd 2.20	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66	
Cs 0.79	Ba 0.89	LANTHANIDES	Hf 1.3	Ta 1.5	W 2.36		Os 2.2	Ir 2.20	Pt 2.28	Au 2.54	Hg 2.00	Tl 2.04	Pb 2.33	Bi 2.02	Po 2.0	At 2.2	
Fr 0.7	Ra 0.9	ACTINIDES															

La 1.10	Ce 1.12	Pr 1.13	Nd 1.14	Pm 1.2	Sm 1.17	Eu 1.2	Gd 1.20	Tb 1.2	Dy 1.22	Ho 1.23	Er 1.24	Tm 1.25	Yb 1.1	Lu 1.27
Ac 1.1	Th 1.3	Pa 1.5	U 1.38	Np 1.36	Pu 1.28	Am 1.3	Cm 1.3	Bk 1.3	Cf 1.3	Es 1.3	Fm 1.3	Md 1.3	No 1.3	

a) Using red for values 3.00 or more, yellow for values between 2.00 and 2.99, green for values between 1.00 and 1.99 and dark blue for values below 1.00, colour in four areas of the periodic table.

b) Why are no values given for the inert gases?

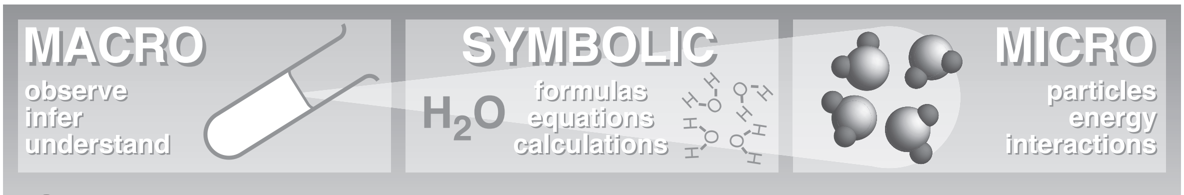
____

____

c) Differences in electronegativity values can help decide:

- the order of the elements in a binary compound formula – the least electronegative element is placed first eg. NO, UF_6
  - if the bonds between two different elements are ionic or covalent; if the difference between the electronegativities of the two elements is greater than 1.7 the bond is usually regarded as ionic.

Underline the compounds in this list that you would predict contain ionic bonds: CsI, CuI, SiO_2, BaO, PbF_2, $SnCl_2$.



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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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