3 Reactions of metals

KEY KNOWLEDGE

In this topic you will investigate:

Reactions of metals

- the common properties of metals (lustre, malleability, ductility, heat and electrical conductivity) with reference to the nature of metallic bonding and the existence of metallic crystals
- experimental determination of a reactivity series for metals based on their relative ability to undergo oxidation with water, acids and oxygen
- metal recycling as an example of a circular economy where metal is mined, refined, made into a product, used, disposed of via recycling and then reprocessed as the same original product or repurposed as a new product.

PRACTICAL WORK AND INVESTIGATIONS

Practical work is a central component of VCE Chemistry. Experiments and investigations, supported by a **practical investigation eLogbook** and **teacher-led videos**, are included in this topic to provide opportunities to undertake investigations and communicate findings.

3.1 Overview

Numerous **videos** and **interactivities** are available just where you need them, at the point of learning, in your digital formats at www.jacplus.com.au. Just look for the icons.

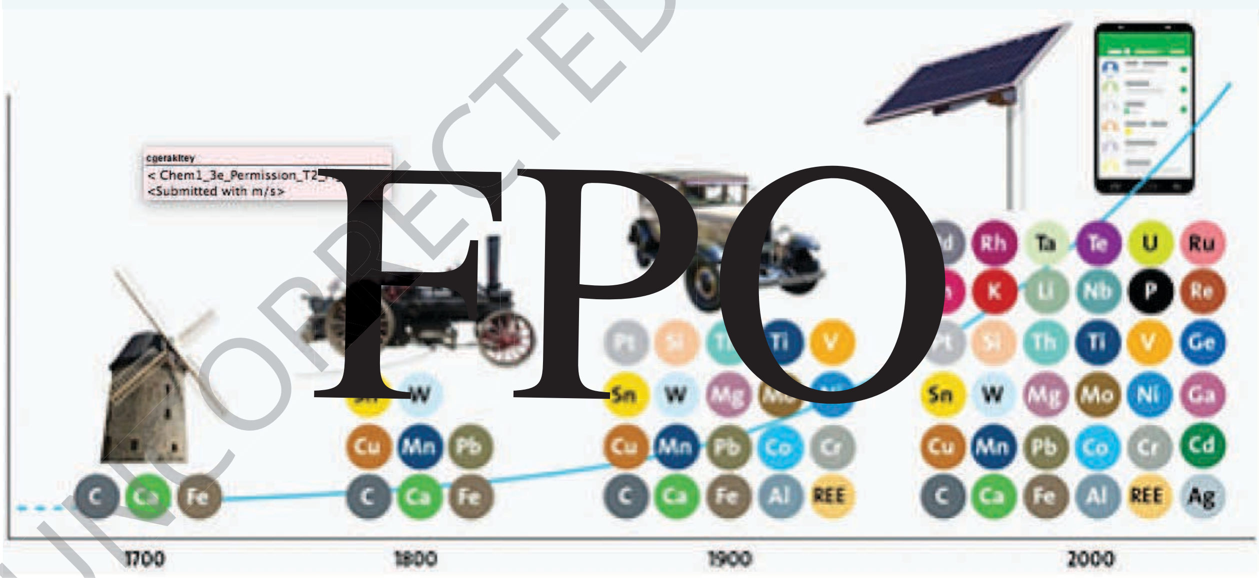
3.1.1 Introduction

Humans have known for centuries that elements can be divided into two broad groups: metals and non-metals. The largest group is the metals. The first metal to gain widespread use was copper, which was first mined and used in Iran around 9000 years ago. Copper's popularity was mainly due to its relatively low melting point (1084 °C) and the ease with which it could be extracted from its ores. In contrast, aluminium, which is the most common metal in the Earth's crust, was difficult and expensive to extract from its ore and has become widespread only in the last century due to technological advances. The number of different metals presently in use has increased significantly, either as pure metals or combined with other elements as alloys.

Your mobile phone, for example, contains up to 62 different metals, each chosen because of their specific properties. These metals include gold, which is very stable and a very good conductor of electricity; lithium, in batteries, because of its reactivity; and copper, also an effective conductor. Because of increasing population and the widespread use of digital devices, more of these metals are required as well as many less abundant metals.

During mining, metals are extracted from ores using a variety of processes, but resources are limited. The good news is that metals can be recycled and still retain their original properties. Currently, producing metals requires large amounts of energy, and causes considerable damage to the environment withan enormous quantity of waste generated. A more sustainable approach is needed that minimises the use of raw materials, limits waste and protects the environment for the benefit of future generations. This new methodology focuses on a more innovative circular economy rather than the linear economy that is more common at present.

FIGURE 3.1 The number of different metals we use has increased over time.



LEARNING SEQUENCE

3.1 Overview 2
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3.4 Recycling metals 18
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Resources

Practical investigation eLogbook	Practical investigation logbook — Topic 3 (elog-1607)
Digital documents	Key science skills (doc-37066) Key terms glossary — Topic 3 (doc-37069) Key idea summary — Topic 3 (doc-37070)
Exam question booklet	Exam question booklet — Topic 3 (eqb-0083)
Solutions	Solutions — Topic 3 (sol-0801)

3.2 Properties of metals

KEY KNOWLEDGE

- The common properties of metals (lustre, malleability, ductility, heat and electrical conductivity) with reference to the nature of metallic bonding and the existence of metallic crystals

3.2.1 The physical properties of metal

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Since more than 80 metal elements exist, it is not surprising that some of their properties vary widely.

At room temperature, for example, mercury is a liquid, but magnesium is a solid; zinc is brittle, iron is hard and sodium (figure 3.2) can be cut with a knife; lead has a high density (11.3 g/cm^3) and sodium has a low density (0.97 g/cm^3). Look around you and identify where metals are used and suggest why each metal was chosen. Most metals, however, have the following properties in common.

FIGURE 3.2 Sodium, like other group 1 and 2 metals, has a low density and can be cut with a knife.

Metals:

- are lustrous (have a shiny surface when polished)
- are malleable (can be hammered, bent or rolled into sheets or other shapes)
- are ductile (can be drawn out into wires)
- are good conductors of heat
- are good conductors of electricity
- generally have a high density (mass per unit volume)
- have a range of melting points (but most are quite high)
- are often hard (have high resistance to denting, scratching and bending).

3.2.2 Crystal nature of metallic bonding

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Metallic atoms have low electronegativities, which means they tend to lose their outer shell electrons easily. Once a metallic atom has lost its outer shell electron, it becomes a **cation** (positively charged). This produces electron configurations similar to the group 18 elements (noble gases) and, hence, a more stable state.

X-ray studies show that metals occur as crystal lattices. Chemists imagine these **metallic lattice structures** as being made up of a patterned array of cations (see figure 3.3). The electrons from each metallic atom overlap each other forming a sea of mobile electrons that can flow between all the cations. They are referred to as **delocalised** electrons (figure 3.4).

Electrostatic forces of attraction between the cations and the negatively charged valence electrons occur in all directions and this holds the lattice together. This type of non-directional bonding is known as **metallic bonding**. This means that metal atoms are hard to separate but relatively easy to move.

cation a positively charged atom or group of atoms

metallic lattice structures crystal lattice made up of an array of cations

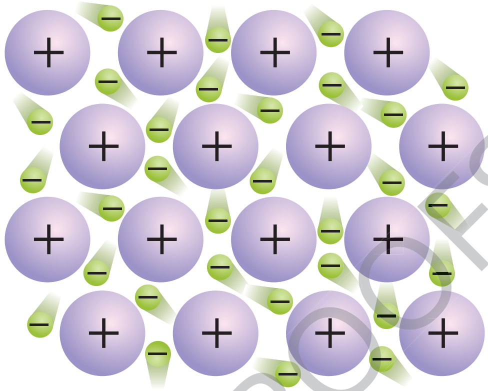
delocalised describes electrons that are not bound to any one atom but are free to move throughout a lattice

Electrostatic force attractive or repulsive force between particles that are due to their electric charges.

metallic bonding positively charged metal cations arranged in a lattice with delocalised valence electrons being able to flow around them

FIGURE 3.3 This box of oranges gives a representation of a repeated pattern array of cations in a lattice structure.

FIGURE 3.4 Metal cations vibrate about a fixed position surrounded by a sea of delocalised electrons.



3.2.3 The structure and properties of metallic crystals

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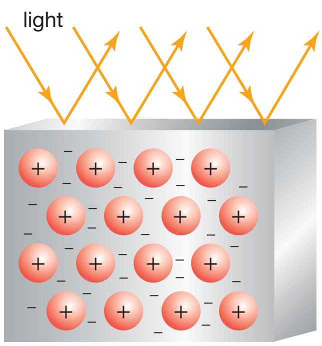
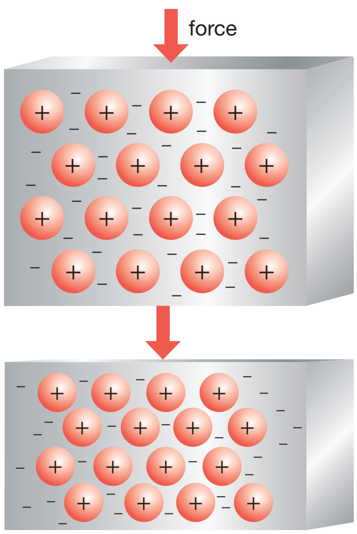
The lattice structure of metals may be used to explain many of their properties. These properties give metals their many applications in our society.

lustrous having a shiny surface

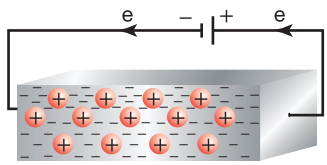
malleable able to be hammered or pressed into shape without breaking or cracking

ductile able to be drawn out into a thin wire

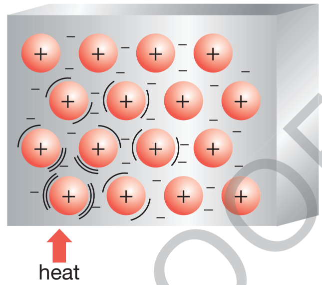
TABLE 3.1 How the properties of metals relate to structure

Property of metal	Diagram
Lustre The **lustrous** appearance of a metal is due to the mobile electrons within the lattice being able to reflect light back into your eye, causing the metal to look shiny.	
Malleability and ductility Metals are **malleable** and **ductile**, rather than brittle, as a result of the non-directional nature of metallic bonds. The attractive forces exerted by the cations for the mobile electrons occur in all directions. This means that layers of atoms can move past one another without disrupting the force between the cations and the negative sea of electrons. The nature of the metal does not change when the metal becomes thinner.	

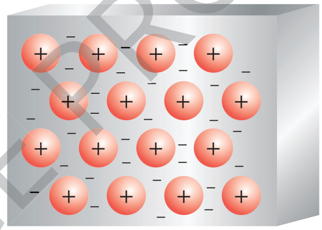
Electrical conductivity
Metals are good conductors of electricity. When an electric field is applied to a metal, one end of the metal becomes positive and the other becomes negative. All the electrons experience a force towards the positive end. This flow of charge (movement of electrons) is what we call an electric current.



Heat conductivity
Metals are good conductors of heat. Electrons gain kinetic energy in hotter areas of the metal and quickly transfer it to other colder parts of the metal lattice due to the electron's freedom of movement. The heat causes the electrons to move faster, and the 'bumping' of these electrons against each other and the protons transfers the heat throughout the metal.



Density
Most metals have relatively high densities because metallic lattices are close-packed.
Melting points and hardness
The generally high melting points and hardness of metals indicate that metallic bonding is quite strong (although not as strong as covalent or ionic bonding). Melting points and hardness increase with an increase in the number of outer shell electrons, since this greater number means a greater attractive force exists between the cations and the electrons.



on Resources

Weblink Structure of metals
Structure and bonding
Metallic crystals

FIGURE 3.5 Steel can be pressed and rolled into sheets, as at this factory. What metallic property is illustrated here?

EXTENSION: Limitations of models

Although many of the properties of metals can be explained using the lattice model, other properties are not explained. For example:
- Why is iron magnetic and copper non-magnetic?
- Why is platinum 20 times as dense as sodium?
- Why is lead malleable whereas iron is tough?
- Why does such a difference exist between the hardness of the different metals?
- Why is mercury a liquid and most other metals solid at room temperature?

As with many models the 'cations in a sea of elections' model provides a simplified representation of the structure of metals to allow greater understanding, and to explain the majority of metal properties. Other factors alsocontribute to the differences in properties, and these include the number of valence electrons and atomic mass, and how atomic size impacts on how well the atoms fit together. Metal properties can be changed by heat treatment when they are manufactured and by combining them with other metals or non-metals to form alloys.

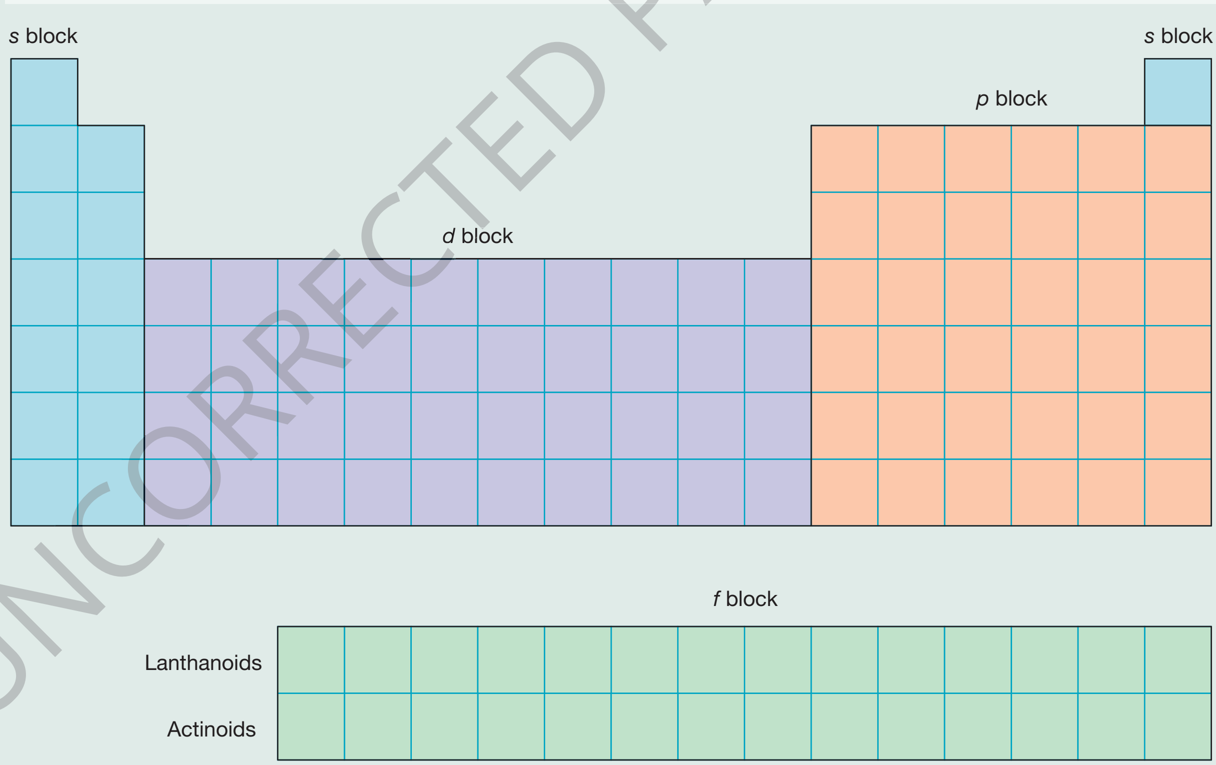
TABLE 3.2 Examples of the variety in each of these properties of metals and non-metals

Element	Metal/metalloid/metal	Density (g mL^{-1})	Hardness (Moh's scale)	Thermal conductivity (W $m^{-1}K^{-1}$)	Electrical conductivity (S/m)	Melting point (°C)
Aluminium	Metal	2.7	2.8	235	3.77×10^7	660
Copper	Metal	9.0	3.0	400	5.96×10^7	1085
Silver	Metal	10.5	2.5	430	6.30×10^7	961
Iron	Metal	7.9	4.0	80	1.00×10^7	1535
Silicon	Metalloid	2.3	6.5	150	4.35×10^{-4}	1410
Boron	Non-metal	2.3	9.4	27	10^{-4}	2300
Phosphorus	Non-metal	1.8	0.5	0.24	1.0×10^{-10}	44
Sulfur	Non-metal	2.1	2.0	0.205	10^{-16}	115
Oxygen	Non-metal	0. 0014	0	0.0277	N/A	–223

EXTENSION: Properties of main group and transition metals

Metals are widely used in our society. Their different properties make them useful for particular purposes. The different blocks of the periodic table were introduced in topic 1, and are shown in figure 3.6.

FIGURE 3.6 The blocks of the periodic table



Properties of the *s*-block metals

The *s*-block metals include the alkali metals (group 1) and the alkali earth metals (group 2). Their properties are related to having only one (alkali metals) or two (alkaline earth metals) electrons in their outer shell.

Properties of alkali metals	Properties of alkaline earth metals
• Very reactive and are not found in elemental form. Most uses involve their compounds.	• Reactive metals, usually found as compounds. Less reactive than alkali metals.
• Low densities. The atoms are larger than other atoms in the same period, and they are not as efficiently packed together.	• Harder and denser than alkali metals.
• Relatively low melting points.	• Higher melting points than alkai metals.
Uses: Sodium is used as a coolant in nuclear reactors, in the manufacture of titanium and for street lights. Lithium is used in rechargeable batteries and, because of its lightness, is combined with other metals to make alloys.	Uses: Magnesium is used in alloys for aircraft and guided missile parts where lightness and high tensile strength are essential. The compound calcium carbonate is used to make calcium oxide for neutralising soils, glassmaking and as a component of cement.

Properties of the *p*-block metals

The *p*-block of the periodic table contains metals such as aluminium, tin and lead, as well as metalloids and non-metals.

- Aluminium is the most abundant metal in the Earth's crust and is very versatile. When exposed to air it develops a coating of aluminium oxide, Al_2O_3, which prevents further reactions with oxygen, and hence further corrosion. Aluminium is strong and light, and is used in transport, building, and food storage and preparation such as drink cans and saucepans. The good electrical conductivity and low density of aluminium make it ideal for use in overhead wires.
- Tin does not corrode easily, and tin cans are highly resistant to the corrosive properties of acidic foods, such as tomatoes. The alloys solder, bronze and pewter all contain tin.
- Lead has been used since Roman times because it is easily worked and resistant to corrosion. Lead was used for water pipes, in pottery glazes and paint pigments, in jewellery and as a petrol additive. Due to health hazards, these uses for lead have significantly declined in recent decades. Current uses include car batteries, roofing, exercise weights and bullets.

Properties of the *d*-block metals

The *d*-block metals are transition metals. These elements have a number of interesting properties.

- Many (except scandium and zinc) form coloured compounds, and are used in stained glass.
- The magnetic metals — iron, cobalt and nickel — are transition metals.
- They can form ions of different charges and, therefore, a wide variety of compounds. For example, iron forms two compounds with chlorine — $FeCl_2$, which is a green compound, and $FeCl_3$, which is an orange compound.
- As with other metals, most *d*-block metals are used in the form of alloys. Iron is widely used in construction, often in alloy form as steel, which is less brittle and more resistant to corrosion than elemental iron.
- They are useful catalysts. A catalyst is a substance that increases the rate of a chemical reaction without itself being chemically changed. Iron is used as a catalyst in the production of ammonia.
- They are good conductors of electricity, with copper used in saucepans and gold in electrical wiring.

FIGURE 3.7 Transition elements form coloured solutions.

3.2 Activities

learnON

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at www.jacplus.com.au. A **downloadable solutions** file is also available in the resources tab.

3.2 Quick quiz on	3.2 Exercise	3.2 Exam questions

3.2 Exercise

1. MC What is the metallic bonding model best described as? **(1 mark)**
   A. An electrostatic attraction between metal atoms and delocalised electrons
   B. The tendency of metal atoms to lose electrons when bonding with other elements
   C. The electrostatic attraction between layers of positive metal ions and negative metal ions
   D. Layers of metal cations held electrostatically by surrounding delocalised electrons
2. MC Which of the following *cannot* be explained by the metallic bonding model?
   Property I: Magnetism
   Property II: Ductility
   Property III: Variations in melting temperatures
   A. All three properties can be explained by the metallic bonding model.
   B. Property I only.
   C. Properties I and III only.
   D. All three properties are unable to be explained by the metallic bonding model.
3. Lithium exists as a crystalline solid at temperatures lower than 180 °C.
   a. Write the electron configuration of a lithium atom.
   b. Write the symbol and electron configuration of its cation.
   c. Describe how lithium atoms are bonded together in the solid.
4. Explain the following properties of iron.
   a. Hard
   b. Malleable and ductile
   c. Able to conduct electricity in solid and molten form
5. Magnesium is produced from the mineral dolomite, $CaMg(CO_3)_2$.
   a. Describe the bonding in magnesium metal crystals.
   b. Magnesium crystals are silver-white and shiny. Explain this property of lustre in terms of structure and bonding.
6. a. The model of metals that describes them as consisting of 'cations in a sea of electrons' does not explain all properties of metals. Why is it used?
   b. State two properties of metals that are not explained by this model
7. Explain why aluminium is used for drink cans whereas 'tin' cans are used for other foods.
8. Give three reasons silver and gold are used for jewellery.
9. Choose a metal that would be best suited for fabrication of the following.
   a. Car bodies
   b. Beer cans
   c. Household electrical wiring
   d. Fishing sinkers
   Justify your choices.
10. Electricity transmission lines for industry are usually made from aluminium even though copper is a better electrical conductor. Suggest two reasons aluminium is used.

3.2 Exam questions

Question 1 (1 mark)

MC Which of the following best describes the metallic bonding model?

A. A lattice of metal molecules connected by delocalised electrons
B. A lattice of metal cations held electrostatically to a 'sea' of moving electrons
C. A lattice of metal cations and non-metal anions held by strong ionic bonds
D. A lattice of metal atoms closely held together by electrostatic forces

Question 2 (1 mark)

MC A sample of element *Z* can be hammered out into sheets.

Which of the following describes other properties of element *Z*?

A. Non-conductor of electricity, low melting point
B. Non-conductor of electricity, high melting point
C. Conductor of electricity, low melting point
D. Conductor of electricity, high melting point

Question 3 (2 marks)

Some properties of four elements *M*, *N*, *O* and *P* are as follows.

M melts at 2200 °C, is hard and is a non-conductor.
N has a high density and can be drawn into wires.
O is liquid at room temperature and can conduct electricity.
P is lustrous, has a melting point of 1410 °C and is a non-conductor of electricity.
State which elements are metals.

Question 4 (5 marks)

List two metallic properties required for each of the following objects.

a. Plane **(1 mark)**
b. Saucepan **(1 mark)**
c. Mobile phone cover **(1 mark)**
d. Bridge **(1 mark)**
e. Outdoor furniture **(1 mark)**

Question 5 (3 marks)

Copper has far better electrical conductivity than aluminium and is used for household wiring.

a. Explain why aluminium is used instead of copper for overhead wiring. **(1 mark)**
b. Describe why the structure of these substances allow them to conduct electricity. **(1 mark)**
c. Name the property that refers to the ability to be drawn out into wires. **(1 mark)**

3.3 Reactivity of metals

KEY KNOWLEDGE

- Experimental determination of a reactivity series for metals based on their relative ability to undergo oxidation with water, acids and oxygen

3.3.1 Reactivity and the periodic table

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Most elements found on the periodic table (around 80 per cent) are metallic — but they vary widely in reactivity with water and other substances. Sodium and potassium, for example, react vigorously with water, but gold and silver are unreactive.

Reactivity of metals

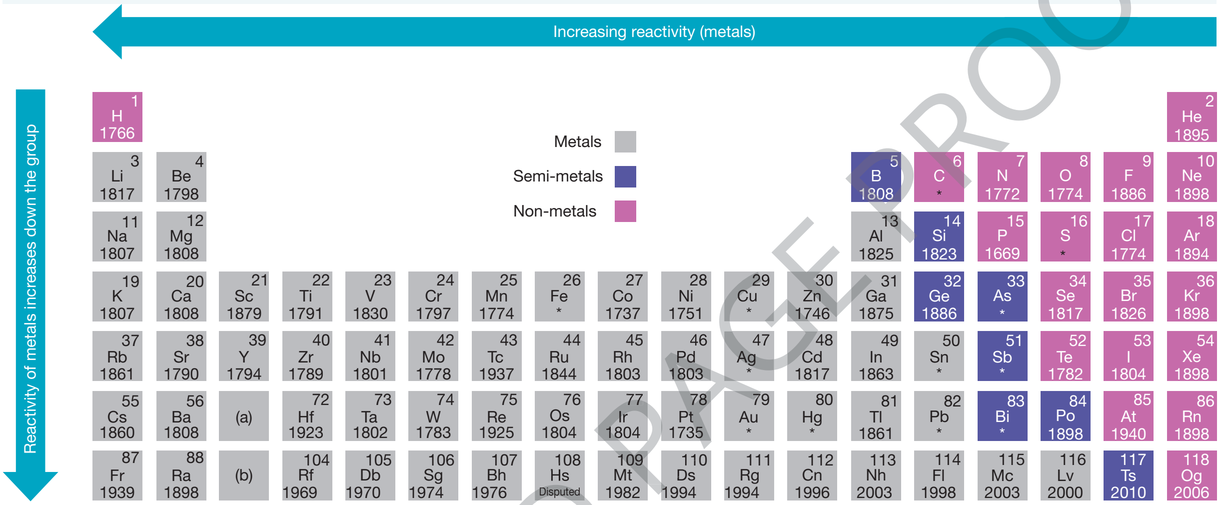
- The reactivity of a metal is dependent on its tendency to lose electrons to form cations (positive ions).
- Reactivity can be observed qualitatively and quantitatively.

The energy required to form cations is measured as ionisation energy (refer to Topic 1). This chemical property distinguishes metals from semi-metals and non-metals because they do not form cations. Being able to predict the **products** of reactions between metals and their compounds is key to understanding many industrial processes.

Determining qualitatively the reactivity of samples of different metals is possible through investigating experimentally how readily they react with oxygen, cold water, steam and dilute acids (a summary of the reactions can be found in section 3.3.5).

product chemical species obtained as the result of a chemical reaction

FIGURE 3.8 General trends in reactivity in the metallic elements



3.3.2 Relative reactivity of metals with water

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Potassium reacts very vigorously with water to produce hydrogen gas and potassium hydroxide (see figure 3.9). The heat given off in this exothermic reaction is sufficient to ignite the hydrogen gas, and allows it to burn in air with a bright lilac flame. But not all metals react with water; fortunately, stainless steel is unreactive and so water can be stored safely in metallic drink bottles.

As figure 3.8 indicates, group 1 (alkali metals) and group 2 (alkaline earth metals) are highly reactive, and some of these metals react with water at room temperature to produce alkalis and hydrogen gas, as shown in the following equations. Alkalis are metal hydroxides that are soluble in water and form solutions that neutralise acids. These highly reactive metals must be stored under oil to prevent their reaction with atmospheric water vapour.

FIGURE 3.9 Although the lattice structure of metals is strong, they can still react — as potassium does on contact with water.

	Group 1 metal	+	water	→	group 1 metal hydroxide	+	hydrogen gas
Example:	potassium	+	water	→	potassium hydroxide	+	hydrogen gas
	$2K(s)$	+	$2H_2O(l)$	→	$2KOH(aq)$	+	$H_2(g)$

	Group 2 metal	+	steam	→	group 2 metal hydroxide	+	hydrogen gas
Example:	magnesium	+	steam	→	magnesium hydroxide	+	hydrogen gas
	$Mg(s)$	+	$2H_2O(g)$	→	$Mg(OH)_2(aq)$	+	$H_2(g)$

In each of the reactions shown in the equations, the solid metal reactant is converted into a metal ion in solution in the products. In effect, the metal atoms have given away electrons to form metal ions. The electrons are taken up by the water, forming hydrogen gas. This type of reaction is known as an oxidation reaction. Oxidation reactions and the accompanying reduction reactions are discussed in more detail in Topic 12.

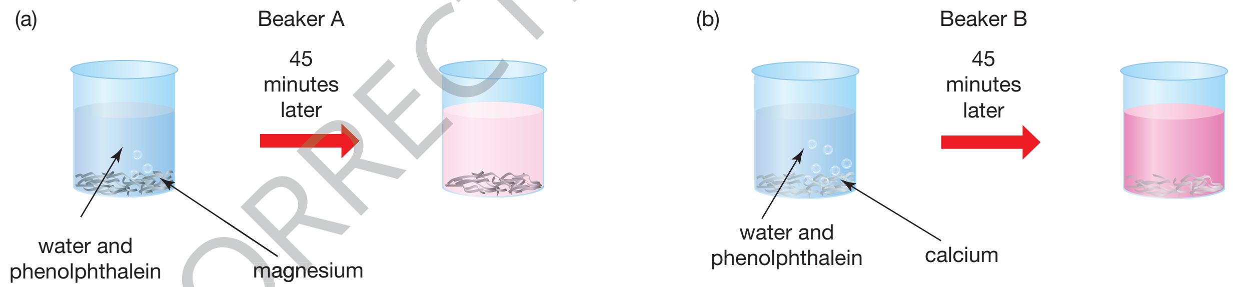
on Resources

Weblinks Introduction to the periodic table: alkali metals
Alkali metal reactivity

Relative reactivity down a group

The experiment illustrated in figure 3.10 shows how the relative reactivity of magnesium and calcium can be observed. When equal amounts of freshly sanded magnesium ribbon and strips of oil-free calcium react with water in beakers A and B as shown, hydrogen gas and a hydroxide compound are formed. The presence of the hydroxide compound is indicated by phenolphthalein. After 45 minutes, beaker B has a more intense pink colour, suggesting that more hydroxide compound has been produced by the reaction. We can deduce qualitatively from this that calcium is more reactive with water than is magnesium.

FIGURE 3.10 Demonstration of relative reactivity of (a) magnesium and (b) calcium



In general terms, if a metal reacts with cold water, a hydroxide and hydrogen gas is formed, whereas if a metal only reacts with steam, it tends to form metal oxides as the high temperatures decompose the hydroxides into the oxide.

Reactions between metals and water

Reactive metal + water → metal hydroxide + hydrogen tlvd-####

SAMPLE PROBLEM 1 Writing an equation for the reaction of a metal and water

Barium, a group 2 metal, reacts readily with cold water and considerable bubbling is observed in the solution. When phenolphthalein indicator is added, the solution becomes an intense pink colour. Write a balanced equation for this reaction.

THINK	WRITE
1. Write out the formulas of the reactants: barium and water.	1. $Ba + H_2O$
2. Write out the formulas of the products: barium hydroxide and hydrogen. Remember that barium is in group 2 and so its ion is Ba^{2+}, while the hydroxide ion is OH^-. Hydrogen is a diatomic gas, H_2.	2. $Ba(OH)_2 + H_2$
3. Write out the equation.	3. $Ba + H_2O \rightarrow Ba(OH)_2 + H_2$
4. Balance the equation.	4. $Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2$
5. Add states.	5. $Ba(s) + 2H_2O(l) \rightarrow Ba(OH)_2(aq) + H_2(g)$

PRACTICE PROBLEM 1

The density of lithium, a group 1 metal, is about half that of water so it floats. Lithium reacts with the water producing some bubbles and a clear and colourless solution. Write a balanced equation for this reaction.

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3.3.3 Relative reactivity of metals with acids

Hydrogen is also produced when the more reactive metals react with acids. The simple pop test can be used to confirm that the gas is hydrogen. A burning wooden splint is placed into the test tube of collected hydrogen, which thenmakes a 'pop' sound. The other product is a metal salt. A **salt** is a neutrally charged chemical compound made of cations (positive ions), which are usually metallic, bonded to anions (negative ions), which are usually non-metallic. Besides observing the formation of gas bubbles when doing these experiments, heat is released and the container may feel warm. The more reactive metal will react faster and produce more bubbles.

FIGURE 3.11 Reactivity of metals with hydrochloric acid; from left to right: calcium, magnesium, zinc, copper

	Group 1 metal	+	acid	$\rightarrow$	salt	+	hydrogen
Example:	lithium	+	hydrochloric acid	$\rightarrow$	lithium chloride	+	hydrogen
	$2Li(s)$	+	$2HCl(aq)$	$\rightarrow$	$2LiCl(aq)$	+	$H_2(g)$

	Group 2 metal	+	acid	$\rightarrow$	salt	+	hydrogen
Example:	magnesium	+	sulfuric acid	$\rightarrow$	magnesium sulfate	+	hydrogen
	$Mg(s)$	+	$H_2SO_4(aq)$	$\rightarrow$	$MgSO_4(aq)$	+	$H_2(g)$

salt a neutrally charged chemical compound made of cations (positive ions) which are usually metallic, bonded to anions (negative ions) which are usually non-metallic

Note that electrons have also been donated by the metal atoms in these reactions in order to form metal ions. The metals are described as being oxidised in an oxidation reaction.

TABLE 3.3 Salts produced when metals react with acids

Acid	Salt formed
Hydrochloric (HCl)	Metal chloride; e.g. $NaCl$, $MgCl_2$
Nitric (HNO_3)	Metal nitrate; e.g. $NaNO_3$, $Mg(NO_3)_2$
Sulfuric (H_2SO_4)	Metal sulfate; e.g. Na_2SO_4, $MgSO_4$

Reactions between metals and acid

Reactive metal + acid → metal salt + hydrogen

tlvd-####

SAMPLE PROBLEM 2 Writing an equation for the reaction of a metal and an acid

When a small piece of potassium is added to hydrochloric acid, a very vigorous reaction occurs — the metal immediately ignites and burns with a lilac flame. The products are a solution and hydrogen gas. Write a balanced equation for this reaction.

THINK	WRITE
1. Write out the formulas of the reactants: potassium and hydrochloric acid.	1. $K + HCl$
2. Write out the formulas of the products: potassium chloride and hydrogen gas. Remember that potassium is in group 1 and so its ion is K^+, while chlorine is in group 17 so chloride ion is Cl^-. Hydrogen is a diatomic gas, H_2.	2. $KCl + H_2$
3. Write out the equation.	3. $K + HCl \rightarrow KCl + H_2$
4. Balance the equation.	4. $2K + 2HCl \rightarrow 2KCl + H_2$
5. Add states.	5. $2K(s) + 2HCl(aq) \rightarrow 2KCl(aq) + H_2(g)$

PRACTICE PROBLEM 2

The products formed when magnesium reacts with nitric acid depend on the concentration of the nitric acid. A small spatula of magnesium powder was added to a beaker that contained dilute nitric acid solution, HNO_3. Bubbles were initially observed. When bubbles were no longer observed, more magnesium powder was added and the reaction again produced bubbles. This was repeated until magnesium powder remained in the beaker and no further bubbles were observed. When a flame was placed at the mouth of the test tube, the gas burned with a squeaky pop.

Answer the following.

a. **Identify the gas produced.**
b. **Give the name of the colourless solution formed in this reaction.**
c. **Write a balanced equation for the reaction.**
d. **Suggest why the reaction stopped.**

3.3.4 Relative reactivity of metals with oxygen

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Many metals react with oxygen to form metal oxides. Very reactive metals such as potassium and sodium (group 1) react very vigorously with pure oxygen (see figure 3.12) and rapidly with air, which is why they need to be stored in oil. Generally, reactive metals form metal oxides when they react with oxygen.

FIGURE 3.12 Sodium reacting violently with pure oxygen

Iron will burn in air but only if in powder form or a thin wire. Copper will not burn, but if heated very strongly a layer of black copper oxide will form. Gold and silver will not react with oxygen even after strong heating. An oxide layer can form on some metals and cause the metals to appear dull, but when this layer is removed or the metal is cut, the shiny surface appears.

The thin oxide layer on aluminium protects the metal underneath from further reaction and so prevents corrosion. Unlike aluminium oxide, when iron rusts, the oxide forms a permeable layer that allows air and moisture to pass through and continue to corrode the metal. Therefore, iron usually needs some form of protection to prevent corrosion.

$$\begin{array}{lccccc} & \text{Group 1 metal} & + & \text{oxygen} & \rightarrow & \text{metal oxide} \\ \text{Example:} & \text{sodium} & + & \text{oxygen} & \rightarrow & \text{sodium oxide} \\ & 4Na(s) & + & O_2(g) & \rightarrow & 2Na_2O(s) \end{array}$$

$$\begin{array}{lccccc} & \text{Group 2 metal} & + & \text{oxygen} & \rightarrow & \text{metal oxide} \\ \text{Example:} & \text{calcium} & + & \text{oxygen} & \rightarrow & \text{calcium oxide} \\ & 2Ca(s) & + & O_2(g) & \rightarrow & 2CaO(s) \end{array}$$

The metals in these reactions have donated electrons and are oxidised.

Reactions between metals and oxygen

Reactive metal + oxygen → metal hydroxide + hydrogen

tlvd-0513

SAMPLE PROBLEM 3 Understanding reactions of metals

Why is it necessary for magnesium to be freshly sanded for a reaction to occur with cold water?

THINK

Magnesium, and some other metals, appear to be unreactive, but this is not always the case. Consider what happens to the magnesium when it is exposed to air that may affect the reaction with cold water.

WRITE

Metals like magnesium (and especially aluminium) react readily with atmospheric oxygen, forming a protective coating of the metal oxide. This metal oxide coating acts as a barrier, preventing water from coming into direct contact with the metal and, therefore, no reaction or a slow reaction occurs.
Sanding the magnesium allows the water to come into contact with the pure metal, allowing a reaction to occur.

PRACTICE PROBLEM 3

Explain why calcium is stored in oil and why is it necessary for it to be oil-free for a reaction to occur.

elog-1670

INVESTIGATION 3.1

online only

Reactivity of metals

Aim

To investigate the reactivity of different metals through reactions with water and acid

eles-####

3.3.5 The reactivity series of metals

By observing experiments showing reactions of metals with water, acids and oxygen, a list from most reactive to least reactive metal can be established. This is known as the **reactivity series of metals**. Displacement reactions (see topic 12) can be used to confirm the general order of metals in the series. A summary of the order of reactivity of metals is shown in table 3.4.

reactivity series of metals an ordered list of how readily the metals react with oxygen, water, steam, dilute acids and salt solutions

TABLE 3.4 Reactivity series of metals

<table>
<tr><th>Element</th><th>Appearance of metal</th><th>Reaction with oxygen</th><th>Reaction with water or steam</th><th>Reaction with dilute acids</th></tr>
<tr><td>K</td><td rowspan="2">Dull, stored under oil</td><td rowspan="7">Oxidises in air at room temperature to give oxides</td><td rowspan="3">Hydrogen formed from cold water</td><td rowspan="2">Hydrogen formed violently</td></tr>
<tr><td>Na</td></tr>
<tr><td>Ca</td><td rowspan="7">Generally dull</td><td rowspan="5">Hydrogen formed with cold acid</td></tr>
<tr><td>Mg</td><td rowspan="4">Hydrogen formed with steam</td></tr>
<tr><td>Al</td></tr>
<tr><td>Zn</td></tr>
<tr><td>Fe</td></tr>
<tr><td>Sn</td><td rowspan="4">Oxidises when heated in air or oxygen to give oxides</td><td rowspan="3">No reaction at bunsen burner temperatures</td><td rowspan="2">No visible reaction</td></tr>
<tr><td>Pb</td></tr>
<tr><td>Cu</td><td rowspan="4">Generally shiny</td><td rowspan="4">No reaction</td></tr>
<tr><td>Hg</td><td rowspan="3">No reaction</td></tr>
<tr><td>Ag</td><td rowspan="2">No reaction</td></tr>
<tr><td>Au</td></tr>
</table>

Note: aluminium metal often appears to be less reactive than the reactivity series indicates because it has a coating of aluminium oxide and this protects it from reacting further with oxygen. This coating can be thickened by a process called anodising.

on Resources

Weblinks Metals in aqueous solution
Metals and reactivity series

3.3 Activities

learnon

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at www.jacplus.com.au. A **downloadable solutions** file is also available in the resources tab.

3.3 Quick quiz on	3.3 Exercise	3.3 Exam questions

3.3 Exercise

1. MC Which of the following will not react with water?
   A. Sodium
   B. Calcium
   C. Silver
   D. Copper
2. MC Name the products of the reaction of zinc and sulfuric acid.
   A. Zinc sulfate and oxygen gas
   B. Zinc sulfate and hydrogen gas
   C. Zinc chloride and oxygen gas
   D. Zinc chloride and hydrogen gas
3. MC Complete the following equation: $4Fe\ (s) + 3O_2\ (g) \rightarrow$
   A. $4Fe_3O_2$
   B. $4Fe_2O_3$
   C. $2Fe_2O_3$
   D. $2FeO$
4. MC Which four numbers are required to balance the equation?
   $\mathbf{a}\ Li(s) + \mathbf{b}\ H_2SO_4(aq) \rightarrow \mathbf{c}\ Li_2SO_4(aq) + \mathbf{d}\ H_2(g)$
   A. 2, 1, 1, 2
   B. 1, 2, 1, 1
   C. 2, 2, 1, 2
   D. 2, 1, 1, 1
5. MC As we move across a period from left to right, what happens tothe reactivity of metals with oxygen?
   A. Increases
   B. Decreases
   C. Stays the same
   D. Increases then decreases
6. Write the balanced equation (including state symbols) for the reaction of a sample of pure calcium metal with room temperature deionised water.
7. Write fully balanced equations, including states, for the following reactions.
   a. Potassium + oxygen
   b. Caesium + water
   c. Tin + nitric acid, HNO_3
8. Why must sodium and potassium be stored in an oil?
9. Magnesium metal reacts vigorously with a solution of hydrochloric acid, producing a gas that gives a trademark 'pop' sound with a lighted match. An ionic salt is formed at the same time. Write the balanced equation for this reaction including symbols of state.
10. You have samples of three metals, *X*, *Y* and *Z*. Describe a possible method to find out the order of reactivity, including any chemicals and equipment required, and the reactants formed.

3.3 Exam questions

Question 1 (1 mark)

MC Which of the following metals would be expected to react most vigorously with an acid solution?

A. Copper
B. Calcium
C. Aluminium
D. Magnesium

Question 2 (1 mark)

MC What are the products of the reaction of magnesium with water?

A. Magnesium hydroxide and oxygen gas
B. Magnesium oxide and oxygen gas
C. Magnesium hydroxide and hydrogen gas
D. Magnesium oxide and hydrogen gas

Question 3 (1 mark)

MC An experiment was carried out with metals *M*, *Q* and *R*. The following results were obtained.

Metal	Reaction in water	Reaction with dilute hydrochloric acid
M	No reaction	No reaction
Q	No reaction	Bubbling
R	Bubbling	Vigorous bubbling

Based on the observations, what can be inferred?

A. Metal *M* is more reactive than *Q* but less reactive than *R*.
B. Metal *Q* is more reactive than *M* but less reactive than *R*.
C. Metal *R* is the least reactive metal of the three.
D. Metal *Q* is the least reactive metal of the three.

Question 4 (5 marks)

The following is a section of the reactivity series of metals:

K Ca Mg Pb Cu Ag

Choose a metal from the list for each of the following.

a. This metal is used extensively for household wiring because it is a good conductor. **(1 mark)**
b. This metal is found as an element in nature. **(1 mark)**
c. Under the same conditions, when reacted with acid this metal produces the greatest volume of hydrogen in 5 minutes. **(1 mark)**
d. This metal is in group 2 and is more reactive than magnesium. **(1 mark)**
e. This metal is very malleable and dense. **(1 mark)**

Question 5 (6 marks)

Sodium and calcium are reactive metals.

a. Describe two similarities between the reactions of these metals and water. **(2 marks)**
b. Describe two differences between the reactions of these metals and water. **(2 marks)**
c. How could you confirm what the products of these reactions are? **(2 marks)**

3.4 Recycling metals

KEY KNOWLEDGE

- metal recycling as an example of a circular economy where metal is mined, refined, made into a product, used, disposed of via recycling and then reprocessed as the same original product or repurposed as a new product.

3.4.1 Use and re-use of metals

eles-####

Metals are used for an incredible range of products, from minute circuits in electronic devices to gigantic skyscrapers. When no longer useful, these metals are often disposed of as waste. As seen in topic 1 this is no longer sustainable. Reserves of many materials are becoming scarce and the damage to the environment to extract more resources is considerable. By following a circular economy model, materials should be designed and used to ensure little or no waste — including during both manufacture and at the end of a product's useful life, where metals should be reused or recycled. The circular economy also requires that no harm comes to the health of individuals or the environment during any of these processes.

CASE STUDY: Environmentally friendly Olympic medals

About 5000 medals were required for the 2021 Tokyo Olympics. The officials decided that sourcing these in an environmentally friendly and sustainable manner was important. So, remarkably, the gold, silver and bronze were extracted from used electronic devices, 79,000 tonnes of them, including more than 6 million used mobile phones. This meant that this waste did not go into landfill. This is beneficial, not only from a waste-management perspective, but also because electronic waste is highly toxic. As consumers, we should all be aware that many of the resources used in electronic devices are quickly being depleted.

FIGURE 3.13 Tokyo Olympic medals

3.4.2 Mining metals

eles-####

The benefits to society of metal production include not only providing essential materials but also offering employment in mining, production, transport and sales. Exporting metal ores substantially contributes to the economy and, therefore, the wealth of Australia. These benefits must be balanced with the costs of obtaining and transporting the raw materials, and the energy requirements for the process. The cost to the environment is also considerable. Mine waste has caused substantial damage to the environment with destruction of the landscape, damage to ecosystems and pollution of air and land.

Mining

Mining is the process in which metals are extracted from ores in the Earth. **Ores** are rocks that are mixtures of different compounds and from which it is economically viable to separate out the metal. Copper, for example, which ranks second only to iron in its importance in human history, is extracted from the ore chalcopyrite (see figure 3.14).

mining the process of extracting metal ores from the earth.

ore a rock containing minerals from which a valuable metal can be removed for profit

FIGURE 3.14 (a) Copper can be extracted from the ore chalcopyrite. (b) Today, the main use of copper is in electrical cables, pipes and wires, shown here ready for recycling.

(a) (b)

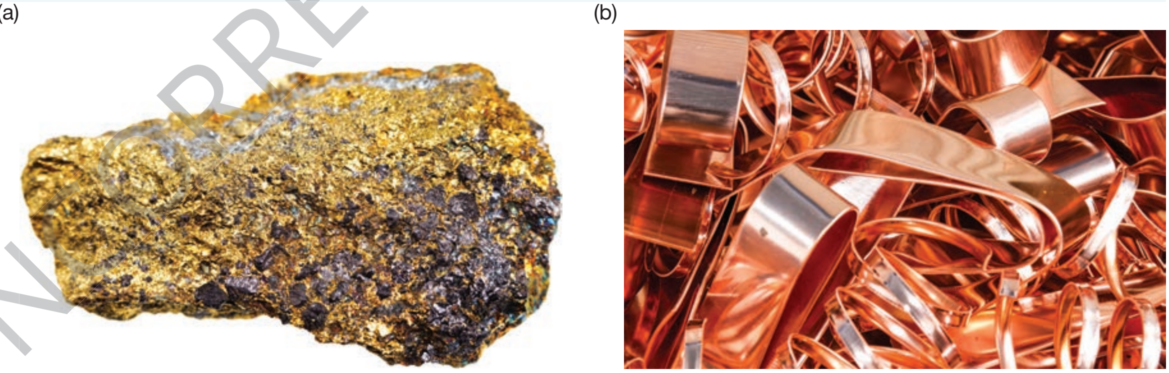


TABLE 3.5 Examples of economically valuable metals, and their reactivity and extraction technique

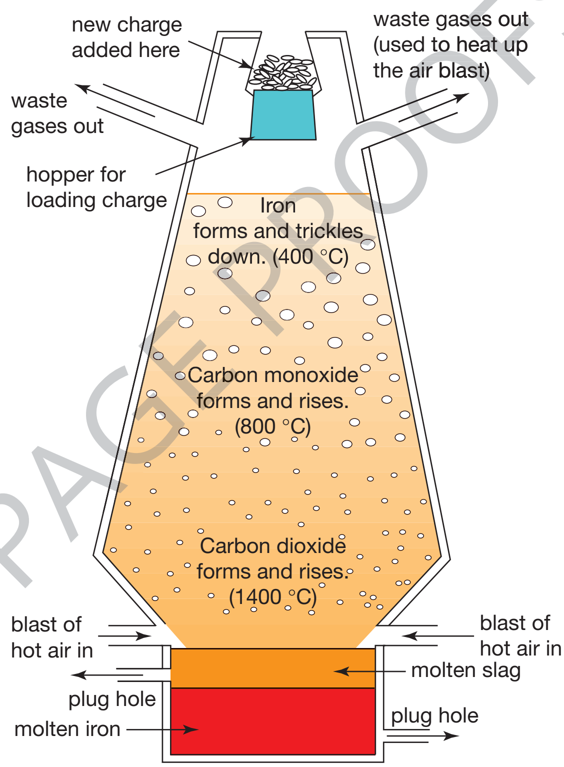
Reactivity	Metal	Extraction
Very reactive	K, Na, Ca, Mg, Al	Electrolysis of molten compound, using electricity to cause a chemical reaction
Reactive	Zn, Fe, Sn, Pb	Heating the metal ore with carbon
Less reactive	Cu, Hg, Ag	Heating the metal ore in air
Unreactive	Ag, Pt, Au	Can occur as free elements

The two main forms of mining are **open-cut** (surface) and **underground**. The choice of method depends on the type of ore that is to be mined, how far it is below the surface and whether the cost of extraction will result in a profit for the company. Often, an enormous amount of rock at the surface must be removed to reach the ore and, once the ore is reached, waste rock must be separated from the ore. The ore is then crushed into small pieces and then finely ground with water, producing even more waste called **tailings**.

Metal extraction

The reactivity of a metal influences how easily it is extracted from its ore (see table 3.5). Silver and gold, for example, are unreactive and can often be found naturally in their elemental state. This is why they have been known and used since ancient times. Gold, for example, can be found through the process of panning in stream beds. Today, however, economically viable deposits of gold and silver require extraction from the **host rock**, because large occurrences of elemental gold and silver have already been found.

FIGURE 3.15 Iron production in a blast furnace



More reactive metals such as iron must be extracted from their ores. Our society is highly dependent on iron for transport, construction, machinery, containers and appliances. Because iron is a metal of medium reactivity, it is extracted from its ores by reaction with carbon (charcoal) in a blast furnace in a **reduction** reaction (see figure 3.15). Impurities are removed from the molten metal as a glassy by-product called **slag**. Iron ore is composed of several different minerals (iron-rich compounds), from which iron is extracted. The most used iron ore is haematite, Fe_2O_3.

Overall reaction: $Fe_2O_3\,(s) + 3CO\,(g) \rightarrow 2Fe\,(l) + 3CO_2\,(g)$

In general: metal oxide (from ore) $\xrightarrow{\textit{reduction}}$ metal

The most reactive metals are extracted from their ores by **electrolysis**, a process that requires an electric current to breakdown the ore. Most metals can be obtained from their ores by electrolysis, but this requires a huge amount of electricity, so it is only used if other methods are not suitable. Aluminium is a reactive metal that can be obtained from the ore, bauxite. It is the most abundant metal on Earth but there was a time when aluminium was more valuable than gold because of the difficulty in obtaining it. This changed in 1882, when scientists discovered how to produce aluminium metal using electricity. In their process, alumina (Al_2O_3) is heated to about 960 °C. A large amount of electricity is passed through this molten material and aluminium is formed at the base of the container. Electrolysis, including modern innovations, is examined in Unit 3.

Refining metals

Metals formed in the processes described are sometimes not particularly pure and need to be refined after the initial main steps are completed and before the metal can be made into a commercial product. The method of **refining** depends on the metal and the type of impurity. Typical impurities include other metals, unreduced oxides of the metal, and non-metals such as carbon, silicon, phosphorus or sulfur. For example, the iron produced in the blast furnace is very brittle with low tensile strength. Further processing is required to remove impurities. The process of electrolysis is also used to refine copper — that is, to obtain pure copper from a sample of impure copper.

open-cut a surface mining technique that removes ore and waste rock from an open pit from the surface

underground a variety of mining techniques that use tunnels and shafts to extract ore and waste rock from under the ground; this process minimises waste rock removal when the ore body is deep below the surface

tailings waste material remaining after the removal of the ore from the host rock

host rock the rock surrounding or containing the ore minerals

reduction a gain of electrons (decrease in oxidation number)

slag waste material from the smelting or refining of ore

electrolysis the decomposition of a chemical substance (in solution or the molten state) by the application of electrical energy

refining metals purifying a metal

3.4.3 Metals and the circular economy

eles-####

The proportion of pure metal in ores is very small; for example, the percentage of copper in copper ore is about 1 per cent. So a considerable amount of waste material results from metal manufacturing. According to the principles of a circular economy, waste material must be limited if it cannot be eliminated, energy should be conserved, damage to health and environment must be controlled, and products must have a life cycle.

Applying the principles of the circular economy

Table 3.6 summarises examples of the current challenges in metal production, along with opportunities to move towards a circular economy model.

Table 3.6 Challenges and opportunities in metal production

Consideration	Challenge	Circular economy opportunity
Raw materials	• Many resources on Earth are finite. • Populations are increasing so demand for products is also increasing.	• Raw materials must be minimised, reused or used elsewhere. • Manufactured goods should be repaired, repurposed or recycled wherever possible. For example, 'urban mining' can be used to recycle components of technical devices.
Mineral processing: waste generation	• Mining produces large quantities of waste material.	• Waste solids can be used for backfilling (refilling holes), landscaping and road construction. • Some waste material can be reprocessed to obtain other metals; e.g. historical gold tailings can be reprocessed to remove remaining gold using newer, more efficient techniques.

Mineral processing: water use	• Water is used during extracting and processing the metal. Wastewater is often acidic and can be contaminated with hazardous chemicals containing arsenic, cobalt, copper, cadmium, lead, silver, mercury and/or zinc. These can find their way into water sources, affecting the health of humans and wildlife.	• Mine water can be:
		  • recycled through the plant
		  • used for dust suppression or as a coolant
		  • monitored and treated to remove harmful chemicals by raising the pH through the addition of limestone or caustic soda (which also results in precipitate forming that either settles or can be filtered out)
		  • reprocessed to remove trace metals.

Impacts on the environment	• Mining has detrimental effects on ecosystems and land use, including contamination, deforestation, erosion and potential loss of biodiversity.	• Processing at mine sites can be more regulated (e.g. dust and hazardous substance air filtration), and regeneration can occur during mining and at the end of the mine's life. • Gases released can be collected and used in other industries; e.g. sulfur dioxide can be used to make sulfuric acid.

(continued)

Table 3.6 Challenges and opportunities in metal production *(continued)*

Consideration	Challenge	Circular economy opportunity
Energy use	• Initial manufacture using raw materials uses significant amounts of energy. • Renewable energy should be used wherever possible; e.g. solar and battery storage.	• Recycling materials requires less energy than the initial manufacture; e.g. aluminium recycling uses 95% less energy than aluminium production from ore.
Product life	• Few products are currently designed considering recycling opportunities at the end of the product's life. • Products are often designed to be replaced rather than repaired.	• Manufactured goods should be repaired, repurposed, or recycled to conserve energy and resources, and also built to last where possible. • Regulations should be changed to ensure product design includes end-of-life recycling. • Consumer behaviour can change to purchasing higher quality (often more expensive) goods that last longer and/or can be recycled.
Human health	• Mining can be hazardous, both due to accidents and long-term illness. • Local communities can be subjected to pollution.	• Health and safety regulations should protect the health of workers and communities. • Design processes should be introduced that are more effective, efficient and safe.
Ethical considerations	• Often mining occurs in land covered by native title.	• Regulation and dialogue should occur between the mining/processing companies and indigenous land holders. • Care must be taken to respect cultural sites. • Indigenous peoples' concerns about the impact of mining on their landscape, cultural heritage and traditional way of life should be considered.
Economic considerations	• Mining and mineral processing is very expensive, making raw materials required for product development expensive.	• Metal recycling processes should be financially beneficial. • Economic benefits come through the recycling industry saving raw materials, using less energy, reducing damage to the environment and providing employment.

The opportunity exists for more innovative design of manufacturing processes to achieve sustainable goals. Recycling metals can reduce some of these problems. Less energy is used to recycle metals than the original process, and resources are conserved, resulting in lower costs and less pollution. Collecting waste gases and focusing on revegetation after mining can also reduce some of the environmental impact.

3.4.4 Recycling metals

eles-####

Metals can be divided into two types: ferrous and non-ferrous.

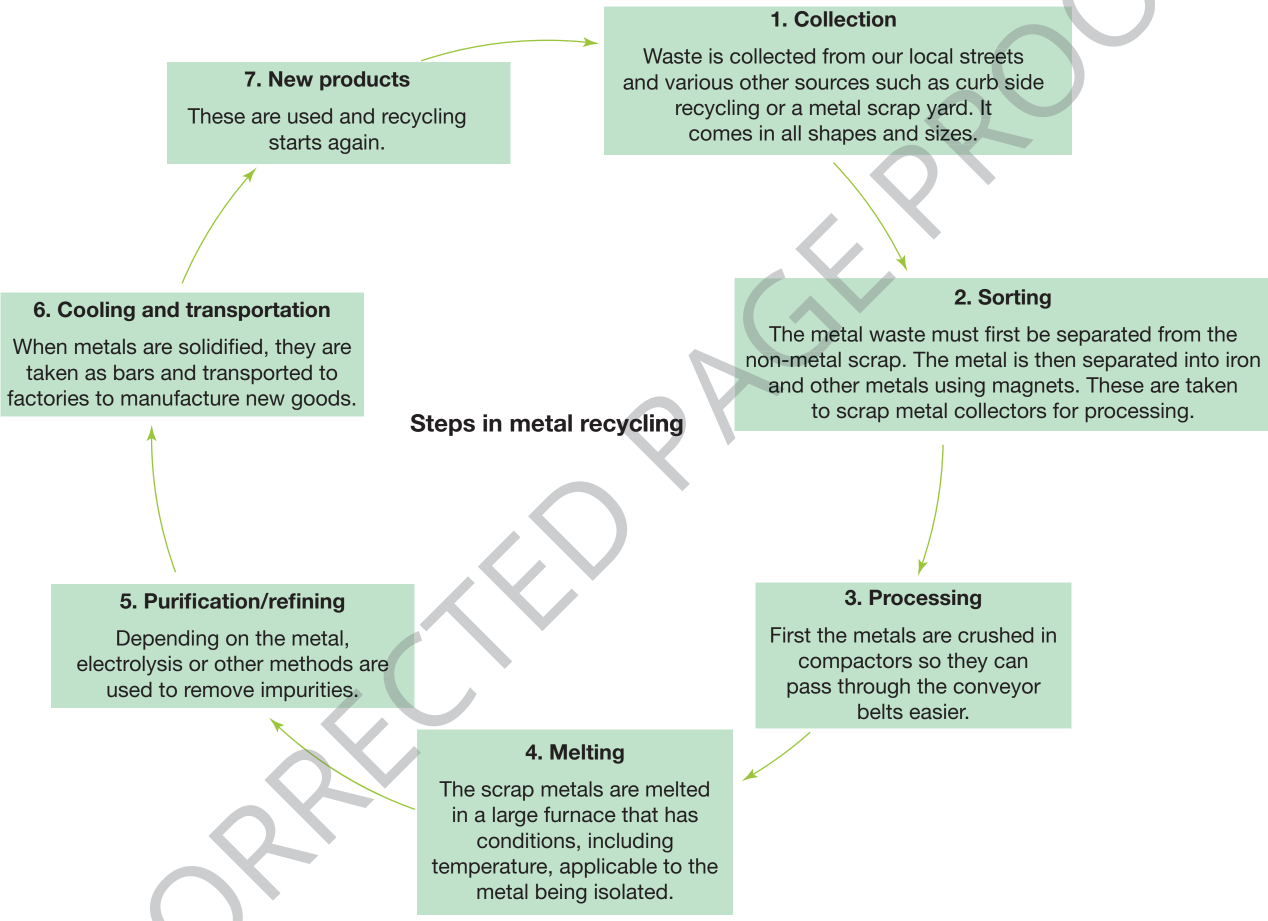
- Ferrous metals include iron and its alloy, steel.
- Non-ferrous metals include aluminium, copper and gold.

Steel is 100 per cent recyclable and is the most recycled metal. Sorting these two types of metals is relatively easy due to iron's magnetic property. Iron products include cans, containers, whitegoods, bicycles, steel or alloy wheels and many other items including the kitchen sink. Larger steel structures include ships, railroad tracks, farm machinery and, especially, vehicles.

Steps in metal recycling

The process of metal recycling depends on the metal being recycled; figure 3.16 outlines the general steps involved.

FIGURE 3.16 Generalised steps in metal recycling



Some precious metals such as gold, silver, platinum and palladium can be extracted from discarded electronic devices. This process of obtaining metals from waste and metal scrap is described as **urban mining**. While about 75 per cent of gold is obtained from mine production, demand requires that recycled gold is used. Using recycled gold means reduced environmental damage and using less chemicals. Interestingly, one tonne of mobile phones contains more gold than one tonne of gold ore.

3.4.5 Using microbes to extract metals from waste

eles-####

Bioleaching (biomining) is a new technology that uses specific bacteria or fungi to extract valuable metals from metal ores, tailings, e-waste or contaminated water. The microorganisms efficiently catalyse the breakdown of minerals and gain energy in an oxidation reaction process. The bacteria are sourced from the mine environment. The reaction takes place in large, closed tanks (**bioreactors**)

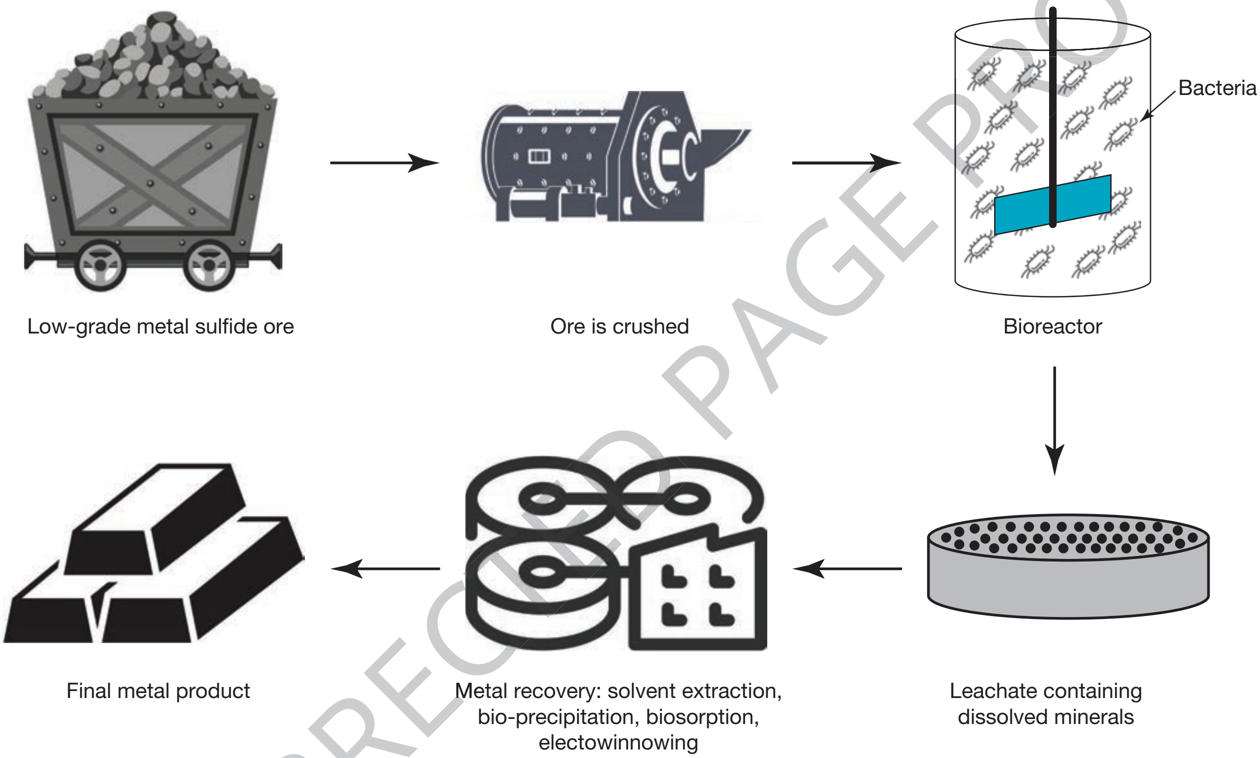
urban mining obtaining metals from e-waste and other materials already in our cities

Bioleaching (biomining) the process of extracting metals from ores or waste by using microorganisms

bioreactors an industrial device that allows a biological process to occur that are continually stirred. Low-grade ores can be treated to produce an acidic solution containing metal ions. Copper is one of the metals commonly obtained but other metals such as nickel, silver, cobalt and gold can also be extracted using this process.

This method is simpler and more sustainable than smelting, and helps ensure a more circular economy. The process is also more economical and uses less energy because high temperatures are not required. Although toxic acid is produced, this can be used in other industries and sulfur dioxide emissions are reduced. If used in mining, environmental damage is also reduced, and fewer health problems arise for miners. Manufacture of metals using bioleaching takes a longer time and only a few plants are currently using the technology on an industrial scale. Research is continuing to improve the efficiency of the process.

FIGURE 3.17 Low-grade metal sulfide ore can be processed using bioleaching before the metal recovery phase.



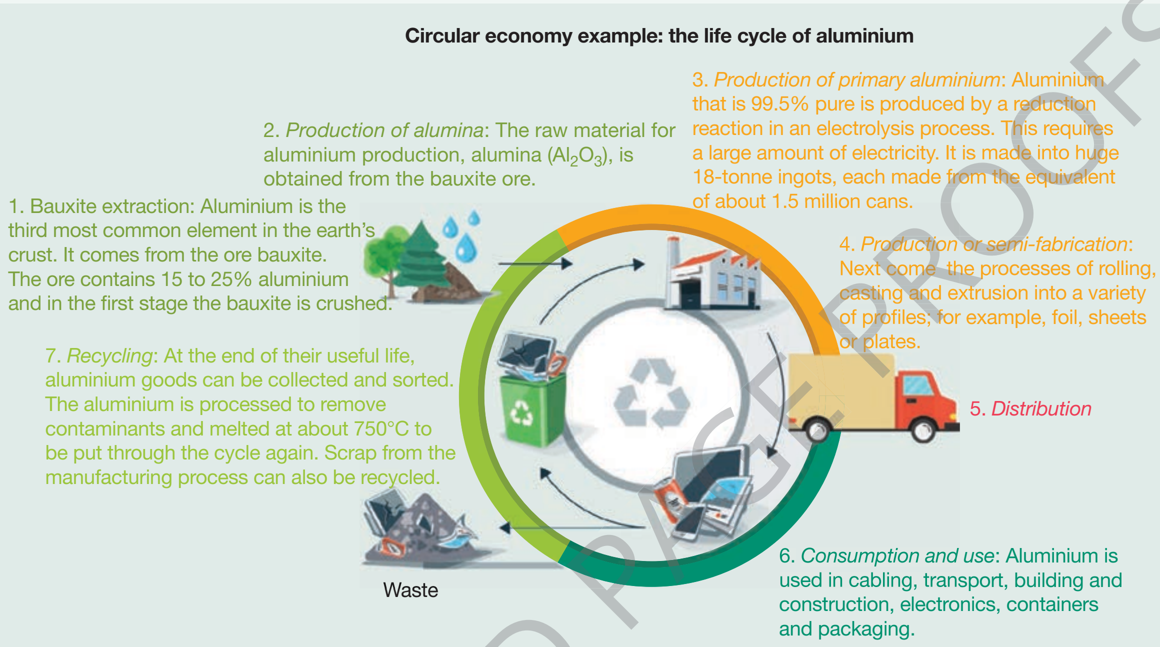
CASE STUDY: Life cycle of aluminium

An ideal metal for the circular economy is aluminium. It is lightweight, strong and corrosion resistant. Aluminium is used not just in cans, but also in construction, packaging, aviation, shipping and rail industries. The demand for aluminium is growing annually; for example, aluminium use in cars is increasing because it is lighter than steel — meaning the cars require less fuel. Recycling aluminium can help meet this increased demand. Aluminium is 100 per cent recyclable, and recycling saves 95 per cent of the energy required to manufacture the aluminium from bauxite ore. Indeed, 75 per cent of all aluminium produced is still in use, compared to 9 per cent of plastics (although plastic is cheaper).

Some other aspects that need to be considered include cost of collection, how easily products can be disassembled, and disposal of waste created in the recyling process. Good design can be beneficial. Firstly, good design can help reduce the use of unnecessary joining materials. Secondly, materials being built to last will reduce the need for recycling.

When aluminium products are melted, impurities are separated to form 'salt cake'. This not-so-delicious cake contains aluminium oxides, aluminium, carbides, nitrides, sulfides and phosphides, and is highly toxic so must be disposed of carefully. Engineers are trying to find innovative ways to use this, possibly in asphalt and cement. Energy is required for recycling and some gas pollutants are released; however, these are considerably less than in the initial production of aluminium. So make sure that used can is placed in the recycling bin!

FIGURE 3.18 Life cycle of aluminium



CASE STUDY: Titanium bicyles

Materials research has become an important component of competition preparation in many sports. Track and field athletes look for running shoes that provide stability, support and track grip. Tennis players seek the ultimate racquet that will give them a larger 'sweet spot' (the optimum position on the mesh from which to hit the ball), greater power and more control. Bicycle frames have until recently been built from steel, aluminium and carbon fibre composites. A new material has now emerged as the preferred frame material — titanium. (Titanium bike frames were first made in 1986 but only in recent years has the cost of these frames dropped sufficiently to make them a viable alternative for cyclists.)

FIGURE 3.19 Titanium mountain bike frames are also becoming popular.

Each frame material has its advantages and disadvantages, as shown in table 3.7.

Titanium is preferred by cyclists for use in bicycle frames due to its combination of toughness, elasticity and resilience. Bicycles that are built stiffly, so that they resist pedalling forces, often provide a harsh, uncomfortable ride. Although titanium frames are very stiff against high pedalling forces, they seem to transmit much less road shock than bicycles made of other materials. Steel, for example, has a significantly higher density than titanium, but shock waves travel faster in steel than in titanium. Despite the fact that titanium's high vibration dampening properties are not yet fully understood, we do know that titanium provides three things crucial to cyclists: low weight, stiffness and a smooth ride.

TABLE 3.7 Materials used in bicycle frames

Material	Advantages	Disadvantages
Aluminium	• Light • Stiff	• Low resistance to repeated stresses
Steel	• Strong • Economical • Easily shaped to required specifications	• Rusts • Heavy
Carbon fibre composites	• High strength-to-mass ratio • Good shock-dampening power • Good vibration-dampening power	• Very expensive
Titanium	• Less than half the density of steel • Excellent resistance to metal fatigue • High corrosion resistance	• Expensive • Difficult to shape

Titanium is a lustrous, silvery metal with a high melting point (1667 °C). Found as an ore, titanium is quite abundant in the Earth's crust, ranking ninth of all the elements. Metals are usually extracted from their ores by heating them with carbon. The extraction of titanium, however, is quite difficult since carbon cannot be used due to the formation of titanium carbides. Titanium's unusual ability to stretch makes it hard to shape by machine. It tends to push away from even a very sharp cutting blade, giving a rather unpredictable final edge.

However, the superior bicycle that results is worth all these difficulties.

3.4 Activities

learnon

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at www.jacplus.com.au. A **downloadable solutions** file is also available in the resources tab.

3.4 Quick quiz on | **3.4 Exercise** | **3.4 Exam questions**

3.4 Exercise

1. Explain why some metals are found as metals and others are found combined with other elements in minerals.
2. What is an ore? Give an example of a metal and its ore.
3. MC Which of the following is not an environmental benefit of recycling metals?
   A. It reduces the amount of waste created.
   B. Less energy is required than extracting from an ore.
   C. The cost of the metal is less.
   D. More resources remain in the ground.
4. Metals are used in a variety of ways, from carrying oxygen in our blood to batteries and building bridges.
   a. What are two advantages of metals to society?
   b. Mining metals has serious implications for the environment. Describe how each of the following is involved in manufacturing metals and how their detrimental effects can be minimised.
      i. Waste rock
      ii. Raw materials
      iii. Land use
5. a. Explain what bioleaching is.
   b. What are two advantages of this process in the extraction of metals?
   c. What are two disadvantages?

3.4 Exam questions

Question 1 (1 mark)

MC When is a mineral described as an ore?

A. If a metal is present in the mineral
B. If a metal can be produced from it
C. If it is magnetic
D. If a metal can be profitably obtained from it

Question 2 (1 mark)

MC Recycling metals is often thought of as a better way to provide more metals. Which of the following is NOT an advantage of the recycling process?

A. It is more economical than extraction from the ore.
B. Ecosystems are destroyed.
C. Natural resources are saved.
D. More landfill space is required.

Question 3 (3 marks)

a. Describe what 'urban mining' is. **(1 mark)**
b. Provide an example of urban mining. **(1 mark)**
c. Why is urban mining important? **(1 mark)**

Question 4 (6 marks)

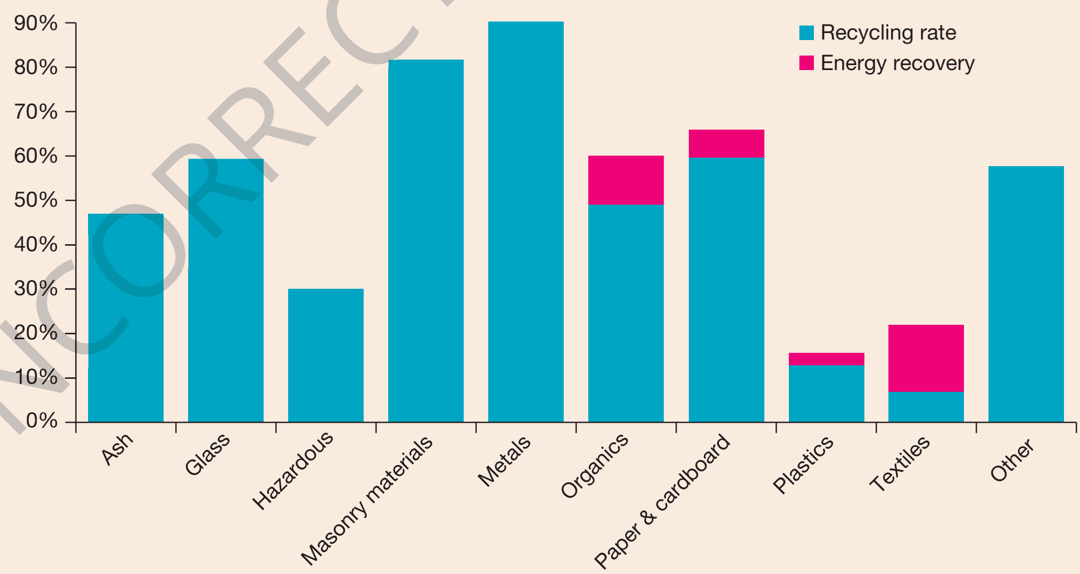
Aluminium is a widely used metal and is manufactured using electricity in the process of electrolysis from bauxite ore.

a. Using an aluminium can as an example, show flow charts indicating the difference between a linear and circular economy. **(4 marks)**
b. State two advantages of using a circular economy rather than a linear economy. **(2 marks)**

Question 5 (5 marks)

The following graph shows the recovery and recycling rates by material category in Australia, 2018–2019.

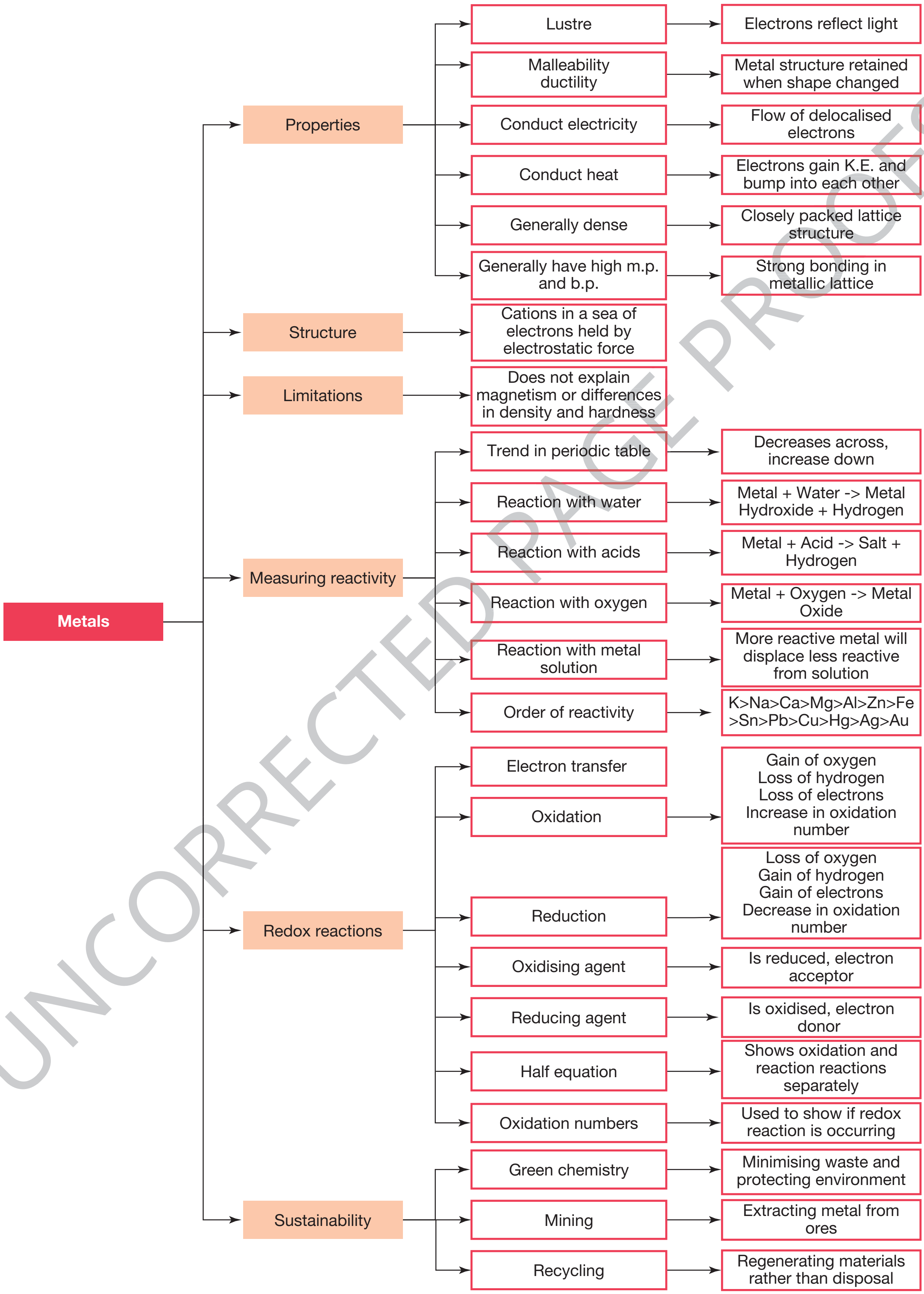
Recovery rate	47%	59%	30%	82%	90%	60%	66%	15%	22%	58%
Recycling rate	47%	59%	30%	82%	90%	49%	60%	13%	7%	58%



a. Compare the information provided for metals with that provided for plastics. **(4 marks)**
b. The main metals recycled in Australia are iron, copper and aluminium. Why do you think these metals are more likely to be recycled? **(1 mark)**

3.5 Review

3.5.1 Topic summary



3.5.2 Key ideas summary

doc-12345

learnON

Now that you have finished this topic, go to **learnON** to access the dot point summary for this topic. While you're there, you can:

- review your **results** to identify your areas of strength and weakness
- watch **teacher-led videos** to revise the key content and skills
- practise **past VCAA exam questions** with detailed worked solutions.

on Resources

Practical investigation eLogbook	Practical investigation logbook — Topic 3 (elog-1607)
Digital documents	Key science skills (doc-37066) Key terms glossary — Topic 3 (doc-37069) Key idea summary — Topic 3 (doc-37070)
Exam question booklet	Exam question booklet — Topic 3 (eqb-0083)
Solutions	Solutions — Topic 3 (sol-0801)

3.5 Activities

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at www.jacplus.com.au. A **downloadable solutions** file is also available in the resources tab.

3.5 Review questions

1. What single feature in the metallic bonding model gives rise to the following properties: thermal conductivity, lustre, malleability and electrical conductivity?

2. Why does aluminium, a fairly reactive metal, not react with oxygen gas in air?

3. Consider the following:
   - Metal G slowly reacts with cold water.
   - Metal H is generally shiny.
   - Metal E readily reacts with oxygen.
   - Metal F produces hydrogen when it reacts with acid.

   What is their reactivity order, from the most to the least reactive?

   A. $H > G > F > E$ **B.** $H > E > F > G$
   C. $F > H > G > E$ **D.** $H > G > F > E$

4. Which of the following substances contain metallic bonding?
   a. Lithium
   b. Sulfur
   c. Sodium bromide
   d. Mercury(II) fluoride
   e. Calcium
   f. Argon

5. The electron configurations of elements A, B, and C are as follows.
   - A: 2, 6
   - B: 2, 8, 1
   - C: 2, 8, 5

   Which of these elements is a metal?

6. Silver is a transition metal used for jewellery because it shows very high reflectivity; sodium is an alkali metal found in group 1 of the periodic table.
   a. State two differences about the chemical or physical properties of these metals.
   b. State two similarities about the chemical or physical properties of these metals

7. Calcium is a reactive metal. When it burns in oxygen, a white powder is formed. It reacts slowly with cold water and rapidly with dilute hydrochloric acid.
   a. State the group and period of the periodic table where calcium is found.
   b. State the electron configuration of calcium.
   c. Write balanced chemical equations with states for the following.
      i. Reaction with oxygen
      ii. Reaction with cold water
      iii. Reaction with dilute hydrocholoric acid
   d. How could you demonstate the products formed in the reaction with water?

8. Describe three ways the environment is affected by mining.

9. List the steps involved in recycling metals.

10. a. Draw a flow chart showing the bioleaching process.
    b. What are two advantages of bioleaching?

3.5 Exam questions

Section A — Multiple choice questions

All correct answers are worth 1 mark each; an incorrect answer is worth 0.

Question 1

How can the structure and bonding in solid sodium metal at room temperature be described?

A. A network lattice of closely packed sodium atoms, held together by strong ionic bonds
B. A lattice of Na_2 molecules
C. A network lattice of sodium ions, held together by a 'sea' of electrons
D. A lattice of Na_2 molecules held together by weak bonds

Question 2

How can the physical properties of solid metals best be explained?

A. Each metal atom is held in the crystal lattice by covalent bonds.
B. Positive metal ions are arranged in an orderly way, with delocalised electrons able to move freely throughout the crystal lattice.
C. Positive and negative metal ions are arranged in an orderly way, with delocalised electrons able to move freely through the crystal lattice.
D. Each metal atom is surrounded by a variable number of valence electrons, which complete a 'noble gas' electronic structure in the crystal lattice.

Question 3

What is the property of metals that enables them to conduct an electric current?

A. The outer electrons of metal atoms are not firmly bound to the atom.
B. Metal atoms are better suited as charge carriers than non-metal atoms.
C. Ions in the metal can move freely through the metallic lattice.
D. Metal atoms are not as firmly bonded to each other as are non-metallic atoms.

Question 4

Which is formed by the reaction of zinc with hydrochloric acid?

A. Zinc hydroxide + hydrogen
B. Zinc sulfate + chlorine
C. Zinc chloride + hydrogen
D. Zinc chloride + water

Question 5

What is a disadvantage of extracting aluminium from aluminium ore?

A. The aluminium ore contains many impurities that must be removed.
B. The aluminium obtained corrodes readily.
C. The aluminium obtained from the blast furnace is impure.
D. The aluminium ore is a finite resource.

Question 6

Place the elements magnesium, lead, calcium and silver in order from the most to least reactive.

A. Lead, potassium, magnesium, silver
B. Magnesium, potassium, lead, silver
C. Potassium, magnesium, lead, silver
D. Potassium, magnesium, silver, lead

Question 7

What are metals categorised as?

A. A renewable resource
B. A non-renewable resource
C. A biodegradable resource
D. A degradable resource

Question 8

Why are metals recyclable?

A. They retain their structure at the end of the process.
B. They are malleable.
C. They are ductile.
D. They are hard.

Question 9

Iron oxide reacts with carbon monoxide in a blast furnace to produce iron. What are the correct coefficients to balance the equations?

$$Fe_2O_3 + CO \rightarrow Fe + CO_2$$

A. 1, 2, 3, 2
B. 2, 6, 2, 3
C. 1, 3, 2, 3
D. 2, 4, 6, 4

Question 10

Three metals X, Y and Z are added individually to test tubes containing hydrochloric acid and then to test tubes containing water. The observations were recorded in the table below.

Metal	Hydrochloric acid	Water
X	bubbles	no reaction observed
Y	bubbles	bubbles
Z	no reaction observed	no reaction observed

List the metals in order from least reactive to most reactive

A. X, Y, Z
B. Z, Y, X
C. X, Z, Y
D. Z, X, Y

Section B: Short answer questions

Question 1 (8 marks)

Metals can be obtained from their ores in different ways. Consider the following metals.

Metal *A* is extracted from its oxide by heating with carbon.

Metal *B* occurs naturally in the ground.

Metal *C* is obtained from its oxide by the process of electrolysis.

a. What is an ore? **(1 mark)**
b. List these metals in order of decreasing reactivity, giving reasons for your answer. **(3 marks)**
c. Explain which metal would be most suitable to use for jewellery. **(1 mark)**
d. Why are metals relatively easy to recycle? **(1 mark)**
e. Give two reasons it is better to recycle these metals rather than dispose of them as waste after use. **(2 marks)**

Question 2 (8 marks)

The reactivity of metals can be determined by their reaction with water, acids and oxygen. Four metals were tested and some of the observations are as follows.

Manganese reacts readily with dilute hydrochloric acid to form $MnCl_2$ and bubbles of gas.

Barium (Ba) is in group 2 and reacts moderately with cold water and vigorously with steam.

Silver does not react with water, acid or oxygen.

Nickel (Ni) reacts slowly with sulfuric acid.

a. List the metals in order of increasing reactivity. **(1 mark)**
b. Write a balanced equation with states for the reaction of manganese and dilute hydrochloric acid. **(2 marks)**
c. In the periodic table, calcium is in group 2 period 4, and barium is in period 6. Explain if you would expect calcium to be more reactive or less reactive than barium. **(2 marks)**
d. Write a balanced equation for the reaction of barium and water. **(2 marks)**
e. Explain if you would expect silver to be found naturally or need to be extracted from its ore. **(1 mark)**

Question 3 (3 marks)

The metals in group 1 are stored in oil but metals like copper and lead are not.

a. Explain why group 1 metals are stored in oil. **(1 mark)**
b. State another property of group 1 metals that is different from copper and lead. **(1 mark)**
c. State a property of group 1 metals that is the same as copper and lead. **(1 mark)**

Question 4 (7 marks)

Manganese reacts with an acid to form two products

a. State the names of the two products. **(2 marks)**
b. Describe the tests used to identify each product and the result. **(4 marks)**
c. What observation would you make if a more reactive metal was added to the same acid that had the same concentration? **(1 mark)**

Question 5 (5 marks)

If you were given the opportunity to be part of an expedition to Mars to establish a colony, explain why you might recommend taking a selection of microbes from specific mining environments. What other items would be needed?

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