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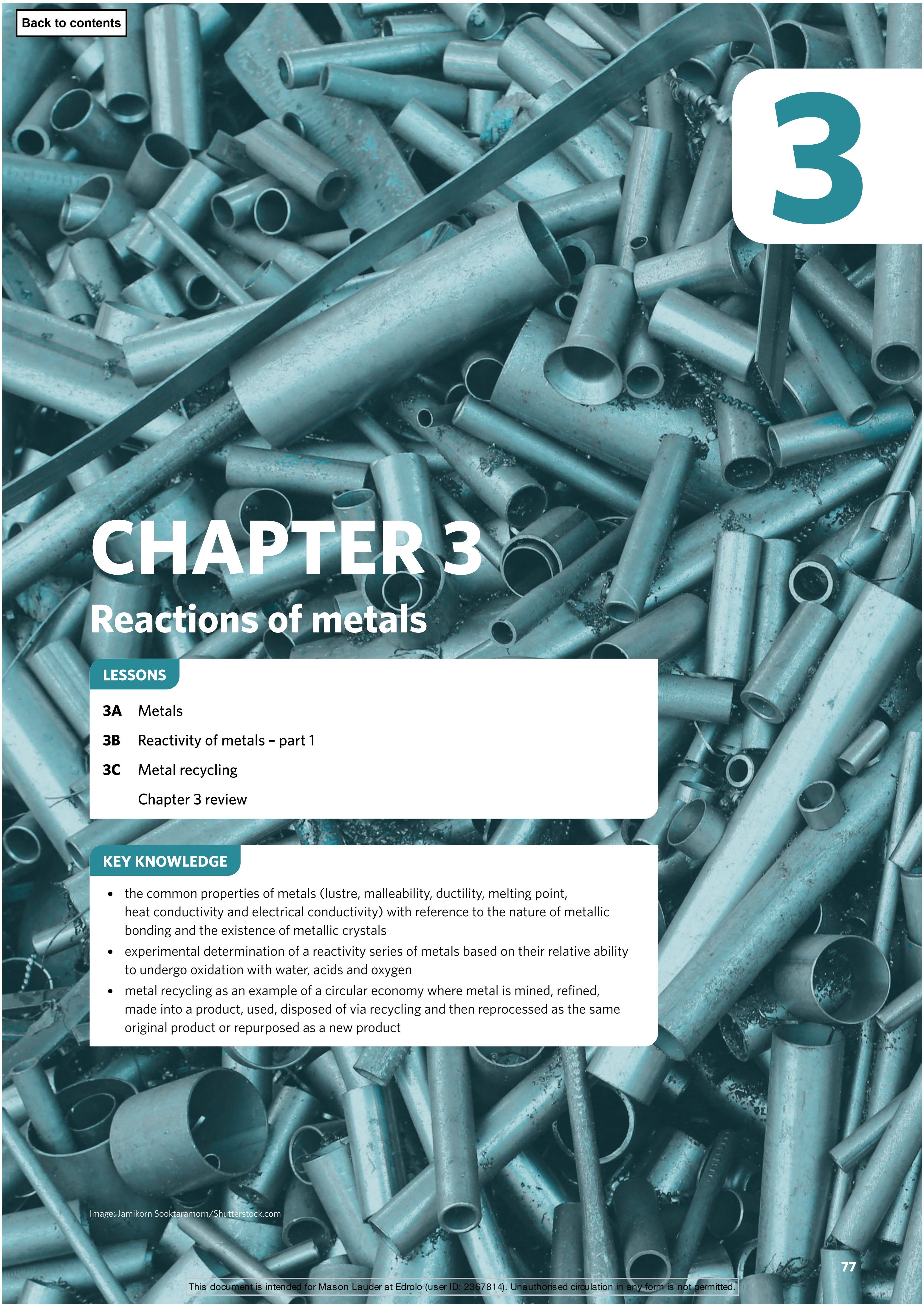

3

CHAPTER 3

Reactions of metals

LESSONS

KEY KNOWLEDGE

- the common properties of metals (lustre, malleability, ductility, melting point, heat conductivity and electrical conductivity) with reference to the nature of metallic bonding and the existence of metallic crystals
- experimental determination of a reactivity series of 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

Image: Jamikorn Sooktaramorn/Shutterstock.com

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3A Metals

STUDY DESIGN DOT POINT

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

3A 3B 3C

1.1.10.1 Metallic bonding

1.1.10.2 Properties of metals

ESSENTIAL PRIOR KNOWLEDGE

1C Ionisation energy

See question 16.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How do the properties of tungsten allow it to melt at 3410 °C?

Metals are the most abundant type of elements found on Earth and are used in our daily lives. In this lesson, we will learn about how metal particles are arranged in a solid **crystal lattice** and their special properties.

KEY TERMS AND DEFINITIONS

Cation positive ion formed when an atom loses its valence electron(s)

Crystal lattice (metallic) atoms of one type of metal element that are metallically bonded and organised in a pattern

Ductility ability to be hammered or stretched into a thin shape without breaking

Electrical conductivity ability to allow an electric current to flow through

Electrostatic of attraction attraction between opposite charges

Heat conductivity ability to allow heat to pass through

Lustre shiny and glossy appearance

Malleability ability to deform under force without breaking

Metallic bonding the electrostatic force of attraction between delocalised electrons and cations in a metallic lattice structure

Ore deposit in Earth's outermost layer containing metals and other minerals

Sea of delocalised electrons electrons that freely move between metal cations in the metallic bonding model

Metallic bonding 1.1.10.1

The **metallic bonding** model explains how metal atoms bond to each other when in solid form.

What does the metallic bonding crystal lattice model look like?

Metals are extracted from deposits of minerals formed over long periods of time. Pure metals that we use are extracted from **ores** in the Earth's crust; the outermost layer of the Earth. Metals are the most common elements found in the periodic table as shown in figure 1.

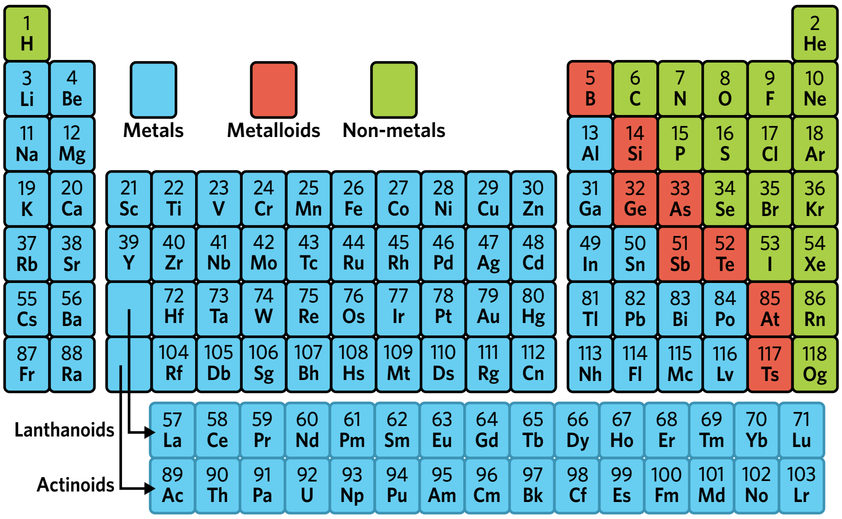


Figure 1 Metals make up most of the periodic table.

As we learned in lesson 1C, metals have low ionisation energies and therefore require a relatively small amount of energy to remove outer valence electrons from their atoms. As a result, it is relatively easy for metal atoms to lose electrons from their outer valence shell and become positive ions called **cations**. Figure 2 shows how a metal atom loses its electrons.

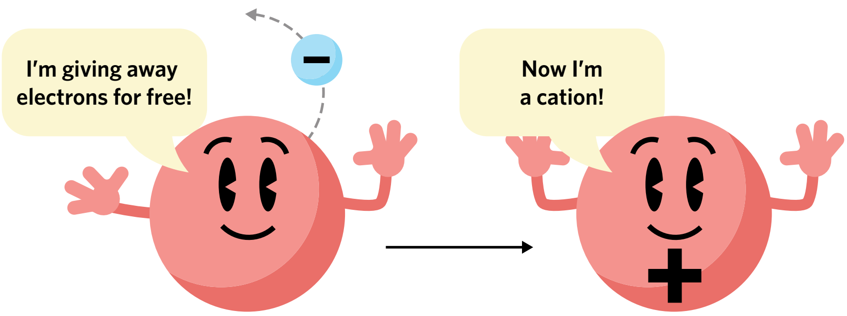


Figure 2 Drawing of a metal atom becoming a metal ion

When in solid form, metals are organised in a crystal lattice structure as shown in figure 3. Electrons removed from the (outer) valence shells of metal atoms are able to move freely within the crystal lattice structure between the positively charged metal cations. These electrons are called a **sea of delocalised electrons**.

The **electrostatic attraction** between the negatively charged delocalised electrons and positively charged metal cations holds the metal cations closely to each other in fixed positions and maintains the structure of the metal. The strong electrostatic force of attraction between the delocalised electrons and cations is referred to as metallic bonding.

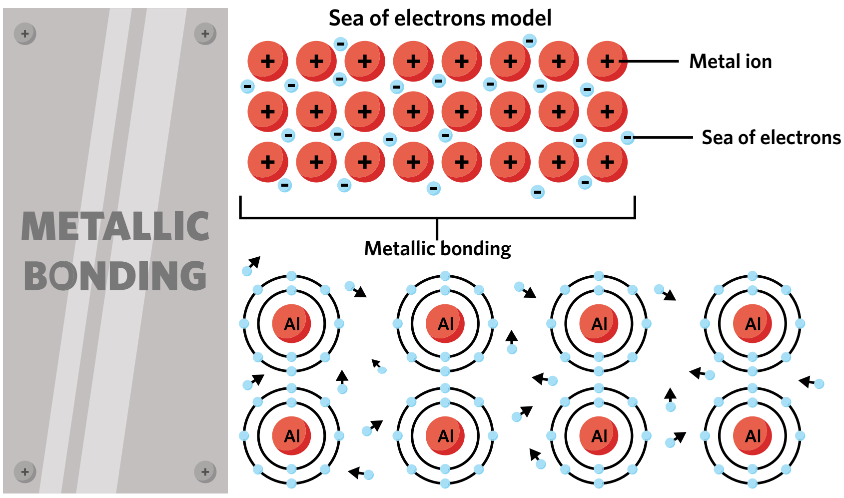


Figure 3 Crystal lattice model of bonding in aluminium

MISCONCEPTION

'When you mix two different metal atoms like copper and zinc they form a metallic bond to each other.'

Metal atoms do not bond with other different metals atoms, they can only form mixtures of different metal atoms which are called alloys.

USEFUL TIP

Metallic bonding is non-directional as the electrostatic forces of attraction present between the cations and the delocalised electrons are in all directions (unlike ionic and covalent bonding which are directional forces).

Progress questions

Question 1

Mercury can be extracted from the red compound shown in the image called cinnabar.

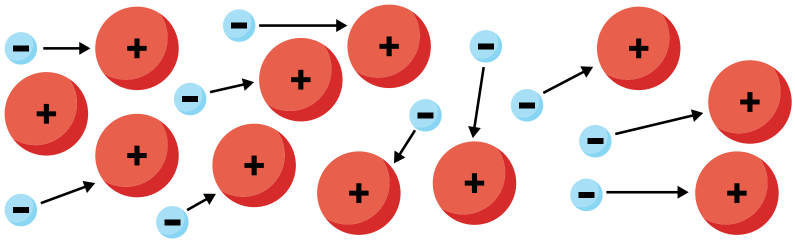
Source: Dan Olsen/Shutterstock.com

These sources of metals are called

A. ores.

B. crusts.

Use the following information to answer questions 2–3.



Question 2

The small freely moving particles illustrated in the image provided are referred to as

A. localised electrons.

B. delocalised electrons.

Question 3

In the metallic bonding model, metal cations are held in fixed positions and kept closely packed together by

A. the directional electrostatic force between delocalised electrons and metal cations.

B. the non-directional electrostatic force between delocalised electrons and metal cations.

Properties of metals 1.1.10.2

Metals exhibit different properties that allow them to be used for many different purposes.

Why do metals have unique properties?

Given that the structure of metals can be explained using the metallic bonding model, most metals share common properties as shown in table 1.

Table 1 Properties of metals

Property	Description
Malleability	Can be bent and hammered into different shapes without breaking
Ductility	Can be drawn into thin wire
Heat conductivity	Allows heat to pass through
Electrical conductivity	Allows electric current to flow through
High melting and boiling point	High melting and boiling temperatures
Lustre	Looks shiny and reflective

The ability of metals to be ductile and malleable is due to the non-directional electrostatic forces of attraction between the cations and delocalised electrons.

When a mechanical force is applied on metals to bend, hammer or to change their shapes, layers of cations are able to roll over each other whilst still being held in place by the electrostatic force of attraction with the delocalised electrons as shown in figure 4. As a result, the structure can take another shape without breaking.

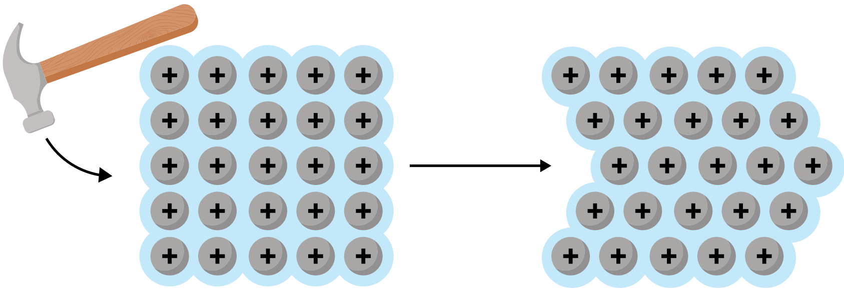


Figure 4 The effect of an applied force on the metallic bonding structure

Metals are considered to be good heat conductors, which can be explained through the metallic bonding model.

- When a piece of metal absorbs heat, the rise in temperature causes the increase in kinetic energy of delocalised electrons and metal ions.
- With this increase in energy, the metallic ions can vibrate more rapidly (about a fixed position) and delocalised electrons can move faster, transferring the kinetic energy to nearby ions and electrons.
- This creates a chain reaction that allows the energy to be passed through the metal as seen in figure 5.
- When the piece of metal is in contact with another conductive object, the kinetic energy carried by moving electrons will transfer to the object in the form of heat.

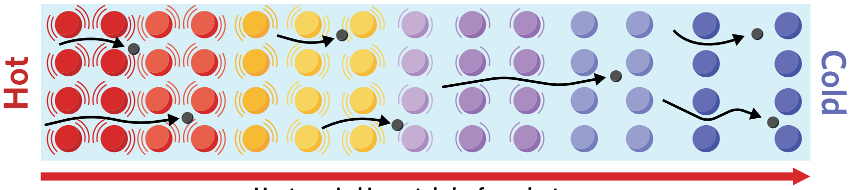


Figure 5 The conduction of heat through a metallic substance

USEFUL TIP

Boiling point gives a more useful indication of metallic bond strength than melting point within a metal as this is the measure of how much heat it actually takes to break the metallic bonds between the cations.

As we can appreciate, the conduction of heat requires particles to transfer the energy from a hot region to a cold region relatively quickly. Therefore, if we were to place a piece of metal into a beaker of iced water, the metal would be able to quickly transfer heat energy from the metal (hot region) to the water (cold region). As a result, the metal would feel cold relatively quickly.

The metallic bonding model can also be used to explain the electrical conductivity of metals, which refers to a metal's ability to conduct electricity. As shown in figure 6, in a basic circuit, electrons are continuously moving away from the negative electrode of a power source towards the positive electrode.

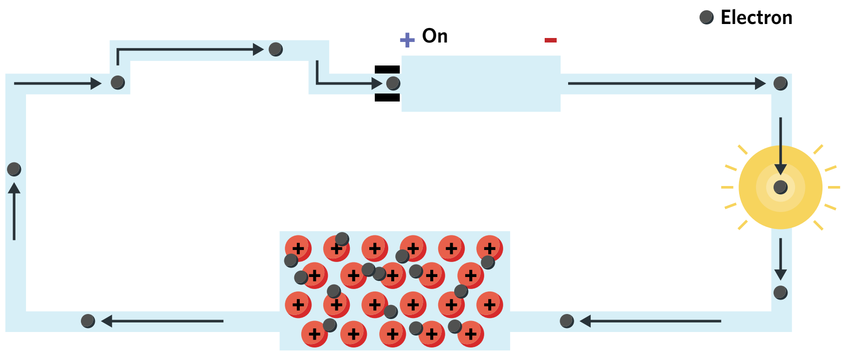


Figure 6 Using the metallic bonding model to explain the electrical conductivity of metals

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Due to the fact that metals contain a sea of delocalised electrons when connected to the circuit, there is a movement of delocalised electrons away from the negative electrode and towards the positive electrode, which generates a current in the circuit. In the case of the circuit in figure 6, this results in the light being turned on. This property is why electrical wires are made from metallic substances.

Metals are generally hard (except for groups 1 and 2) and have relatively high melting and boiling points. This is due to the strong non-directional electrostatic force of attraction that holds metal cations and the sea of delocalised electrons together in all directions (figure 7). As a result, a large amount of heat is required in order to break the metallic bonds and deform the structure of metal crystal lattices.

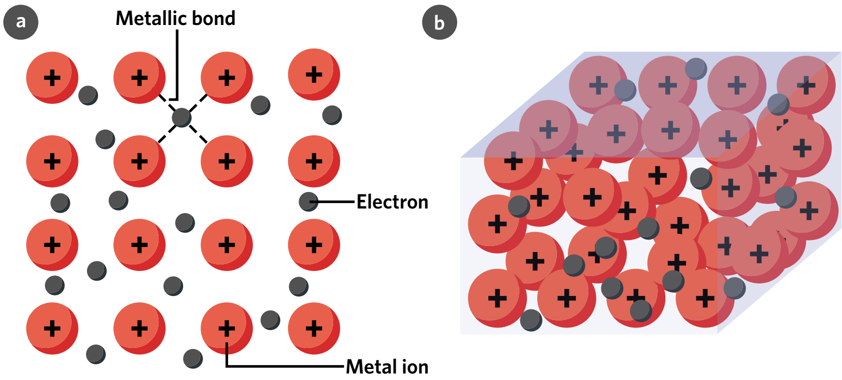

Figure 7 Crystal lattice metallic bonding models in 2-D **(a)** 3-D **(b)**

The shiny or lustrous nature of metals is due to the sea of delocalised electrons, which can reflect light of any wavelength.

WORKED EXAMPLE 1

Use the metallic bonding model to explain why copper is widely used to make wires that conduct electricity.

What information is presented in the question?
Use the metallic bonding model.

Copper is widely used to make wires that conduct electricity.

What is the question asking us to do?
Explain why copper wire is widely used to make wires that conduct electricity.

What strategies do we need in order to answer the question?

1. Describe the metallic bonding model of copper.
2. Use the metallic bonding model to describe what occurs when copper wire is connected to an electrical source.
3. Conclude the electrical conductivity of copper.

Answer
In the metallic bonding model of copper, the sea of delocalised electrons move freely in between copper cations. Therefore, when one end of the copper wire is connected to the positive electrode and the other end is connected to the negative electrode of an electrical source, delocalised electrons move away from the negative electrode and towards the positive electrode, which generates a current in the circuit that lights up the bulb. Hence, copper is widely used to make wires that conduct electricity.

What are the limitations of the metallic bonding model?

Even though the metallic bonding model can be used to explain some properties of metals, it isn't able to explain the variations in the properties shown by different metals. Particularly, it cannot be used to fully explain:

- the different melting and boiling points of different metals,
- the difference in electrical conductivity of different metals,
- and magnetic properties shown by iron, nickel and cobalt.[1]

As the explanation for these properties falls outside the study design, we will not be going into any further detail about the metallic bonding model.

KEEN TO INVESTIGATE?

[1] **Why are only these transition metals naturally magnetic?**
Search YouTube: Magnetic properties of the transition elements

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Progress questions

Question 4

Some properties of metals can be explained by the metallic bonding model.

A. True

B. False

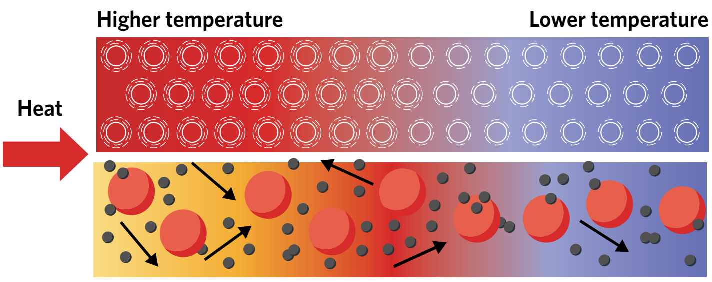
Question 5

Metals are malleable due to

A. the non-directional electrostatic force between delocalised electrons and metal cations that hold metal cations closely and tightly together in the crystal lattice.

B. the directional electrostatic force between localised electrons and metal anions that hold metal cations closely and tightly together in the crystal lattice.

Question 6

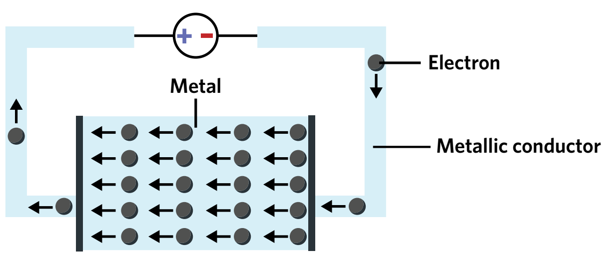


When a piece of metal is heated, the ________ electrons absorb the heat to increase their ________. Therefore, they move faster and transfer the kinetic energy to the ________ electrons nearby. As a result, heat is transferred along the piece of metal.

A. delocalised, kinetic energy, delocalised

B. localised, chemical energy, delocalised

Question 7



The electrical conductivity of metals can be explained by the movement of

A. delocalised electrons away from the positive electrode and towards the negative electrode.

B. delocalised electrons away from the negative electrode and towards the positive electrode.

Question 8

Many metals have a boiling point that is over 2500 °C. This suggests that

A. metallic bonds are relatively strong.

B. delocalised electrons are able to move quickly through the lattice.

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3A QUESTIONS

Theory summary

- In the metallic bonding model, the non-directional electrostatic forces of attraction between the sea of delocalised electrons and metal cations keep metal cations closely packed together.
- Metals exhibit lustre, malleability, ductility, heat and electrical conductivity which can be explained by the metallic bonding model.
- A pure sample of a metal has a crystalline lattice structure.
- The model of metallic bonding has limitations.

3A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed

Use the following information to answer questions 9–11.

As shown in the periodic table, there are many different types of metals that exist on Earth.
The table provided shows the melting points of different metals.

Metal	Melting point (°C)
Iron	1535
Aluminium	660
Copper	1083
Magnesium	650

Question 9 (1 MARK) 🌶

Based on the information provided by the table, which metal could be considered as being most resistant to melting?

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

Question 10 (1 MARK) 🌶

With regards to the metallic bonding, order each metal based on the strength of their bonds from strongest to weakest.

A. Iron, aluminium, copper, magnesium
B. Magnesium, copper, aluminium, iron
C. Iron, copper, aluminium, magnesium
D. Copper, iron, magnesium, aluminium

Question 11 (4 MARKS) 🌶🌶

A building company wanted to build the basic frame structure for a four storey concrete apartment block. Using your understanding of bond strength explain which of the metals listed above would allow for the most sturdy structure?

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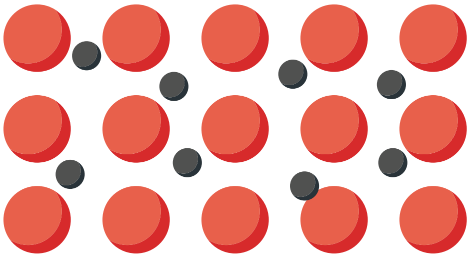
Exam-style

Question 12 (5 MARKS)

The structure of metals allows them to exhibit a wide range of properties.

a. Label the structure shown assuming that it is a representation of the structure of a metal. (2 MARKS)



b. Gold is known to be very malleable. As a result, it is able to be made into many different types of products. Explain, using the model shown, how gold is able to be malleable. (3 MARKS)

Question 13 (3 MARKS)

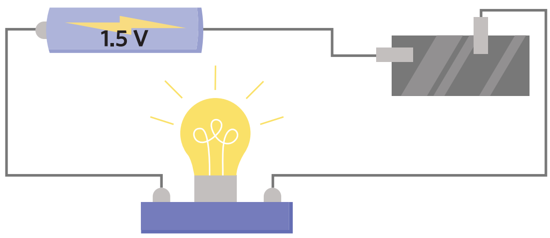
Nick conducted an experiment to investigate the properties of metals. He placed a metal spoon into a bowl of boiled water. After 30 seconds, he had a 'burning' feeling when he touched the spoon.

a. What property of metals does this phenomenon demonstrate? (1 MARK)

b. Explain the identified property of metals using the metallic bonding model. (2 MARKS)

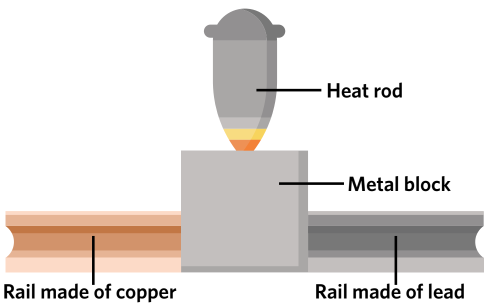
Question 14 (3 MARKS)

A student argued that metals conduct electricity because metal cations can move from one electrode to the other. Is the student's explanation correct? Justify your answer with the metallic bonding model.



Question 15 (7 MARKS)

With a rising population, the city of Dalton commissioned an engineering company to develop a railway using materials that were able to withstand high levels of heat whilst being low conductors of heat. As part of their investigation, they developed an experiment involving two metals as shown in the diagram. Two pieces of rail track developed using different metals were joined to a metal block. The engineers then applied heat to the metal block through an electric heat rod at increasing temperatures. Observations made during the experiment are shown in the table.



Temperature (°C)	Copper rail track	Lead rail track
200	Unchanged	Unchanged
400	Unchanged	The rail was beginning to lose its shape
600	It was glowing red but the structure remained unchanged.	No solid metal left, there was a lot of hot liquid in place of where the piece of rail used to be.

a. Which of the two metals used would be considered as having a higher melting point? Explain. (4 MARKS)

b. Is it possible to use the results provided to compare the heat conductivity of both metals? Explain. (3 MARKS)

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3A QUESTIONS

Key science skills

Question 16 (3 MARKS)

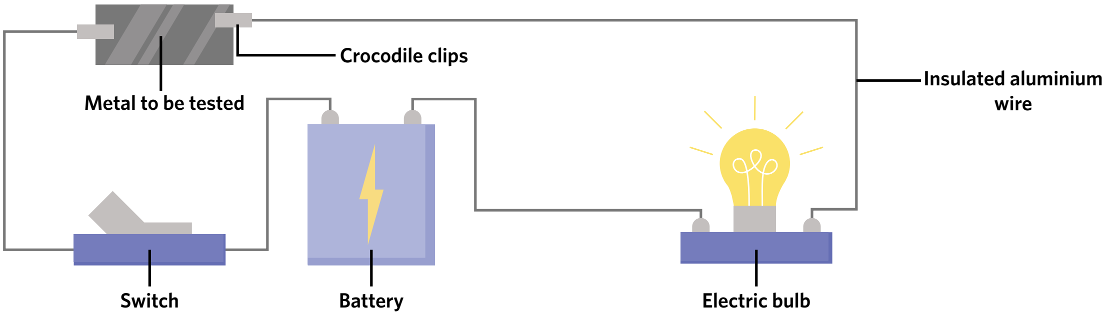
Gabriella conducted an experiment to confirm if her ring is entirely made of silver.

Materials

- 1 × electric bulb
- 1 × battery
- 1 × switch
- Insulated aluminium wires
- 2 × crocodile clips
- The ring
- 1 × piece of pure silver

Method

The diagram of the electrical circuit designed by Gabriella.



Results

Object	Observation
The ring	Dull light from the bulb
Piece of pure silver	Strong and dazzling light from the bulb

a. From the obtained results, what can Gabriella conclude about the material of her ring? Explain your answer. (2 MARKS)

b. Gabriella's friend told her that her conclusion might not be correct because the electricity might not be completely transferred through the wires. Suggest one change Gabriella can make to increase the validity of her experiment. Explain your suggestion. (1 MARK)

FROM LESSONS 16C & 16D

Questions from multiple lessons

Question 17 (4 MARKS)

A biomedical engineer wants to choose a material to design hip implants. Due to the wide range of movement of the human hips, the hip implants are required to withstand strong bending force without breaking. The engineer is considering choosing either titanium or a plastic (covalently bonded) material.

a. Should the engineer choose titanium or plastic to create hip implants? (1 MARK)

b. Justify your answer. (3 MARKS)

FROM LESSONS 1A & 2B

Hints

12a. In general, metals have low ionisation energies.

12b. The nature of bonds allows substances to exhibit particular properties.

13a. 'Burning' feeling when touching the spoon.

13b. Increased temperature can increase kinetic energy of delocalised electrons and metals in the metallic bonding model.

14. Delocalised electrons can move freely in the metallic bonding model.

15a. Changes to the structure of a substance can indicate its properties.

15b. Even with similar structures, metals exhibit slightly different properties.

16a. Same observations should be obtained from the same pure metals.

16b. Different metal wires have different electrical conductivities.

17a. Consider the relative strength of the two materials.

17b. Properties of metals and non-metals.

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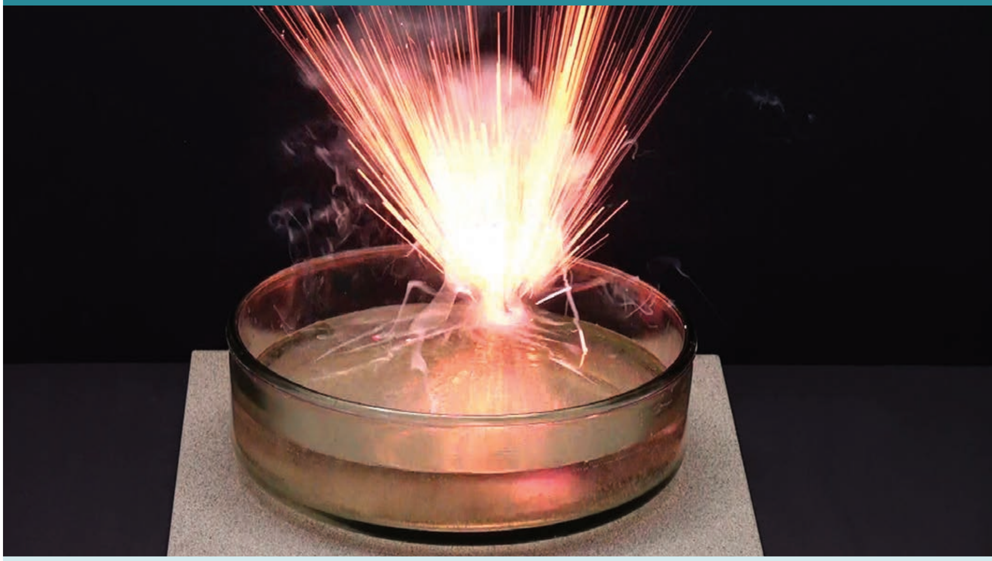
3B Reactivity of metals – part 1



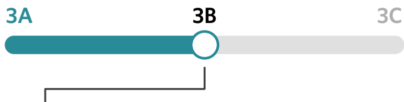
Why do some metals like potassium explode in water?

In the previous lesson of this chapter, metals and their physical properties have been introduced. But how do they react with other substances or elements and why do their metallic characters determine their reactivity?

Observations of these reactions allows you to **qualitatively** determine the relative reactivity of metals. This lesson will guide you through these concepts and explain why certain metals can explode when exposed to water.

STUDY DESIGN DOT POINT

- experimental determination of the relative reactivity of metals based on their ability to undergo oxidation with water, acids and oxygen



1.1.11.1 Reactions of metals with acids

1.1.11.2 Reactions of metals with water

1.1.11.3 Reactions of metals with oxygen

ESSENTIAL PRIOR KNOWLEDGE

1C Ionisation energy

1C Trends in atomic radii

See questions 17–18.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

Corrosion occurs when some metals react with gases in the atmosphere (mainly oxygen)

Hydrogen pop test test used to indicate a reaction between a metal and an acid

Metal oxide formed as a result of a reaction between a metallic element and oxygen

Oxidation chemical reaction where a chemical species loses electrons

Qualitative describes non-numerical (descriptive) data collected based on observations taken during an experiment

Reactions of metals with acids 1.1.11.1

Most metals can react with acids, however they will do so to different degrees. Metals tend to lose their outer electrons more easily than non-metals due to their lower ionisation energies. When metal atoms lose electrons this process is called **oxidation**.

How do some metals react with acids?

In a solution, an acid is separated into positive and negative ions. For example, hydrochloric acid (HCl) appears as H^+ and Cl^- ions in HCl solution. When a reactive metal like magnesium (Mg) is placed into HCl solution, Mg atoms will give up their two outer electrons and become positive Mg^{2+} ions. These Mg^{2+} ions will then be attracted by free negative chloride ions (Cl^-) in the solution to form $MgCl_2$ which is a soluble salt. The remaining H^+ ions combine with each other to form H_2 gas bubbles. We will learn more about ions in lesson 4A. The reaction between Mg and HCl is demonstrated in figure 1. **Corrosion** of metals is one of the biggest problems caused by acidic rainwater.

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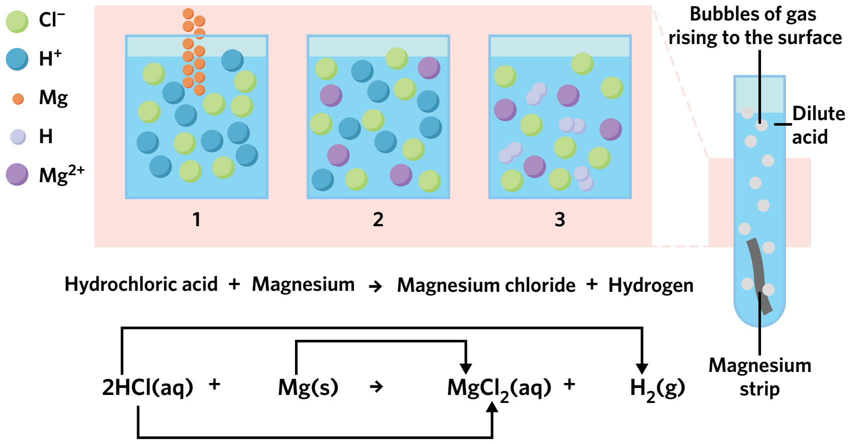

Figure 1 Demonstration of the reaction between Mg(s) and HCl(aq) – atoms and ions are not drawn to scale.

By looking at the reaction equation between Mg(s) and HCl(aq) in figure 1, a general equation can be developed to show the reactions between reactive metals and acids. The ionic salt formed may or may not dissolve in water depending on which acid is used - this will be covered in more detail in lesson 4C.

acid + reactive metal → ionic salt + hydrogen gas

Why are some metals more reactive in acids than others?

Since reactions between reactive metals and acids produce hydrogen gas, qualitative observations of the amount of gas bubbles produced can be used to indicate their relative reactivity. However, from lesson 1C, we know that some metals have higher ionisation energies than others, so they react differently with acids. For example, calcium (Ca) has a higher ionisation energy than potassium (K) due to its smaller atomic radius and greater number of protons in the nucleus. Consequently, more energy is required for calcium to lose electrons than for potassium to lose electrons. Therefore, the reaction of calcium with acids is slower. Figure 2 shows the trends in the reactivity of metals in the periodic table.

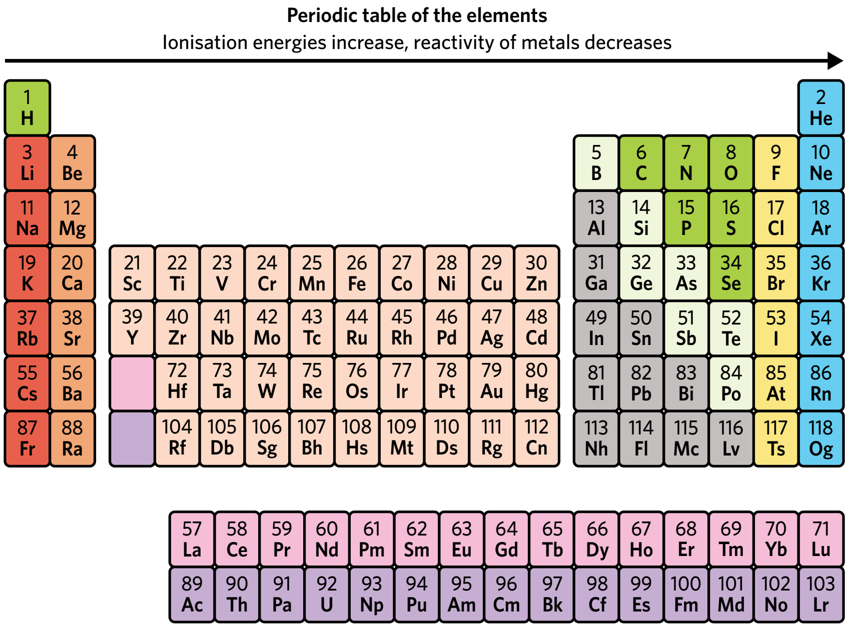

Figure 2 Trends in the periodic table

In the periodic table, as we go across a period from the left to the right, ionisation energy increases. This means that the reactivity of metals decreases, and therefore the reactions with acids occur more slowly with less hydrogen gas bubbles produced. On the other hand, as we move down a group from the top to the bottom, ionisation energies decrease and the reactivity of metals increases. How rapidly different metals react with acid is shown in figure 3.

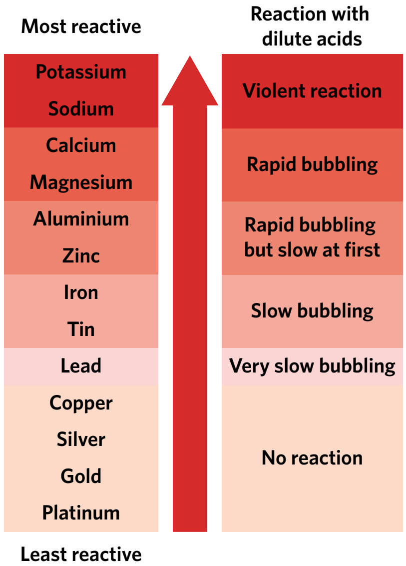

Figure 3 The trend in reactivity of different metals with acids

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WORKED EXAMPLE 1

Does a reaction of tin with HCl or a reaction of sodium with HCl occur more quickly?

Use the difference in ionisation energies of the two metals to justify your answer.

What information is presented in the question?
Two different metals.

What is the question asking us to do?
Determine the reaction of which metal with HCl occurs more quickly.

What strategies do we need in order to answer the question?

1. Compare the ionisation energies of the metals.
2. Use the difference in ionisation energies to compare the reactivity of the metals.
3. Use the difference in reactivity of the metals to determine which metal reacts more quickly with acid.

Answer
Sodium has lower ionisation energy than tin, so it is easier for sodium to lose its outer electrons, meaning that sodium is more reactive than tin. Therefore, sodium reacts more quickly with HCl.

As reactions of some metals with acids occur slowly and do not produce enough bubbles of hydrogen gas to see, a **hydrogen pop test** can be used to indicate a successful metal-acid reaction. When a burning splint is placed inside a tube, a "pop" sound will be heard if there is hydrogen gas produced from a metal-acid reaction. This is because hydrogen gas is highly flammable and therefore will readily react with oxygen in the air in the presence of a flame. The use of a hydrogen pop test can be seen in figure 4.

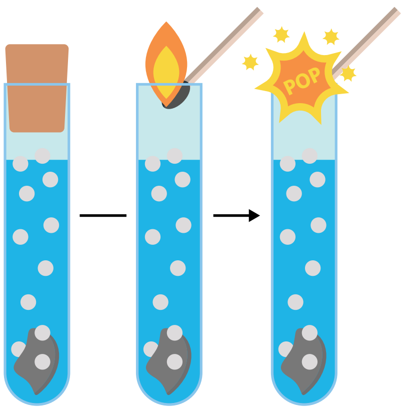

Figure 4 Stages of the hydrogen 'pop' test

Progress questions

Question 1

Some metals are able to react with acids.

A. True

B. False

Question 2

In a solution, metals tend to undergo oxidation becoming positive ions because

A. they tend to lose electrons.

B. they tend to gain electrons.

Question 3

Across the periods from the left to the right in the periodic table, the reactivity of metals with acid

A. increases.

B. decreases.

Question 4

One of the products of a reaction between a metal and acid is

A. oxygen gas.

B. hydrogen gas.

Continues →

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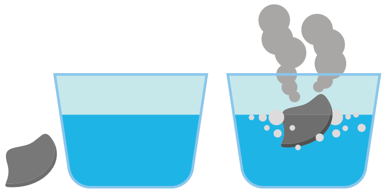
Question 5

All metallic elements on the periodic table react with water to the same extent.

A. True

B. False



Reactions of metals with water 1.1.11.2

Some metals can react with water while other metals cannot.

KEEN TO INVESTIGATE?

[1] **Is this a safe way to dispose of sodium?**
Search YouTube: The disposal of surplus sodium 1947

Figure 5 Explosive reaction between sodium and water

Why are some metals explosive in water?

While metals play an important role in industry, there are some certain rules in storing and disposing of metals. This is because metals in group 1 like lithium, sodium, potassium, rubidium and caesium (alkali metals) and metals in group 2 like calcium and magnesium can readily react with water[1] as shown in figure 5. For this reason, group 1 and 2 metals are often stored under oil to ensure they do not come into contact with water or oxygen.

A general equation demonstrating a reaction of a reactive metal with water can be represented by:

metal + water → metal hydroxide + hydrogen gas

For example, a reaction between sodium and water will produce sodium hydroxide and hydrogen gas as shown (equations will be covered in more detail in lesson 4B):

sodium + water → sodium hydroxide + hydrogen gas

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

Metal	Reaction with water	Reactivity
Potassium	Violent with cold water	Most reactive
Sodium		
Calcium	Slow with cold water, rapid with steam	
Magnesium		
Aluminium	Usually no reaction	
Zinc		
Iron	Rusts slowly	
(Hydrogen)		
Copper	No reaction	
Silver		
Gold		Least reactive

Figure 6 The trend in reactivity of common metals with water

USEFUL TIP

Although some metals like magnesium react very slowly with water at room temperature they react vigorously with water vapour (steam).

Not all metals react with water in the same way. Across a period in the periodic table from the left to the right, ionisation energy of metals increases, meaning that it is more difficult for the metals to lose electrons and therefore the reactivity of the metals with water decreases. For example:

- group 4 metals react more slowly with water in comparison to group 1 metals,
- and ionisation energy of metals decreases down a group, meaning it is easier for them to lose electrons; they will therefore react more quickly down a group.

The trend of reactivity of common metals with water can be seen in figure 6.

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Progress questions

Question 6

A group 1 metal was placed into a beaker of water. When ignited, the gas produced __________ makes a "pop" sound in a hydrogen test.

A. would

B. would not

Question 7

The product of a reaction between calcium and water is

A. calcium hydroxide.

B. calcium oxide.

Question 8

Which of the following gases can form an explosive mixture with oxygen?

A. Hydrogen

B. Carbon dioxide

MISCONCEPTION

'All metals rust.'

Rust is only formed when iron reacts with both oxygen and water to produce a red/brown solid called hydrated iron (III) oxide or more commonly rust.[2] Other metals do not rust – they corrode or oxidise.

KEEN TO INVESTIGATE?

[2] **Why is rusting like an electronic cell?**
Search YouTube: Rusting of iron IPTV

Reactions of metals with oxygen 1.1.11.3

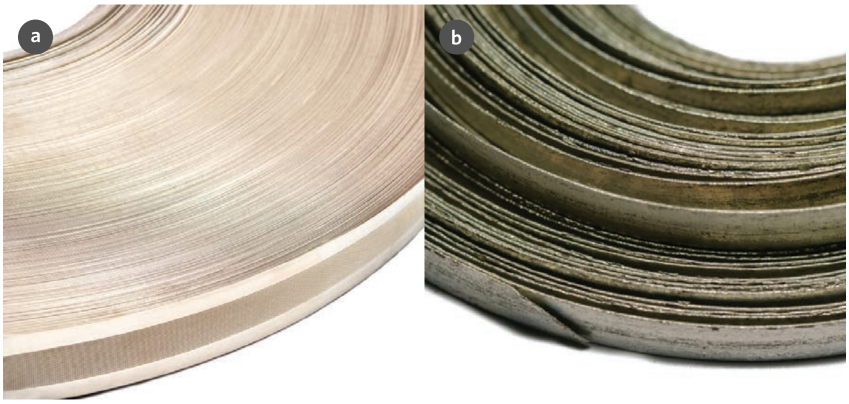
Corrosion occurs due to the reactions between metals and oxygen.

How does the corrosion of metals occur?

It is a common occurrence to come across some form of corrosion. When exposed to oxygen over a certain period of time, metals react with oxygen to form compounds called **metal oxides**. Most metals react with oxygen except for platinum (Pt) and gold (Au). The reactions between those that can react with oxygen have the general equation.

metal + oxygen gas → metal oxide

For example, if a piece of magnesium ribbon is left in the atmosphere, a reaction between magnesium and oxygen will take place as shown in figure 7.



Images (left to right): Stephen Barnes/andregric/shutterstock.com

Figure 7 Pure magnesium ribbon **(a)** is corroded (oxidised) at its surface when left exposed to oxygen gas **(b)**.

The chemical equation for this reaction is:

magnesium + oxygen gas → magnesium oxide

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

The trend of reactivity of metals with oxygen is similar to the trend of reactivity with water and acid. In the periodic table, the reactivity of metals with oxygen decreases as we go across a period from the left to the right, and increases as we move down a group. The trend of the reactivity of common metals with oxygen is shown in figure 8.

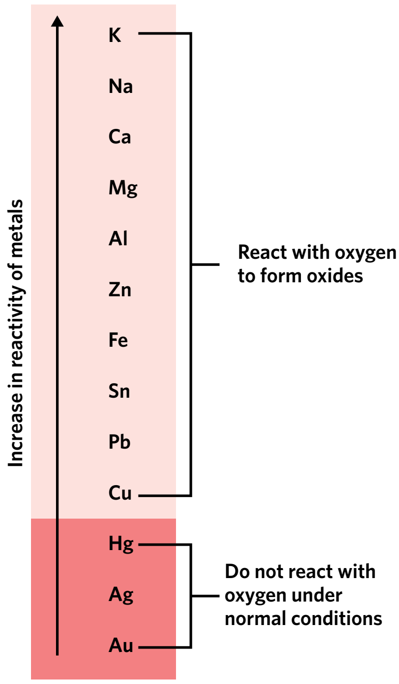


Figure 8 The trend in reactivity of common metals with oxygen

MISCONCEPTION

'Aluminium is unreactive.'

We often use aluminium foil which is unreactive. This is because the aluminium is covered in a protective oxide layer which forms a barrier (aluminium oxide) preventing it from further reacting with oxygen.

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USEFUL TIP

Although all oxidation reactions involve the loss of electrons, there are sometimes easier ways to spot if something has undergone oxidation. The gaining of oxygen or the loss of hydrogen by an element, compound, or species also indicates that oxidation has occurred.

Progress questions

Question 9

A toy truck has rust built up on it after being left exposed to the air and water for many years. This is the result of a reaction

A. between iron and carbon dioxide.

B. between iron, oxygen and water.

Image: Sergey Skleznev/shutterstock.com

Question 10

All metals can react with oxygen under normal conditions.

A. True

B. False

Question 11

__________ can react with oxygen under normal conditions, whereas __________ cannot.

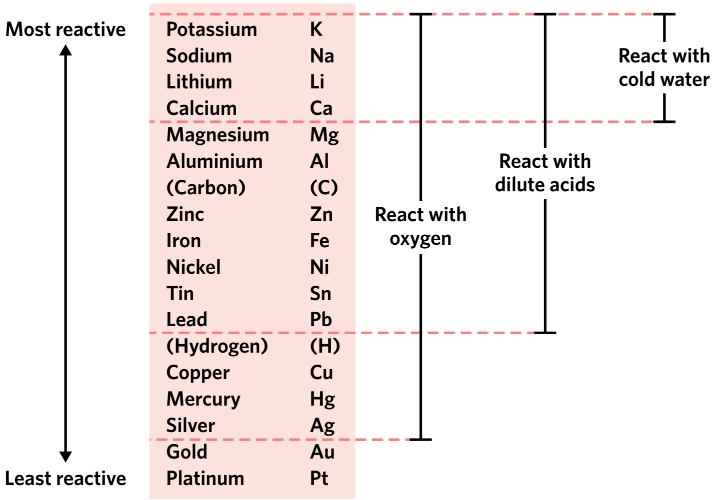
A. Zinc, silver

B. Silver, zinc

Theory summary

- A reaction between a metal and an acid will produce an ionic salt and hydrogen gas.
- A hydrogen pop test can be used to detect reactions between metals and acids.
- A reaction between a metal and water will produce a metal hydroxide and hydrogen gas.
- A reaction between a metal and oxygen will produce a metal oxide.
- Qualitative relative reactivity can be found by observing the amount of bubbles produced or the extent to which metals react (e.g. explosions with water).
- Metals react differently with acids, water and oxygen.

Reactivity series of metals



The content in this lesson is considered fundamental prior knowledge to primary galvanic cells and fuel cells as sources of energy (Unit 3 AOS 1).

3B Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed

Use the following information to answer questions 12–14.

Giao is a chemical engineer. While working in the laboratory on a humid day, she noticed that there was a small explosion with some gas produced on the shelf where she left some metals exposed to the air. No materials were burned by her colleagues during that time and the room temperature was maintained constant.

Question 12 (1 MARK) 🌶

What condition of the room can lead to the explosion?

A. Humidity

B. Temperature

C. Atmospheric pressure

D. All of the above

Question 13 (1 MARK) 🌶

What types of metals may have been affected in the explosion?

A. Group 3 metals with low ionisation energies

B. Group 1 metals with low ionisation energies

C. Group 2 metals with high ionisation energies

D. Transition metals

Question 14 (3 MARKS) 🌶🌶

Provide a possible cause of the small explosion and the presence of gas. Justify your answer including the type of metals that might have been affected in the explosion.

Exam-style

Question 15 (1 MARK) 🌶

Which of the following metals react with water at room temperature?

A. Fe, Mg, Na, K

B. Ni, Ag, Na, K

C. Na, K, Ca, Li

D. Hg, Cd, Na, K

Question 16 (1 MARK) 🌶

Which row in the table below correctly identifies the relative reactivity of the metals shown?

		Reacts with dilute acid	Reacts with oxygen gas	Reacts with water at room temp.	React with water vapour (steam)
A.	Copper	✓	✓	✓	✓
B.	Magnesium	✓	✓	✓	✓
C.	Calcium	✓	✗	✓	✗
D.	Sodium	✗	✓	✓	✓

Question 17 (2 MARKS) 🌶🌶

Two boxes A and B contain two different metal pieces, calcium and lithium. Thomson placed one piece of metal from each box into a tube containing dilute sulfuric acid and observed the results shown in the table.

Identify the metals contained in box A and B. Justify your answer with reference to the difference in ionisation energies of the two metals.

Box	Observation
A	Bubbles appear very slowly
B	More bubbles were produced at a faster rate

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Question 18 (2 MARKS)

An engineer wants to choose a metal to make agrimotors for farmers to use during the rainy season. Which metal, iron or barium, should the engineer choose? Explain your answer.

Question 19 (5 MARKS)

A chemistry student is given two jars of metals lithium and zinc which have lost their labels. The student suggests that the type of metals in each jar can be determined by placing 1 g of metal from each jar into a beaker of dilute hydrochloric acid, HCl.

a. Is the student's method correct? Explain. (2 MARKS)

b. Depending on the type of metals involved in a reaction, it is possible to distinguish between two metals based on their reactive nature. Based on what you learned in the lesson, suggest another method that can be used to determine the metal in each jar. Include balanced chemical equation(s) in your answer. (3 MARKS)

Key science skills

Question 20 (8 MARKS)

5 g of solid copper turnings was mixed with solid calcium and solid magnesium. A group of chemistry students tried to separate pure solid copper from the mixture by the following steps.

1. Place cold water into the mixture and wait for 5 minutes.
2. Separate the remaining solid mixture and the solution produced.
3. Place dilute sulfuric acid into the remaining solid mixture.
4. Collect the remaining solid which should be pure copper.

a. Identify the metals in the solid mixture in step 2. Justify your answer including the balanced chemical reaction(s). (3 MARKS)

b. One student in the group suggested that concentrated sulfuric acid should be placed into the mixture first instead of the cold water. Is the student's suggestion correct? Explain your answer. (2 MARKS)

c. After finishing all four steps, the students weighed the collected sample of copper and realised that they collected 5.3 g of copper. Explain why the mass could be greater than 5.0 g and suggest one change that the students can make to obtain the original 5.0 g of pure copper. (3 MARKS)

FROM LESSON 16B

Questions from multiple lessons

Question 21 (4 MARKS)

Use the list of symbols of elements to answer the following questions. Be, P, N, Mg, Na, Fe.

a. Which of the elements are not considered to be metals? (1 MARK)

b. Which metal is likely to be used for making cars? (1 MARK)

c. Which of the elements is considered a critical element? Suggest a way that we can preserve its supply? (2 MARKS)

FROM LESSONS 1D & 3A

Hints

15. Only group 1 and 2 metals react with water at room temperature.

16. All metals react with oxygen (except gold and platinum), and some react with steam but not water at room temperature.

17. Different metals have different ionisation energies.

18. Rain water reacts differently with the metals.

19a. Two different metals can be distinguished if different observations are obtained from their reactions with the same substance.

19b. Choose a substance that the metals react with differently.

20a. Only some metals react in cold water.

20b. Many metals can react with acids.

20c. Only some metals react completely in very dilute acids.

21a. Look at the periodic table locations.

21b. Reactive metals are not very useful.

21c. Most critical elements are non-metals.

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3C Metal recycling

Image: JasminkaM/Shutterstock.com

How are metals recycled?

Metals are valuable resources that can be **recycled** many times without degrading their properties. The **sustainable** process of recycling metals is crucial to preserving natural resources, the environment and reducing energy consumption.

STUDY DESIGN DOT POINT

- 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

3A 3B 3C

1.1.12.1 Circular economy

1.1.12.2 Metal recycling

ESSENTIAL PRIOR KNOWLEDGE

3A Metals do not form compounds with other metals

See question 19.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

Atom economy mass of desired products divided by mass of all reactants given as a percentage conversion

Circular economy a continuous cycle that focuses on the optimal use and re-use of resources from the extraction of raw materials through to production of new materials, followed by consumption and re-purposing of unused and waste materials

Green chemistry principles aimed at reducing the chemical-related impact on both humans and the environment through dedicated sustainability management programs

Life cycle the management of the production and processing, storage, transportation, use, and disposal of a chemical product

Linear economy operates on a 'take-make-dispose' model, making use of resources to produce products that will be discarded after use

Recycle convert a waste product into a reusable product

Renewable resources comes from sources that naturally renew themselves at a rate that allows them not to become depleted

Sustainable can be produced at a rate that is greater than consumption without compromising future generations

Circular economy 1.1.12.1

In the past chemical manufacturers have not factored in what happens to a chemical product after it has been used.

What is a circular economy?

Resources are at risk of becoming scarce due to a growing global population and rising prosperity levels. Available resources must therefore be used as efficiently as possible.

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KEEN TO INVESTIGATE?

1 **What are the main differences between these economies?**
Search YouTube: Circular economy vs linear economy champions

A transition from a **linear economy** towards a **circular economy**[1] is increasingly being adopted by society and industry as a strategy to achieve more sustainable development. Figure 1 shows the differences in these two types of economy.

VCAA Study design 2023–2027 p21

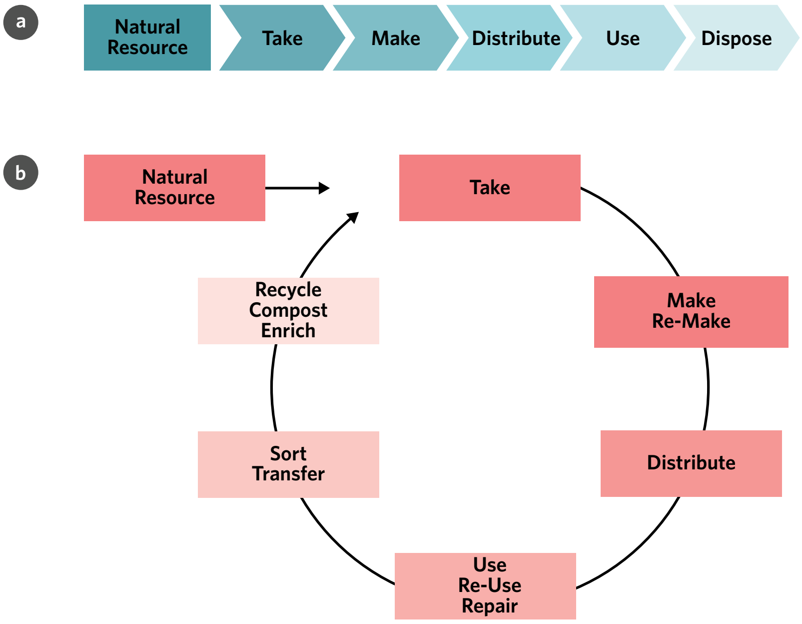


Figure 1 **(a)** Linear economy – open **life cycle** **(b)** Circular economy – closed life cycle

Put simply, a circular economy is when the materials and resources from a product are returned back into the current economy which is a closed product cycle. A linear economy on the other hand is when a product is essentially disposed of in landfill after it has been used.

In Australia, new materials that are useful for society tend to be produced through a linear economy, in which products are purchased, used and then thrown away. Increasingly, manufacturing companies are moving towards a circular economy, which seeks to reduce the environmental impacts of production and consumption while enabling economic growth through more productive use of natural resources and creation of less waste.

How can chemistry contribute to a circular economy?

Society relies on the chemical industry for a variety of products through various chemical processes and pathways. To improve the life cycle management of manufactured goods and their associated processes, a broad and global transformation towards a safe and more sustainable chemical future is required. The creation, use, re-use, disposal and elimination of chemicals should be achieved with the least possible adverse effects on human health and the environment while still providing economic and social benefits.

Green chemistry is the design of new chemical products and manufacturing processes that are safer and more sustainable than traditionally used products and processes. It is underpinned by a set of 12 principles that aim to minimise the impact of the product or process on the environment, Earth's resources, human health and the viability of other living organisms. These principles are based on reducing risk, minimising the production of unwanted by-products and wastes[2],and limiting the amount of energy used and raw materials (particularly non-renewable raw materials) consumed. Creativity and innovation are required to apply green chemistry principles to chemical manufacturing as new products are designed and produced. Of the 12 Principles of Green Chemistry developed in 1991by Paul T Anastas and John C Warner, the following four contribute directly to a circular economy.

MISCONCEPTION

'Reuse and repurpose are the same as recycle.'

Recycling is a process that involves the conversion of materials, whereas, reuse and repurpose does not involve conversion of materials.

KEEN TO INVESTIGATE?

2 **How can gold be recycled?**
Search YouTube: Recycling Gold from Electronic Waste

Back to contents

- **Atom economy**: Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
- Use of **renewable resources:** feedstocks: Raw materials or feedstocks should be made from renewable (mainly plant-based) materials, rather than from fossil fuels, whenever practicable.
- Prevention of wastes: It is better to prevent waste than to treat or clean up waste after it has been produced.
- Design for energy efficiency: Processes/pathways should be designed for maximum energy efficiency and with minimal negative environmental and economic impacts.

VCAA Study design 2023–2027 p21

Progress questions

Question 1

What is the main difference between a linear and circular economy?

The product life cycle of

A. both a linear and circular economy are an open cycle.

B. a linear economy is open, but a circular economy is a closed cycle.

Question 2

Sustainable development is characterised by a

A. linear economy product life cycle.

B. circular economy product life cycle.

Question 3

Which of the following is an example of a sustainable product?

A. Glass milk bottle

B. Single-use plastic bag

Metal recycling 1.1.12.2

Most metals can be recycled repeatedly without degrading their properties.

Why should all steel items be recycled?

Steel, which is made mainly from iron (and small amounts of carbon and other metals), is the most recycled material on Earth. It is extremely sustainable as it can be infinitely recycled as it does not lose any of its inherent strength qualities. Another advantage of recycling iron is that due to its magnetic properties it can easily be separated from other metals. Table 1 shows some of the other most commonly recycled metals and their uses.

Table 1 Commonly recycled metals and their uses

Metal	Uses
Iron	Food cans and construction
Aluminium	Drinking and food cans
Copper	Electrical appliances and electrical wires
Gold	Computers and jewellery
Lead	Roofs and construction

MISCONCEPTION

'Most metals are magnetic.'

Of the 80 or so metals on Earth only three are naturally magnetic – iron, nickel and cobalt.

Figure 2 shows the complex life cycle of recycled steel.

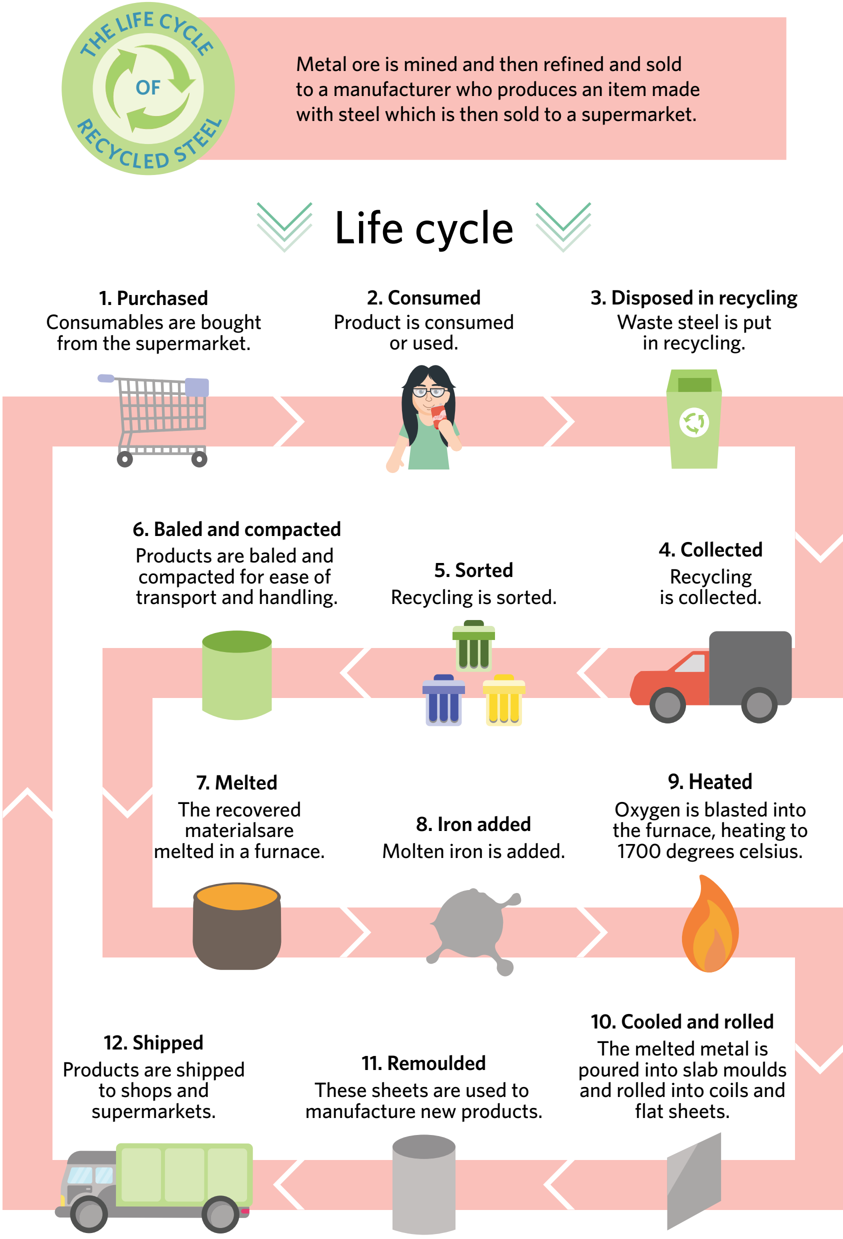


Figure 2 Typical life cycle of a steel can

It is estimated 200 billion steel cans are produced each year, around 25% of which contain recycled steel. Using recycled steel saves around 70% more energy, reduces air pollution by around 85% and reduces water use by 40%.

Source TATA steel

What are the advantages of recycling metals?

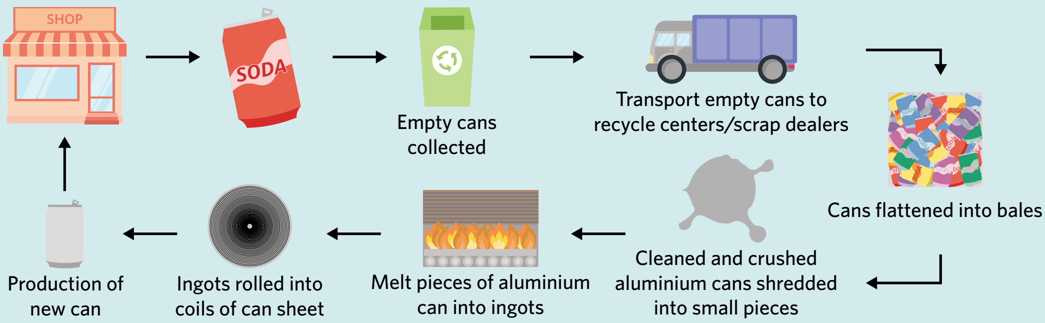
- Reduce energy consumption: the process of recycling waste metal is far more energy efficient; for example, producing a new aluminium can from recycled aluminium requires 95% less energy than a can produced from the ore.
- Reduce landfill: diverts waste from landfill sites as metals take a long time to break down.
- Reduce greenhouse gas emissions[3]: less fossil fuels are required in the production of materials made from recycled metals, thereby reducing the amount of greenhouse gases created which can help combat climate change.
- Conserve natural resources: mining is a disruptive process that depletes natural resources and can have adverse effects on wildlife, local communities and the environment.
- Endless: most metals can be recycled an unlimited number of times.

KEEN TO INVESTIGATE?

[3] **Why are some metals key to a more sustainable future?**
Search: six metals are key to a low-carbon future

WORKED EXAMPLE 1

Using the following infographic, a student concludes that 'The recycling process has a net energy of zero'. Justify whether the student is correct.



What information is presented in the question?

The circular economy of aluminium cans.

What is the question asking us to do?

Justify with reasons why the student's statement is or is not correct.

What strategies do we need in order to answer the question?

1. Decide on whether the statement is correct or not.
2. Carefully look over the infographic highlighting important points to be used as justification.

Answer

Although recycling aluminium saves a lot of energy it still requires an input of energy to supply the recycling process. From the infographic it can be seen that the following processes require an input of energy:

- Transporting the cans to be recycled
- Machine to crush and clean the cans
- Melting the cans
- Rolling the cans
- Producing new cans
- Transporting the cans to the supermarket

Therefore the process of recycling is not net zero and the statement is incorrect.

Progress questions

Question 4

Nearly all metals are recyclable. Which of the following are not metals that can be recycled?

A. Tin, nickel, vanadium

B. Uranium, plutonium, sodium

Question 5

What is a good reason why two thirds of the food cans found on supermarket shelves are made from steel?

A. Iron requires less energy to be extracted than most metals.

B. Aluminium is lighter and stays shiny for longer.

Question 6

Advantages of recycling metals include reducing the

A. number of steel cans manufactured worldwide.

B. amount of natural resources mined.

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Theory summary

- A circular economy is much more sustainable than a linear economy.
- Metals can be recycled over and over again.
- Green chemistry principles contribute to the development of a circular economy.
- The life cycle of a circular economy is complex and has many advantages.

3C Questions

Mild Medium Spicy

Deconstructed

Use the following information to answer questions 7–9.

The following image shows a crane sorting out metal at a recycling centre. Dealing in scrap metal is big business as the value of scrap metal continues to rise.

Image: Silarock/Shutterstock.com

Question 7 (1 MARK)

What property allows certain metals containing iron, nickel or cobalt to be separated out in this way?

A. Electric

B. Density

C. Magnetic

D. Electrostatic

Question 8 (1 MARK)

Why does the cost of some scrap metals keep rising?

A. Due to an increased amount of recycling

B. Production of pure metal has decreased

C. Because mining the ore has become more expensive

D. Greater competition from other companies

Question 9 (3 MARKS)

Outline the main energy inputs that would be involved in the recycling of scrap iron before selling the purified metal back to a manufacturer.

Exam-style

Question 10 (1 MARK)

Green chemistry principles apply across the ________ of a chemical product including its design, manufacture, use, and after its use.

A. properties **B.** efficiency **C.** sustainability **D.** life cycle

Question 11 (7 MARKS)

a. Define what is meant by the term 'sustainable chemistry'. (2 MARKS)

b. For recycling purposes, scrap metals are often classified into ferrous and non-ferrous. Explain the basis of this classification. (2 MARKS)

c. What property of metals allows them to be produced in a circular economy, and why is this property important? (3 MARKS)

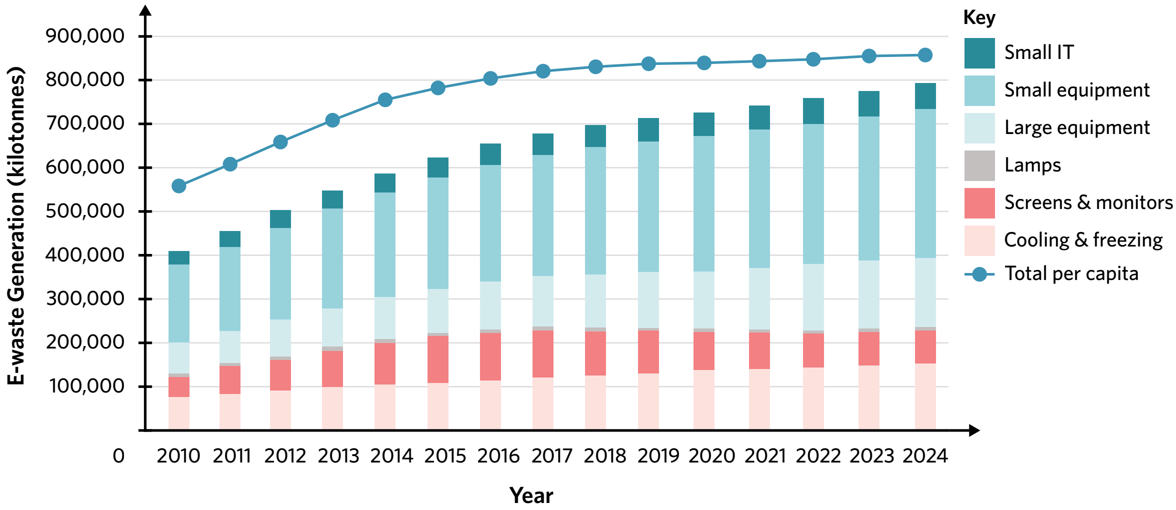
Question 12 (2 MARKS)

Steel requires around 55% less energy to produce when it is made from recycled materials. Give two specific reasons why using 55% less energy is beneficial to the environment.

Key science skills

Question 13 (6 MARKS)

E-waste is a term used when talking about the recovery of precious metals like gold, silver and copper metal from used electronic devices.



a. What is the overall trend shown in the chart? (1 MARK)

b. Which type of equipment is the largest contributor to e-waste? (1 MARK)

c. Which type of e-waste equipment has been decreasing since 2016? (1 MARK)

d. Why is it important that precious metals are recovered by specialised recycling companies? (3 MARKS)

FROM LESSONS 16B & 16C

Question 14 (5 MARKS)

Using only the information provided in the table, write an overall conclusion about the benefits of recycling metals.

Recycling metals	
Fewer raw materials (ores) are used and ores are a non-renewable resource.	The process of extracting a metal from its ore is more costly and requires lots of energy compared to recycled metals.
Recycled metals are generally impure.	Reduces waste that will be sent to landfill.
Recycling provides lots of jobs.	Mining and landfill negatively affect the environment.
Recycling some metals does not meet the demands.	Sorting metals costs lots of time and money.

FROM LESSON 16E

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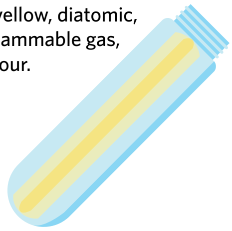
Questions from multiple lessons

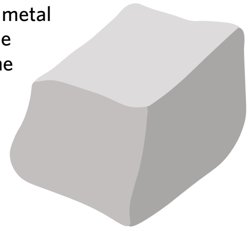
Question 15 (6 MARKS)

Fluorine gas and sodium metal are both very reactive elements that react vigorously with water.

Fluorine is a pale yellow, diatomic, highly corrosive, flammable gas, with a pungent odour.



Sodium is a silvery-white metal belonging to group 1 of the periodic table, which is the alkali metals group.



They react according to the following equations:

fluorine + water → hydrogen fluoride + oxygen gas
$2F_2(g) + 2H_2O(l) \rightarrow 4HF(aq) + O_2(g)$

sodium + water → sodium hydroxide + hydrogen gas
$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

a. What type of chemical reaction does sodium undergo when it reacts with water? (1 MARK)

b. How could you test for the presence of hydrogen gas in this reaction? (2 MARKS)

c. Why is fluorine gas referred to as a diatomic gas? (1 MARK)

d. Explain why both fluorine gas and sodium metal react very vigorously with water. (2 MARKS)

FROM LESSONS 1B, 2A & 3B

Hints

10. Consider what is described by the phrase 'design, manufacture, use, and after its use.'
11a. Check out the definitions at the start of the lesson.
11b. Ferrous is the latin name for an element which has the symbol Fe.
11c. Metals do not form compounds and alloys are mixtures which can be separated.
12. Focus on how less energy used will impact the environment.
13a. Use the blue trend line to see the pattern (per capita)
13b. Use the colour coded sections of the bars.
13c. Use the colour coded sections of the bars.
13d. Precious metals are in high demand which outstrips supply.
14. Address each statement and try to group any that are similar, do not just repeat the statements. Synthesise them into a concise sentence.
15a. The sodium lost an electron.
15b. A procedure for an explosive test.
15c. All of group 17 elements exist in pairs.
15d. The life and times of an electron can differ.

Chapter 3 review

Multiple choice (10 MARKS)

Question 1 (1 MARK)

In which group on the periodic table would we find the most reactive metals?

A. Group 17
B. Group 4
C. Group 2
D. Group 1

Question 2 (1 MARK)

Sodium, rubidium and caesium are all alkali metals. Which of the following options orders the metals in increasing order of reactivity?

A. Rubidium, sodium, caesium
B. Sodium, caesium, rubidium
C. Caesium, rubidium, sodium
D. Sodium, rubidium, caesium

Question 3 (1 MARK)

In chemistry, rust is also referred to as a

A. metallic hydrolyte.
B. hydrated iron (III) oxide.
C. dihydrogen oxide.
D. metalloid.

Question 4 (1 MARK)

Gold jewellery is produced by heating solid gold to a temperature above 1064 °C and allowing it to melt so that it can be poured into different shaped moulds. This suggests that metallic substances

A. are highly combustible.
B. are expensive.
C. contain strong bonds.
D. are easily malleable.

Question 5 (1 MARK)

A company wanted to develop a new chemical product to be used for their newest car model. Before the company starts to produce this new chemical, they should undertake a study to determine the complete ___________ of the product.

A. open cycle
B. life cycle
C. recycle
D. reuse

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Question 6 (1 MARK)

Which of the following materials should not be composed of metallic elements?

A. Gloves used by electricians to fix live wires

B. Wires used in telephone communications

C. Cooking pots

D. Light bulb filaments

Question 7 (1 MARK)

In a reaction between a strong acid and potassium metal, it is expected that we would

A. smell a fruity odour.

B. observe bubbles.

C. observe a change in the colour of the acid.

D. see no change.

Question 8 (1 MARK)

What type of economy is depicted by the image?

A. Linear

B. Financial

C. Circular

D. Chemical

Question 9 (1 MARK)

Which of the following metals is **least** likely to react with water at room temperature?

A. Magnesium **B.** Rubidium **C.** Copper **D.** Beryllium

Question 10 (1 MARK)

Properties such as lustre and heat conductivity of metals are mainly due to

A. the reactivity of metals.

B. the size of metallic atoms.

C. delocalised electrons.

D. electronegativity of metals.

Short answer (30 MARKS)

Question 11 (16 MARKS)

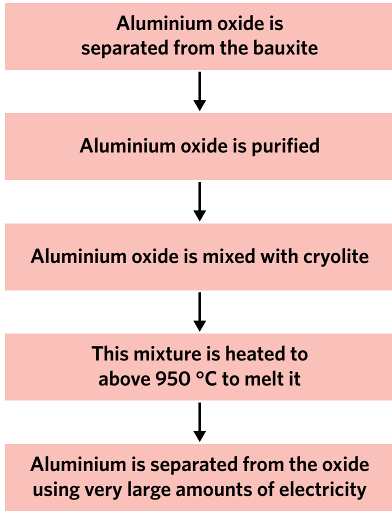
Humans rely on metals to go about their everyday lives. Metals have different properties which determine how they are used in society.

a. Match up each of the metals listed with the relevant information in the table

Copper	Resistant to corrosion due to a strong oxide layer.
Gold	Most recycled element on Earth.
Aluminium	Reacts rapidly with water producing hydrogen gas.
Iron	Used in electrical wiring due to high conductance.
Sodium	Found in the Earth as a pure metal.

(5 MARKS)

b. Aluminium is extracted from an ore called bauxite which is impure aluminium oxide. Pure aluminium oxide has a melting point of over 2000 °C. The flow chart outlines the main steps in the extraction of aluminium from bauxite.



Of the over 3 billion aluminium cans used annually in Australia around 55% are recycled.

When aluminium is recycled the scrap aluminium melts at 700 °C.

Using the information provided:

i. Suggest six reasons why most aluminium is recycled. Refer three of your reasons to the extraction process and three reasons to the recycling process. (6 MARKS)

ii. Using the temperature values provided, explain how this process is designed for greater energy efficiency. (2 MARKS)

iii. What additional steps could be taken to further improve the efficiency and sustainability of the processes making it more of a circular economy? (3 MARKS)

Question 12 (5 MARKS)

A materials scientist wants to create a new type of alloy to use as a wire in a heart pacemaker. Heart pacemakers send electrical pulses to the heart through wires inserted into the body's veins as shown in the image. Therefore, the scientist needs the alloy to exhibit the following properties:

- Electrical conductivity
- Malleability
- Ductility
- Durability

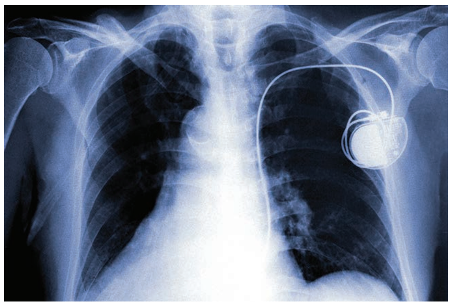


Image: khuruzero/Shutterstock.com

a. What is an alloy? (1 MARK)

b. With reference to metallic bonding, explain why metals are able to conduct electricity. Use a diagram to explain your answer. (3 MARKS)

c. Why would the wires in a heart pacemaker need to be malleable? (1 MARK)

Question 13 (9 MARKS)

Frank has been given three pieces of grey metal which look identical. He knows that one metal is magnesium, one metal is barium and one metal is beryllium. He wants to determine the identity of each metal based on their chemical reactions and properties.

a. Which metal would be expected to have the greatest reactivity? Justify your answer with reference to trends in the periodic table. (2 MARKS)

b. Write the equation of the chemical reaction that would occur between solid barium and water. If this reaction initially occurred in a sealed test tube, what would happen when a flame is placed inside the test tube after removing the seal? (2 MARKS)

c. Frank proposes that he could also determine the reactivity series by leaving the metals out in the open air. What would happen to the metal samples over time (include any relevant equations) and how could this be used to differentiate between them? (5 MARKS)

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Key science skills (10 MARKS)

Question 14 (4 MARKS)

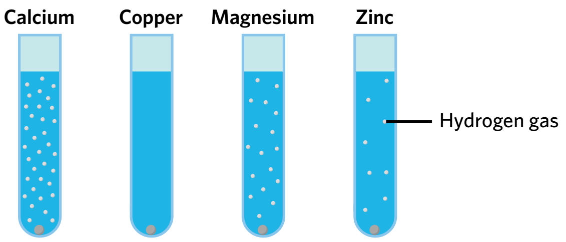
Caesium is a highly reactive metal and is a liquid at room temperature. One of its applications is in atomic clocks which are the primary standards for global timekeeping. A scientist was asked to repair an atomic clock which was being kept in a vacuum with no oxygen present.

a. Before handling caesium, the scientist practices her technique using sodium. Is this a valid way to practice? (2 MARKS)

b. Atomic clocks are very accurate. Do they have to be precise in order to be an effective timekeeping method? Explain your reasoning. (2 MARKS)

Question 15 (6 MARKS)

Patrick and Millie were qualitatively investigating the relative reactivity of different samples of metals in sulfuric acid.



They were having a discussion and decided to write a list of possible variables.

- Mass of each metal sample in grams
- Temperature of the sulfuric acid
- Temperature of the laboratory
- Volume of acid
- Atmospheric pressure in the laboratory
- Concentration of the sulfuric acid
- Temperature of the sulfuric acid

a. Which one of these variables cannot be controlled in this experiment? (1 MARK)

b. What are the independent and dependent variables in this experiment? (2 MARKS)

c. What is an example of a variable that is impossible to control even though it will have a significant impact on the amount of hydrogen gas bubbles produced? (2 MARKS)

d. How could the validity of the methodology used be improved? (1 MARK)

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3A Metals

Progress questions

1. A. Metals are extracted from ores, which are the deposits of minerals containing metals.

2. B. The names of electrons indicate whether they can move freely or they are fixed.

3. B. Delocalised electrons are removed from metal atoms and are therefore attracted to metal cations.

4. A. Malleability, ductility, lustre, heat, and electrical conductivity can be explained by the metallic bonding model.

5. A. Electrostatic force of attraction in the metallic bonding model is the non-directional attractive force between the sea of delocalised electrons and metal cations.

6. A. Delocalised electrons are removed from metal atoms and therefore can absorb heat and transfer kinetic energy to other delocalised electrons.

7. B. Delocalised electrons have negative charge, so they are pushed by the negative electrode and attracted by the positive electrode.

8. A. Metallic bonds are strong, so they can withstand high temperatures.

Deconstructed

9. A

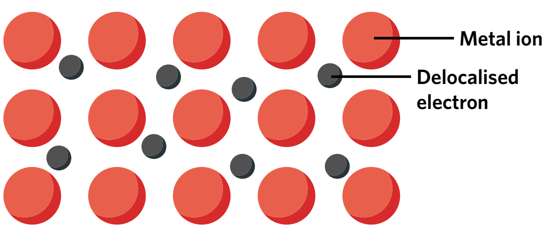
10. C

11. [Based on the data given, iron has the highest boiling point of all the metals.[1]] [This suggests that the metallic bonds involving iron are the strongest.[2]] [Therefore, it would be able to withstand more weight and heat compared to the other metals.[3]] [As a result, iron would be the most suitable metal for the company to use.[4]]

- I have identified the metal with the highest melting point.[1]
- I have identified the metal with the strongest bonds.[2]
- I have described the effect of bond strength on different properties.[3]
- I have linked my answer to the question.[4]

Exam-style

12. **a.**



b. [Metals are held together by the force of attraction that exists between the positive metal cation and the sea of negatively charged delocalised electrons.[1]] [When a force is applied to the lattice structure, the layers of positive ions can move, however due to the delocalised electrons, the 3-D non-directional force of attraction between the electrons and positive ions remains,[2]] [holding the structure together and therefore allowing it to be bent without breaking.[3]]

- I have described metallic bonding.[1]
- I have explained what happens when a force is applied to a metallic structure.[2]
- I have linked my answer to the question.[3]

13. **a.** Nick can conclude that metals can conduct heat.

b. [According to the metallic bonding model, there are many delocalised electrons between metal cations.[1]] [When a piece of metal is heated, the rise in temperature causes the increase in kinetic energy of delocalised electrons and metal cations. Therefore, the metallic ions can vibrate more rapidly and delocalised electrons can move faster, transferring the kinetic energy to nearby ions and electrons.[2]] [Hence, when Nick touched the spoon, the kinetic energy carried by the moving electrons was transferred to his hand in the form of heat energy and he therefore had a 'burning' feeling.[3]]

- I have described delocalised electrons in the metallic bonding model.[1]
- I have used the metallic bonding to explain how metals can conduct heat.[2]
- I have linked my explanation with Nick's experience.[3]

14. [The student's explanation is not correct.[1]] [For a material to be able to conduct electricity, it needs to allow for the movement of electrons.[2]] [Metals can conduct electricity because according to the metallic bonding model, delocalised electrons in a solid piece of metal can move freely. Therefore, when one end of the metal is connected to the positive electrode and the other end is connected to the negative electrode of an electrical source, there is a movement of delocalised electrons away from the negative electrode and towards the positive electrode.[3]]

- I have determined if the student's explanation is correct.[1]
- I have described metal conductivity.[2]
- I have explained how metals can conduct electricity.[3]

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15. **a.** [According to the results, the structures of both metals are unaffected at 200 °C. At 400 °C the lead rail began to lose its structure whereas copper remained unaffected.[1]] [This suggests that the energy supplied at 400 °C was enough to break the metallic bonds within the lead rail, implying that the melting temperature of lead is within the range of 400 °C.[2]] [In contrast, the structure of copper's rail remained unchanged, suggesting that the melting point for copper is greater than 600 °C.[3]][Through these results, it can be seen that lead has a lower melting point than copper.[4]]

- I have identified the key results in the experiment.[1]
- I have explained the effect of heat on the bonding of lead.[2]
- I have explained the effect of heat on the bonding of copper.[3]
- I have linked my answer to the question.[4]

b. [Although the metallic bonding model is able to explain most of the properties of metals, it isn't able to explain why different metals exhibit slightly different variations of certain properties.[1]][For example, for metals to conduct heat, the kinetic energy is passed on through the movement of electrons.[2]][However since all metallic structures contain delocalised electrons, we are unable to use the model to explain why different metals are able to conduct heat more or less efficiently.[3]]

- I have identified the main limitation of the metallic bonding model.[1]
- I have described how heat is conducted through metals.[2]
- I have described the inability of the metallic bonding model to explain heat conductivity.[3]

Key science skills

16. **a.** [Gabriella can conclude that her ring is not entirely made of silver.[1]][There was dull light from the bulb when the ring was implemented in the circuit, while there was strong and dazzling light from the bulb when the piece of pure silver was implemented in the circuit.[2]]

- I have given a conclusion.[1]
- I have used my observation in the experiment to explain my conclusion.[2]

b. Gabriella can use different sets of wires which are made of different metals to confirm that the same results will be obtained.

FROM LESSONS 16C & 16D

Questions from multiple lessons

17. **a.** Titanium

b. [Titanium is a transition metal while plastic is made of non-metal atoms.[1]][Titanium is more durable than the plastic which could wear down or even break.[2]][The plastic might react with body fluids whereas titanium is inert (chemically inactive).[3]]

- I have determined the most appropriate material to be used.[1]
- I have compared the strength and potential reactivity of the two materials.[2]
- I have used my explanation to justify my answer.[3]

FROM LESSONS 1A & 2B

3B Reactivity of metals – part 1

Progress questions

1. A. Not all but the majority of metallic elements in the periodic table can react with acid, water or oxygen.

2. A. Metals have low ionisation energies, so electrons are easily taken from them.

3. B. Across the periods, ionisation energies of metals increase, and therefore their reactivity with acid decreases.

4. B. Since a positive metal ion bonds to a negative ion from an acid to form a salt, free hydrogen ions in the solution bond to each other to produce hydrogen gas

5. B. Metals with lower ionisation energies react more quickly with water, while metals with higher ionisation energies react more slowly with water.

6. A. A "pop" sound is heard when hydrogen gas reacts with oxygen in the atmosphere in the presence of a flame.

7. A. A reaction between a metal and water will produce a metal hydroxide.

8. A. When ignited a mixture of hydrogen and oxygen is explosive. Pure hydrogen burns gently.

9. B. Rust is a result of a reaction between iron and oxygen.

10. B. Some metals, like gold and platinum, cannot react with oxygen under normal conditions.

11. A. Zinc can react with oxygen to produce zinc oxides under normal conditions, while silver cannot.

Deconstructed

12. A

13. B

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14. [Due to the humid condition in the laboratory, there was water in the room atmosphere.[1]] [Group 1 metals are highly reactive due to their low ionisation energies.[2]] [The small explosion was the result of the reaction between group 1 metals with water in the atmosphere at room temperature with hydrogen gas produced.[3]]

- I have described the effect of the humidity on the room atmosphere.[1]
- I have explained the reactivity of group 1 metals.[2]
- I have explained the underlying reason for the explosion observed.[3]

Exam-style

15. C

16. B

17. [Box A contains calcium and box B contains lithium.[1]] [Calcium has higher ionisation energy than lithium, meaning it is more difficult for calcium to lose electrons. Therefore, calcium reacts slower with water and hydrogen gas bubbles are produced more slowly. Lithium has lower ionisation energy than calcium, meaning it is easier for lithium to lose electrons. Hence, lithium reacts more vigorously with dilute sulfuric acid and more bubbles are produced at a faster rate.[2]]

- I have determined the metal contained in each box.[1]
- I have explained the observation of the reaction between the metals and the acid.[2]

18. [The engineer should choose iron.[1]] [Barium reacts more strongly with water than iron so using iron will help maintain better quality of agrimotors during the rain season.[2]]

- I have determined which metal should be chosen.[1]
- I have explained my answer with respect to the reactivity of the metals.[2]

19. a. [The student's method is incorrect.[1]] [Both lithium and zinc can react with hydrochloric acid to produce colourless solutions of salts and hydrogen gas.[2]]

- I have identified the accuracy of the student's method.[1]
- I have described the reaction of the metals with hydrochloric acid.[2]

b. [Lithium and zinc can be distinguished by placing the same amount of each metal into water at room temperature.[1]] [Lithium can react rapidly with water at room temperature to produce hydrogen gas, while zinc cannot react with water at room temperature.[2]]

[$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$
$Zn(s) + H_2O(l) \rightarrow$ no reaction[3]]

- I have suggested one method to distinguish the two metals.[1]
- I have described the outcome of the method chosen.[2]
- I have included the possible balanced chemical equation(s) to support my answer.[3]

Key science skills

20. a. [The remaining solid mixture contains Mg(s) and Cu(s).[1]] [This is because calcium will react rapidly with water to produce a hydroxide solution, whereas magnesium and copper will not react rapidly and therefore remain in the mixture.[2]]

$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$

- I have determined the metals remained in the solid mixture.[1]
- I have justified my answer by comparing the ability to react with cold water of the metals.[2]
- I have included the occurred chemical reaction.

b. [The student's suggestion is not correct and is very dangerous.[1]] [If concentrated sulfuric acid is placed into the mixture first, magnesium, calcium and copper will all react with the acid to produce a solution, meaning that we cannot collect pure solid copper.[2]]

- I have evaluated the student's suggestion.[1]
- I have explained my answer describing what would occur.[2]

c. [The students separated more than 5.0 g of solid copper because a small amount of either calcium or magnesium did not react completely with the dilute sulfuric acid.[1]] [To collect only pure copper, they can increase the temperature of the acid or increase its concentration.[2]] [This would ensure that only copper remained with a mass of 5.0 g.[3]]

- I have explained the reason the students collected more copper than expected.[1]
- I have suggested one change that could be made to collect just copper.[2]
- I have described a reason to support my suggestion.[3]

FROM LESSON 16B

Questions from multiple lessons

21. a. P and N

b. Fe

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c. [P.[1]][Recover phosphorus from human and animal waste, or recycle industrial waste, eating less meat and dairy to reduce the number of livestock eating plants.[2]]

- I have identified the critical element.[1]
- I have described a way in which phosphorus supplies can be preserved.[2]

FROM LESSONS 1D & 3A

3C Metal recycling

Progress questions

1. B. A linear economy life cycle ends up in the disposal of resources and therefore the same amount of resources need to be added to create the product again. A circular economy does not require the addition of the same amount of resources to create the product again as it is not disposed of.
2. B. Economies that do not use as many resources are more sustainable.
3. A. Glass can be infinitely recycled, whereas a single use plastic bag is disposed of in landfill.
4. B. Radioactive (U, Pu) or very reactive metals (Na) are not suitable for recycling as they are very dangerous and need to be managed by special recovery agencies.
5. A. It is better for all if iron is used as it has a reduced impact.
6. B. Recycling does not reduce the number of cans that are produced but it does reduce the amount of new metal that needs to be mined and produced from its ore.

Deconstructed

7. C
8. C
9. [Collecting the scrap metal using trucks.[1]][Using a specialised electromagnetic crane to separate out the magnetic metals.[2]] [The melting of the metals to obtain pure iron.[3]]
   - I have planned a sequence of events starting with collection.[1]
   - I have identified how the iron is separated.[2]
   - I have described how the iron is purified ready for resale.[3]

Exam-style

10. D. In most cases, new chemicals that are produced can persist in the environment for very long periods of time.
11. a. [Can be produced at a greater rate than it is consumed.[1]] [Consequences of the use of this chemical product are minimal for society and the environment.[2]]
    - I have defined sustainable.[1]
    - I have identified possible consequences.[2]

    b. [Ferrous means that it contains some degree of iron.[1]] [Non-ferrous does not contain any iron.[2]]
    - I have understood what ferrous means.[1]
    - I have explained the difference between the two terms.[2]

    c. [When mixtures of metals melt this separates them.[1]] [This then allows them to be purified, recycled and used again and again.[2]][This is part of a closed cycle which is indicative of a circular economy.[3]]
    - I have identified the property.[1]
    - I have explained how they can be separated.[2]
    - I have identified that recycling is part of a closed cycle.[3]
12. [Fewer fossil fuels will need to be combusted which will reduce greenhouse gas emissions.[1]][Fewer fossil fuels will need to be extracted which will help conserve Earth's natural resources and protect communities, wildlife and the environment.[2]]
    - I have mentioned less energy used means less greenhouse gases.[1]
    - I have addressed the issue surrounding Earth's natural resources and the environment.[2]

Key science skills

13. a. The amount of e-waste produced is forecast to continue increasing (per capita).

    b. Small

    c. Screens and monitors

    d. [Precious metals are extremely difficult to find.[1]][They are expensive to mine.[2]][We only have a finite supply.[3]]
    - I have described that they are difficult to find.[1]
    - I have described that they are expensive to mine from the ground.[2]
    - I have described that not a lot of some metals (e.g. gold) are left in the ground.[3]

FROM LESSONS 16B & 16C

14. [Although recycling may be costly,[1]][extracting a metal from its ore will be a lot more expensive.[2]][Recycling metals is much more economical.[3]][It is also more environmentally friendly than extracting new metals.[4]][Mining and extraction are still required due to demand.[5]]

- I have addressed the issue that recycling does cost a lot of money.[1]
- I have addressed the issue that extracting metals from the ore is much more expensive.[2]
- I have used economy to compare extraction and recycling.[3]
- I have addressed the issue of landfill and environmental damage.[4]
- I have mentioned that extraction is still necessary to meet demand.[5]

FROM LESSON 16E

Questions from multiple lessons

15. a. Oxidation

b. [Hydrogen pop test.[1]][Involves carefully capturing hydrogen gas and igniting it and a controlled explosion indicates the presence of hydrogen gas.[2]]

- I described the name of the test.[1]
- I described the procedure for carrying out the test.[2]

c. As in nature it is found as a pair of covalently bonded atoms, $F_2(g)$.

d. [Reactive metals like sodium readily give away electrons.[1]] [On the other hand reactive non-metals like fluorine gas readily accept electrons.[2]]

- I understand that reactive metals give away electrons.[1]
- I understand that reactive non-metals accept electrons.[2]

FROM LESSONS 1B, 2A & 3B

Chapter 3 review

Multiple choice

1. D. The reactivity of metals depends on their ionisation energy.

2. D. The reactivity of metals increases going down a group.

3. B. Rust forms when iron is exposed to oxygen and water over a certain period of time.

4. C. A high melting point is an indicator of the strength of the metallic bonds between metal atoms.

5. B. It is important that the complete life cycle of the chemical product is mapped out.

6. A. Metals are able to conduct electricity due to the movement of delocalised electrons.

7. B. When metals and an acid react, hydrogen gas is produced.

8. A. Linear is an open cycle where products are disposed of.

9. C. Reactivity depends on the ionisation energy of a metal.

10. C. The delocalised electrons in metals are responsible for many of their unique properties including lustre and heat conductivity.

Short answer

11. a. [Copper → Used in electrical wiring due to high conductance.[1]]
[Gold → Found in the Earth as a pure metal.[2]]
[Aluminium → Resistant to corrosion due to a strong oxide layer.[3]]
[Iron → Most recycled material on Earth.[4]]
[Sodium → Reacts rapidly with water producing hydrogen gas.[5]]

- I have identified the electrical properties of copper.[1]
- I have identified the unreactive nature of gold.[2]
- I have identified that aluminium is a reactive metal but its surface is protected.[3]
- I have identified that iron is the most commonly used metal on Earth.[4]
- I have identified that sodium is very reactive.[5]

b. i. [Finite resources of bauxite.[1]][Extracted at 950 °C – large amount of energy required.[2]][More expensive.[3]] [Conserves resources.[4]][Cheaper to recycle.[5]] [Less electricity needs to be used than original extraction of aluminium from bauxite.[6]]

- I have referred to one reason based on the extraction processes.[1]
- I have referred to a second reason based on the extraction processes.[2]
- I have referred to a third reason based on the extraction processes.[3]
- I have referred to one reason based on the recycling processes.[4]
- I have referred to a second reason based on the recycling processes.[5]
- I have referred to a third reason based on the recycling processes.[6]

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ii. [Cryolite reduces the melting point of impure aluminium oxide by around 1300 °C which saves a lot of energy.[1]] [Melting scrap aluminium requires around 250 °C less to melt it which saves energy.[2]]

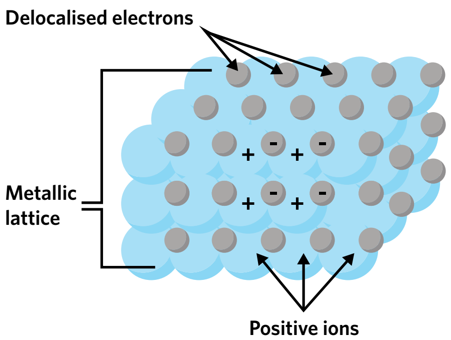
- I have quoted the temperature values when cryolite is used and its effect on energy use.[1]
- I have quoted the temperature values when scrap aluminium is used and its effect on energy use.[2]

iii. [Renewable resources (e.g. solar energy) to provide the electrical energy supply.[1]] [Increase the amount of aluminium that is recycled by doing a regional or national campaign.[2]] [Use renewable fuels in the machinery that is used to extract and recycle the aluminium.[3]]

- I have described how energy can be supplied by alternative renewable fuels.[1]
- I have suggested how more aluminium could be recycled.[2]
- I have described how machinery could be supplied by alternative renewable fuels.[3]

12. a. An alloy is a mixture consisting of a metal physically combined with another element which may be another metal or even a non-metal (normally carbon).

b. [Metallic bonding consists of metal cations in a lattice structure surrounded by a 'sea' of delocalised electrons as shown in the diagram.[1]] [In order to conduct electricity, there needs to be the flow of charged particles within the substance.[2]] [In the case of metals, they can conduct electricity because of the 'sea' of delocalised electrons, which are able to flow throughout the metallic lattice, carrying charge and, therefore, electricity.[3]]



- I have described the model of metallic bonding.[1]
- I have described the requirements for a substance to conduct electricity.[2]
- I have justified why metals are able to conduct electricity.[3]
- I have included a diagram.

c. The wires of a pacemaker need to be malleable to be inserted through the irregularly shaped veins and arteries of the body.

13. a. [Barium would have the greatest reactivity.[1]] [Although all three elements are found in the same group, barium contains more occupied energy shells than beryllium and magnesium. As a result, the valence electrons are further away from the nucleus of the barium atom and are therefore held less strongly to the atom. Subsequently, valence electrons of barium are lost more easily, making it highly reactive.[2]]

- I have identified the element with the greatest reactivity.[1]
- I have explained the difference in reactivity based on the number of energy shells of the atom.[2]

b. [$Ba(s) + 2H_2O(l) \rightarrow Ba(OH)_2(aq) + H_2(g)$.[1]] [If a flame were placed inside the test tube, a 'pop' would be heard due to the ignition of hydrogen gas.[2]]

- I have included a balanced equation.[1]
- I have identified the effect of placing a flame close to the reaction.[2]

c. [Over time, metals exposed to the atmosphere will start to react with oxygen and start to form metal oxides and, therefore, the metals will start to corrode.[1]] [This could be used to determine the reactivity of metals by comparing the times at which they react and form metal oxides.[2]] [Barium is predicted to react first with oxygen according to the equation: $2Ba(s) + O_2(g) \rightarrow 2BaO(s)$.[3]] [Magnesium will be predicted to react next with oxygen according to the equation: $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$.[4]] [Finally, beryllium will be the last to react with oxygen according to the equation: $2Be(s) + O_2(g) \rightarrow 2BeO(s)$.[5]]

- I have identified what will happen when metals are left outside.[1]
- I have explained how this could be used to determine the reactivity of metals.[2]
- I have given the reaction between barium and oxygen.[3]
- I have given the reaction between magnesium and oxygen.[4]
- I have given the reaction between beryllium and oxygen.[5]

Key science skills

14. a. [Validity means whether the experimental technique can support the aim or, in this case, whether practising with sodium is helpful before handling caesium.[1]] [This is a valid technique because sodium is another highly reactive metal in group 1, but it is less reactive than caesium and therefore is safer to use.[2]]

- I have defined validity.[1]
- I have identified whether this technique is valid.[2]

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b. [Accuracy relates to how close a value is to the true value, whereas precision relates to how close results are to each other.[1]] [In this case, atomic clocks could be accurate but they don't have to be precise because different clocks could be accurately timekeeping but not showing the exact same reading (i.e. they may be in different locations).[2]]

- I have defined accuracy and precision.[1]
- I have explained why accuracy does not necessarily result in precision.[2]

15. a. Atmospheric pressure in the lab.

b. [The different samples of metals.[1]] [The relative amount of hydrogen gas bubbles produced.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variable.[2]

c. [Surface area is not the same as mass and this will affect the rate at which bubbles are produced.[1]] [It is very difficult to control or measure the surface area of each different sample.[2]]

- I have identified another variable.[1]
- I have explained why it cannot be controlled.[2]

d. Measure the volume of gas produced quantitatively rather than qualitatively using some sort of gas syringe to measure the volume of gas in mL.