13 Properties of Metals

Introduction

Metals and alloys are important materials and have a wide variety of uses in our daily life. Since the uses of metals depend on their properties, this chapter investigates the physical and chemical properties of metals. And as the properties of metals depend on their structures (introduced in Chapter 7), the structure of alloys is also studied. From the chemical reactions of metals, the reactivity series is deduced and applied. The rusting of iron is also investigated together with methods of preventing rusting.

Chapter Opener (page 189)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

   What is a physical property?

   Answer: A physical property is a property that can be observed or measured without the substance changing into another substance. Copper is ductile and is a good conductor of electricity. These qualities make it useful for use as circuit wires.

   What is the reactivity series? What evidence is there for the order of the metals in the series?

   Answer: The reactivity series is the order by which metals are listed according to their chemical reactivity. Evidence for the reactivity series comes from the reactions of metals with water and dilute acids (refer to Section 13.3 on pages 195–196 of the Textbook).

   What is rusting? What is one method to prevent rusting?

   Answer: The reaction of iron and steel with air and water. Painting can be used to prevent rusting. The surface of the metal is covered with a layer of paint.

2. Carry out an 'Inquiry Preview.'

Stimulation

Here are two ways to introduce this chapter:

Show the class a selection of some common objects made of metals (or alloys). These objects should have properties that are easily observable. For example, gold/silver jewellery can be used to show that metals are shiny, iron to show that metals are strong, circuit wires to show that metals are good conductors of electricity and aluminium drink cans can be used to show that metals have low density and do not corrode. Get the class to suggest the properties of the metals that these uses depend on. You may want to show the class photographs of metal objects used in ancient times to illustrate the historical uses of metals.

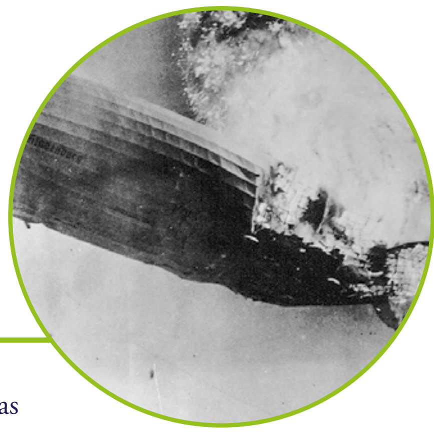
Learning Outcomes

After completing this chapter, students should be able to:

- describe the general physical properties of metals
- describe an alloy and give examples of alloys
- identify representations of metals and alloys from diagrams of structures
- explain why alloys have different physical properties to their constituent elements
- place common metals in order of reactivity by reference to reactions with water, steam, dilute hydrochloric acid and to the reduction of their oxides by carbon and/or hydrogen
- deduce the order of reactivity from a given set of experimental results
- relate the order of metals in the reactivity series to the tendency of a metal to form its positive ions
- describe, with examples and equations, how a more reactive metal can replace a less reactive metal from solution and from metal oxides
- describe the action of heat on carbonates of metals and relate thermal stability to the reactivity series
- describe the essential conditions for the corrosion (rusting) of iron
- describe, with examples, the prevention of rusting using the barrier method and by sacrificial protection

Teaching Notes for

ChemMystery (page 190)



The Hindenburg mystery — what caused the disaster?

There has always been speculation as to the precise cause of the Hindenburg disaster and it has remained something of a mystery. The account discussed here suggests one possible cause that is related to reactions of metals and the reactivity series.

Initial Investigation

- Hydrogen gas has the lowest density of any other substance. It therefore provides excellent lift in airships.
- Airships could travel long distances such as from Europe to the United States which aircraft of the time were unable to do.

Teaching pointers

13.1 What are the Physical Properties of Metals? (page 191)

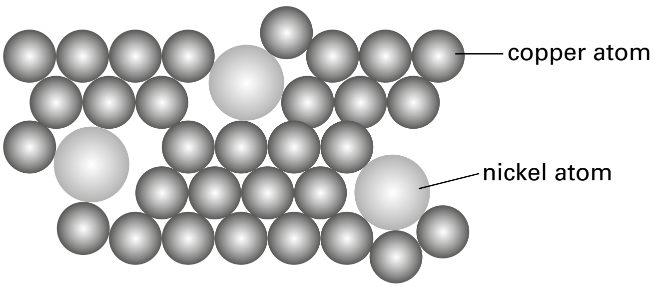
1. Revise the physical properties of metals which were studied in Chapter 7. Link the properties of metals to their structures. A unique feature of metals is that they conduct electricity when in the solid state. This is sometimes taken to be the definition of a metal.
2. Metals are often regarded as being strong. Students may be surprised to know that pure metals are, in fact, somewhat weak. All the 'strong' metals we come across in our daily life are actually alloys.
3. Gold is the most ductile metal. One gram of gold can be drawn to give up to 2400 metres of gold wire.
4. Discuss the structure of an alloy and compare it to the structure of a metal. Discuss how the change in structure affects the physical properties of the metal.
5. Copper and brass (an alloy of copper) can be used to show the difference between a pure metal and an alloy. A strip of brass is much harder and stronger than a strip of copper. It is easier to bend and stretch a piece of copper than a piece of brass. Discuss the difference in their properties in terms of their different structures.
6. Additional Exercise 1 at the end of this chapter compares different kinds of bronze, a widely used alloy of copper. The worksheet may be photocopied and distributed to the class.

Skills Practice (page 166)

1. A physical property of a substance is a property that can be observed or measured without the substance changing into another substance. A chemical property of a substance is a property that describes the change of a substance into another substance.
2. Iron rusts.
3. For example, gold is ductile and shiny, copper is a good conductor of electricity, iron is strong etc.
4. Metals are malleable. In the case of aluminium (which most drink cans are made of), it has a low density.

   Note: Aluminium exhibits corrosion resistance but this is a chemical property.
5. **(a)** Alloy

   (b)



Note: The diagram is not drawn to scale.

Notes for Teachers

Gold and silver alloys

Pure gold is very soft and malleable and so is used to cover the surface of objects, buildings and statues. Gold is alloyed with copper to make it harder. Most gold jewellery is made from gold alloy. The purity of gold is given a carat value, which indicates the proportion of the metal in an alloy. Pure gold is 24-carat. An 18-carat gold object is 18 parts of gold and 6 parts of other metal, i.e. it is 75% gold by mass. Thus 22-carat gold is 91.6% gold. Pure silver is also too weak to be made into jewellery. A lot of silver jewellery sold today is actually an alloy containing 82.5% silver by mass.

Note: The carat is also a unit of mass for precious stones. 1 carat = 200 mg. Thus, a diamond weighing 100 carats is 20 000 mg or 20 g.

Teaching pointers

13.2 What are the Chemical Properties of Metals? (page 192)

1. Teachers often overlook the teaching of the *meaning* of the term 'reactivity'. The reactivity of a metal is related to the speed of the reaction and how much energy is given out. In general, a more reactive metal reacts faster and gives out more heat or light. For example, the reaction of potassium with water is faster than the reaction of lithium with water.
2. If a large piece of potassium or sodium is added to water, an explosion will occur. Show the class videos showing such reactions in the following websites:
   http://www.tb3.com/pyro/
   http://www.theodoregray.com/PeriodicTable/Stories/011.2/
   http://www.powerlabs.org/chemlabs/sodium.htm

   Note: The demonstrations shown on these videos are dangerous and should **not** be attempted at school.
3. For reactions of metals with dilute acids, only dilute hydrochloric acid is used. Refer to 'Notes for Teachers' on the next page for the reasons other acids are not used.
4. In the discussion of the reaction of metals with acids, do not discuss the effect of concentration of acid on the vigour of the reaction.

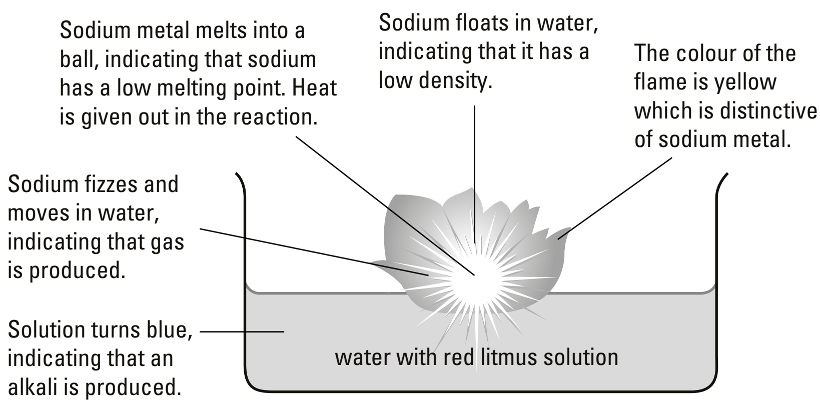
Practical Workbook (page 61)
• **Experiment 2.2**

Reaction of sodium with water
Demonstrate the reaction of sodium with water in a large bowl behind a safety screen. Add red litmus solution (or paper) to illustrate the formation of an alkali. Refer to the diagram below for the important points to emphasise.

Note: Students have not formally studied alkalis in this course yet; their knowledge therefore is based on the work done in Lower Secondary Science.

Safety precautions

As sodium and potassium react vigorously with water, the reactions between these metals and water are potentially hazardous. Special care must be taken when performing these reactions.



Some of the precautions are:

(i) Perform the experiment behind a safety screen.

(ii) Wear safety goggles and rubber/plastic gloves.

(iii) Use pieces of sodium and potassium about the size of a grain of rice.

(iv) Do not attempt to collect the hydrogen gas given off during the reactions.

(v) Place sodium or potassium on the surface of water in a large trough and not a beaker. Also, do not cover the trough while the reaction is proceeding.

(vi) Do not use old or deteriorated stocks of the metals for the experiments.

Skills Practice (page 195)

1. The reactivity of copper with water is very low.
2. For those metals mentioned in Table 13.2 on page 193 of the Textbook:
   (a) potassium, sodium, calcium, magnesium (very slightly)
   (b) zinc and iron
   (c) lead, copper, gold
3. Solutions of potassium hydroxide and sodium hydroxide are formed. These solutions are alkalis and turn the colour of litmus from red to blue.
4. For those metals mentioned in Table 13.3 on page 194 of the Textbook:
   (a) calcium, magnesium, zinc (moderately fast)
   (b) iron, lead
   (c) copper, gold
5. **(a)** $Ba(s) + 2H_2O(l) \longrightarrow Ba(OH)_2(aq) + H_2(g)$
   (b) $2Al(s) + 6HCl(aq) \longrightarrow 2AlCl_3(aq) + 3H_2(g)$

Notes for Teachers

Reaction of metals with dilute acids

Only dilute hydrochloric acid is used in the reaction with metals as all the chlorides formed in the reactions are soluble in water. Dilute nitric acid is not used as it does not behave like a typical acid. It reacts with metals, including copper, to form nitrogen monoxide gas, NO, instead of hydrogen. However, very dilute nitric acid does behave as a typical acid but the reactions are slow. Dilute sulfuric acid is not used as the common metals such as calcium and lead produce insoluble sulfates which form a protective layer around the metal, preventing further reaction.

Teaching pointers

13.3 What is the Reactivity Series? (page 195)

1. Remind students that finding patterns is an important part of the scientific method. The reactivity series is an example of an important pattern in science.
2. You may want to demonstrate the reaction of aluminium with water after the protective oxide layer is removed from the surface of the metal. Refer to the 'Notes for Teachers' on the next page for details on how to carry out this demonstration.
3. Experiment 13.2, on page 65 of the Practical Workbook, involves planning and carrying out an investigation and so is suitable for use as practice in Skill 3 for SPA assessment. The procedure is just a slight modification of that used in Experiment 13.1B, but although such a task may appear simple, students can still find it difficult.

(page 195)

Mystery Clue

An insoluble layer of aluminium oxide (Al_2O_3) on the surface of the metal prevents it from reacting with oxygen and moisture in the atmosphere.

Skills Practice (page 196)

1. Caesium is at the bottom of Group I and so will be more reactive than the other Group I metals. It would be placed at the top of the series, above potassium.
2. It would react vigorously and quickly with cold water.
3. It must be near the bottom of the reactivity series, together with copper and gold.
4. Iron; copper; tin; silver; gold
   Note: Tin and silver are very similar in reactivity and could be put together.

Notes for Teachers

Remembering the Reactivity Series
Mnemonics can be used to memorise lists of unrelated words. A useful mnemonic for remembering the reactivity series is as follows:

"Please send candles, matches and zebras in the long hand cart. My sincere gratitude, Patrick."

P: Potassium
S: Sodium
C: Calcium
M: Magnesium
A: Aluminium
Z: Zinc
I: Iron
T: Tin
L: Lead
H: Hydrogen
C: Copper
M: Mercury
S: Silver
G: Gold
P: Platinum

Demonstration: Reaction of aluminium with water
If a piece of aluminium is rubbed with cotton wool soaked in mercury(II) chloride, $HgCl_2$, the oxide layer is removed. The aluminium then feels hot to the touch due to the reaction of the exposed metal with oxygen in the air. In about 30 minutes, the oxide will have covered the aluminium again. The cleaned aluminium will react very slightly with water but will react with steam. As mercury salts are toxic, the mercury(II) chloride solution must be handled with protective gloves.

Teaching pointers

13.4 What are Some Applications of the Reactivity Series? (page 197)

1. Displacement reactions were introduced in Chapter 12. Refer back to these. Displacement reactions involving metals and halogens should be compared.
2. The loss and gain of electrons is used in the Textbook to explain the reaction of zinc with copper(II) ions. This is the basis of ionic equations and redox reactions which will be introduced later in Chapters 15 and 19 respectively. Do not mention these ideas now. Allow students to first develop a good understanding of metal displacement reactions and become familiar with writing chemical equations for these reactions.
3. Experiment 13.3 of the Practical Workbook involves prediction using the displacement series. Most students find this activity very interesting. An additional, optional experiment is described in 'Notes for Teachers' on page 188.
4. **(a)** Discuss the thermite reaction in "Chemistry in Society". Refer also to Additional Exercise 13.1 at the end of this chapter on this reaction and its use in the welding together of railway lines. The worksheet for this exercise may be photocopied and distributed to the class.

(b) Teachers might like to demonstrate the thermite reaction. Carry out the demonstration behind a safety screen and while wearing protective gear. Alternatively, show a video of the reaction from the Internet. Students can then answer the questions on the worksheet.

5. Experiment 13.3B of the Practical Workbook is another exercise involving planning and carrying out an investigation and so can be used as a practice in Skill 3 of the SPA assessment. The experiment involves the ideas of a fair comparison (controlling variables) and speed of reaction. Although students have not formally studied speed of reaction, they will still have enough general experience to carry out the investigation.

6. At the end of this chapter, two additional experiments on the reactivity series are provided to match the topics on page 199 of the Textbook:
   - Additional Experiment 1: Reaction of Metal Oxides with Carbon.
   - Additional Experiment 2: Investigating the Decomposition of Metal Carbonates

   The worksheets can be photocopied and distributed to the class.

Chemistry in Society (page 198)

Joining Railway Lines Together

Exercise

More railway lines could be built to serve the population better and also alleviate any crowding conditions in the other lines. The lines can also be checked regularly for physical defects such that these can be remedied.

(page 198)

Mystery Clue

When heated, a reaction the same as the thermite reaction described in the "Chemistry in Society: Joining Railway Lines Together" would have occurred.

Skills Practice (page 200)

1. **(a)** A reaction takes place in **(a)** and **(d)** only.
   For **(a)**, iron will displace copper from its solution as iron is above copper in the reactivity series.
   For **(b)**, tin will not displace magnesium from its solution as tin is below magnesium in the reactivity series.
   For **(c)**, copper will not displace tin from its solution as copper is below tin in the reactivity series.
   For **(d)**, magnesium will displace tin from its solution as magnesium is above tin in the reactivity series.

2. A reaction takes place in **(a)**, **(b)** and **(d)**.

3. Silver carbonate will decompose very easily when warm as silver is near the bottom of the reactivity series.

4. **(a)** Magnesium displaces copper from (i) an aqueous solution of copper(II) ions and (ii) copper(II) oxide.
   (b) Magnesium is more reactive / higher in the reactivity series than copper.
   (c) **(i)** $Mg(s) + CuSO_4(aq) \longrightarrow MgSO_4(aq) + Cu(s)$
   (ii) $Mg(s) + CuO(s) \longrightarrow MgO(s) + Cu(s)$

5. **X**, **Z** and **Y** (**X** is the most reactive).

6. **(a)** $2PbO(s) + C(s) \longrightarrow 2Pb(s) + CO_2(g)$
   $2ZnO(s) + C(s) \longrightarrow 2Zn(s) + CO_2(g)$
   (b) Lead(II) oxide is reduced more easily as lead is lower than zinc in the reactivity series.

7. Copper(II) carbonate (decomposes most easily), lead(II) carbonate, magnesium carbonate, calcium carbonate.

Notes for Teachers

Optional experiment: Locating the position of a metal in the reactivity series
Provide students with aqueous nickel(II) sulfate (~1 mol/dm^3) and a piece each of magnesium ribbon, zinc, iron and copper. Ask them to use only these substances to locate the position of the metal nickel in the reactivity series. Nickel metal is not provided.

This can be done by adding the metals one at a time to the nickel(II) sulfate solution and observing whether or not a displacement reaction occurs. Magnesium, zinc and iron displace nickel from nickel(II) sulfate. Copper does not displace nickel. Therefore, nickel must be located below iron but above copper in the reactivity series. Observe the reactions when magnesium, zinc and iron displaces nickel from nickel(II) sulfate. Magnesium displaces nickel readily, zinc displaces nickel less readily and iron displaces nickel slowly. Thus, the decreasing order of reactivity of nickel and the other four metals is: magnesium, zinc, iron, nickel and copper.

IT Link

Simulation of displacement series of metals

Zinc displacing copper from solutions of its ions:
http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/redox/home.html

http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/animations/ZnCutransfer.dcr

Lead displacing silver from a solution of its ions:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/PbAgtransfer.dcr

Videos of the thermite reaction
http://www1.chem.leeds.ac.uk/delights/animations/thermite.html

http://www.tb3.com/pyro/thermite_rxn.mov

http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/019_THERMITE.MOV

Teaching pointers

13.5 What is Rusting? (page 197)

1. Bring some rusted objects into the classroom. Ask the class what has happened to these objects (they have all rusted) and what they are made from (iron or steel). If possible, scrape some rust off the surface of these objects to show that rust falls easily thus exposing the fresh metal. The fresh metal forms rust again and so the process continues.
2. Distinguish between the terms corrosion (a general term) and rusting (a specific term for the corrosion of iron).
3. Experiment 13.4 in the Practical Workbook investigates the factors that are needed for rusting. This experiment also involves the concept of a 'fair' experiment through the control of variables. Spend some time discussing this.
4. A useful activity is for students to look up the following websites on student research into the corrosion of iron to see how other students have designed and carried out an experiment to investigate this.

   http://webcache.googleusercontent.com/search?q=cache:http://youth.net/nsrc/sci/sci030.html

   Title: What Substances Prevent Rust On Metal Nails?

   http://webcache.googleusercontent.com/search?q=cache:http://youth.net/nsrc/sci/sci.012.html

   Title: The Prevention of Oxidation
5. Refer the cost of rusting both to society and to the individual (e.g., discuss the cost of replacing a rusted bicycle or other object) and thus the need to prevent rusting. Surface protection has many applications in our daily life.

   Note: A paint covering is not impervious, so some water and air still get through.

6. Get the class to list common ways used in daily life to prevent rusting by surface protection. Examples are:
    - Use of paint — steel pipes, iron roof, the car, some chair legs.
    - Oil — door and window hinges.
    - Plastic covering — steel paper clips, steel handles.
    - Metal covering — steel cans (tin plating), some chair legs, door knobs, handles, parts of bicycles (chromium plating).
7. Metal plating with tin and zinc is carried out by dipping the steel into the molten metal. Chromium and silver plating is carried out by electroplating (see Chapter 22).
8. Students need to have only a simple understanding of sacrificial protection. Note that in the protection of underground pipes on page 202 of the Textbook, magnesium is used rather than zinc as it is a better sacrificial metal. However, its use necessitates a more frequent replacement of the magnesium metal.

    For underwater pipes, where maintenance is more difficult, zinc rather than magnesium is usually attached to the pipes.

    Note: As galvanising completely covers iron with zinc, it can also be classified as surface protection by metal coating.
9. As stainless steel is expensive, it is usually used for making small objects such as tools and cutlery.
10. Activity 13.3 of the Theory Workbook involves a problem-solving task involving the choice of a suitable method for protecting underground steel gas pipes from rusting.
11. An additional experiment on problems involved in rusting is provided at the end of this chapter. The worksheet may be photocopied and distributed to the class. See also the notes below on this experiment.

Additional Experiment 3: Problems on Rusting

This experiment involves the design and carrying out of experiments to investigate two questions related to rusting. Question 1 can be a modification of Experiment 13.4 in the Practical Workbook. For Question 2, not all five of the methods given need be compared. For this experiment, teachers might introduce the use of a 'rust indicator.' Suggested answers for Question 1 in the experiment are given in the teacher's edition of the Practical Workbook. Suggested answers for Question 2 and the use of rust indicator are given below.

Suggested teaching and learning sequence

Lesson 1 (1 period)
The teacher introduces the activity.
Students, in groups, choose the activity they would like to investigate and begin to discuss the planning of the investigation

Preparation before lesson 2
Students complete their project proposal, discuss it with the teacher and make any necessary changes.
Students' lists of apparatus and materials are handed to the laboratory technician.

Lesson 2 (1 period)
In the laboratory, groups set up their apparatus.
Students then observe the formation of rust over the next few days.

Lesson 3 (1 period)
Groups complete their investigation in the laboratory.

Follow-up activities
Groups prepare a written report of their investigation.

Suggested design for Question 2

Defining the problem
E.g. Not all methods are equally effective in the prevention of iron nails from rusting. Which of the following five methods is the most effective: paint, grease, a plastic covering, a layer of copper or a layer of magnesium?

Plan
Apparatus and materials
E.g. Six test-tubes with stoppers, test-tube rack, 4 iron nails, 1 painted nail, 1 nail covered in light plastic tubing, copper foil strip and magnesium ribbon (long enough to wrap around the iron nails), grease.

Safety precautions
No special precautions needed.

Procedure
1. Prepare the 6 nails as follows:
   - Use one painted nail.
   - Cover one nail with grease.
   - Cover one nail with plastic tubing.
   - Wrap the copper strip around one nail.
   - Wrap the magnesium ribbon around one nail.
   - Use one untreated nail as a control.
2. Place each nail in a test-tube of tap water.
3. Leave the test-tubes for several days, long enough to observe rusting. Observe any appearance of rust around the nails.

Observations
E.g. Most rusting occurs around the nail coated with copper. Least rusting occurs around the nail covered with magnesium.

Note: Results may vary, depending for example, on how well the magnesium and copper are attached to the nails.

Conclusion
E.g. Iron covered with a layer of magnesium is the best way to prevent rusting.

Use of a rust indicator

Potassium hexacyanoferrate(III) solution gives a blue colour with iron(II) ions, which are produced during the rusting process. Hence, it can be used as a 'rust detector'. The darker the blue colour, the greater is the rusting. If potassium hexacyanoferrate(III) solution is used, pour a little of the dilute solution into each test-tube, instead of water, so that it just covers the nails. The rust indicator should be treated like any other indicator, such as phenolphthalein. Do not go into the chemistry of potassium hexacyanoferrate(III).

Chemistry Inquiry (page 203)

Which Method Would You Choose to Prevent Rusting?

Group Discussion

1. E.g. Oil/grease — washed off too easily; people who touch the bridge will get dirty. Use a spray covering of plastic — may look unattractive and 'cheap'. Connection to underground blocks of magnesium or zinc (sacrificial protection) — expensive as the metal blocks need to be replaced at intervals
2. Metal (tin/chromium/silver) plating, galvanising, use of stainless steel — must be done to steel before the bridge is constructed and not when it is already in place. Also, stainless steel would be too expensive.
   Refer also to the answers to Skills Practice Questions 2 to 5.

Skills Practice (page 183)

1. **(a)** The Sahara desert is very dry. Rusting occurs in the presence of water. Hence, the lack of water means little or no rusting.
   (b) As the air in Singapore is humid, both water and oxygen are present so rusting occurs. (The warm temperatures also increase the speed of the rusting.)
   (c) There is no air or water on the moon and so no rusting.
2. Food cans are made of iron covered with a thin layer of tin. When the surface is scratched, the iron is exposed to air and rusting can occur. Galvanised iron is steel coated with zinc metal. The zinc protects the iron by corroding in place of the iron. Even if the zinc layer is broken or scratched, and air and water reaches the iron underneath, the zinc still protects the steel.
3. **(a)** Magnesium, as it is higher in the reactivity series than zinc.
   (b) Zinc is cheaper than magnesium, so it is used to completely cover the metal sheets.
4. **(a)** Metal plating
   (b) Metal plating
   (c) Oil or grease
   (d) Paint
   (e) Use of stainless steel
5. **(a)** Paint and zinc can wear off the steel and this will then result in rusting. When the paint and zinc are worn away, they will need to be replaced. Stainless steel tends to last forever. Also, stainless steel has an attractive shiny appearance but paint and zinc can become dull.
   (b) Stainless steel is expensive.

Notes for Teachers

Cavenagh Bridge
This was one of the first steel bridges to be constructed in Singapore and used to be the bridge across the Singapore River. The steel is protected from rusting by paint. Major General Orfeur Cavenagh, Governor of the Straits Settlements, erected the bridge in 1867.

Additional teaching pointers of preventing rusting

- Surface protection: When paint dries, it flakes off or can be rubbed off. When plated steel are scratched, protection is also lost. In both cases the bare metal is exposed to air and water and will rust.

  Oil and grease and not paint are used on moving gears and chains as they flow and continually spread over the gear wheels and chain.
- Sacrificial protection: Calcium is more effective than magnesium or zinc is preventing rusting as it is higher in the reactive series. However, it is not used as it reacts too quickly with cold water so would soon be removed from the steel objects by rain water for objects exposed to the weather.

13 Chapter Review

Self-Management

Misconception Analysis (page 204)

1. **True** Pure metals are usually too soft to be useful. Most alloys are harder and stronger and so are more useful. For example, steel is stronger than iron and so can be used to make bridges and cars.

2. **False** Metals, such as copper, that are low in the reactivity series, do not react with water and dilute acids.

3. **False** Metals below potassium in Group I, such as caesium, are more reactive than potassium.

4. **False** Aluminium is quite high in the reactivity series, but does not react with water or steam because of a surface layer of aluminium oxide that protects the metal from reacting. If this layer is removed, aluminium will react vigorously with steam.

5. **True** Metals react by losing their outer shell electrons. The more readily metals lose their valence electrons, the more reactive the metal and hence the higher its position in the reactivity series.

6. **False** At Bunsen burner temperatures, carbon cannot react with oxides of metals near the top of the reactivity series such as calcium and sodium. (At very high temperatures, however, a reaction may occur.)

7. **False** Rusting require the presence of both air and water.

8. **True** This is the idea of sacrificial protection; the metal higher than iron in the reactivity series reacts instead of iron.

Practice

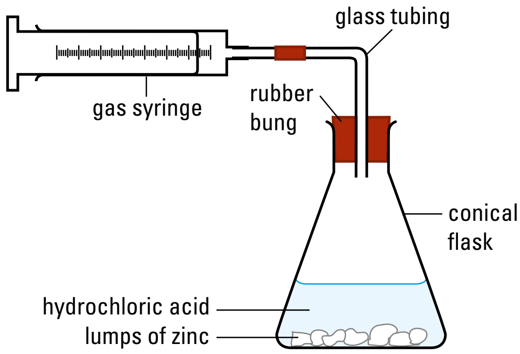
Structured Questions (page 205–206)

1. (a) **C**, **D**, **E**, **A**, **B**
   (b) **E**
   (c) **B**
   (d) Sodium or potassium

2. (a) (i) The surface of the aluminium is covered with a thin layer of aluminium oxide that prevents the metal underneath from reacting.
   (ii) The oxide layer must be removed, e.g. by rubbing its surface with mercury(II) chloride.
   (iii) $2Al(s) + 3H_2O(g) \longrightarrow Al_2O_3(s) + 3H_2(g)$
   (b) (i) $2Al(s) + 3CuSO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3Cu(s)$
   (ii) Aluminium takes the place of copper in the aluminium sulfate.
   (iii) E.g. Aluminium does not react with a solution of calcium ions, as aluminium is lower in the reactivity series than calcium.

3. (a) Scandium, zinc, iron, nickel, copper (Scandium is the most reactive.)
   (b) $2Sc(s) + 3CuO(s) \longrightarrow Sc_2O_3(s) + 3Cu(s)$

4. (a) Copper cannot be used because it does not react with hydrochloric acid. Sodium cannot be used because it is too reactive and might explode with the acid. Zinc is suitable because it will produce a slow stream of hydrogen gas.
   (b) $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$



5. (a) (i) Alloys are stronger than pure metals. A pure metal would be too weak.
   (ii) Zinc
   (b) (i) Brass
   (ii) Copper and zinc
   (c) Chromium must be relatively unreactive and not react with water.
   (d) Chromium is above iron but below zinc in the reactivity series.

6. (a) Fuels tanks are placed underground to keep them cooler, to be away from flames and to save space.
   (b) Both air and water are present in soil.
   (c) (i) Zinc or magnesium
   (ii) The more reactive zinc/magnesium corrodes instead of the iron. This is an example of sacrificial protection.
   (iii)

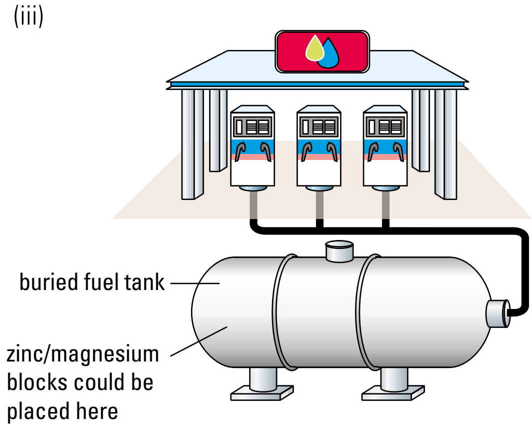


Figure 13.25

Magnesium/Zinc blocks can be attached to the outside of the steel tank.

(d) (i) Stainless steel is very resistant to rusting.
(ii) Stainless steel is very expensive. It is cheaper to replace the steel tanks from time to time.

7. (a) The nails are in contact with copper.
(b) Painting prevents the copper from touching the iron nails.
(c) (i) Zinc could be attached anywhere on the unpainted copper sheet.
(ii) The more reactive zinc reacts instead of the iron nails.
(d) Attaching lumps of zinc is the preferred method. They are easy to replace when they are used up. Painting is not the preferred method as the copper sheet must be painted carefully where it is in contact with the nails. Moreover, the paint can come off easily.

Free Response Questions (page 206)

1. Responses may include the following points:
   – Metals above nickel in the reactivity series will replace nickel from solutions of its compounds/salts.
   – Metals below nickel in the series will not replace nickel from solutions of its compounds.
   – Add metals in the middle of the reactivity series such as zinc, iron and tin to a solution of nickel(II) sulfate.
   – Observe which metals react with the solution/displace nickel and which do not react.
   – Look for a metal with which it reacts followed by a metal in the series with which it does not react.
   – Place nickel between these two metals.

2. Responses may include the following points:
   – Discuss several methods that can both prevent rusting and make the object look attractive, such as painting, use of plastic covering, chromium plating and use of stainless steel.
   – Discuss both the advantages and disadvantages of these methods, such as the relative attractiveness, the degree of resistance to rusting, the cost and how long the rust prevention can be effective.
   – Choose a method with reasons. Various choices are possible; reasons will depend on the method chosen. For example, painting may be suitable if the chairs are not expected to last for very long as it is a very cheap method.

Extension (page 188)

1. **What is the Question?**
   Some possible answers:
   (a) Name the product, other than zinc sulfate, of the reaction between zinc and copper(II) sulfate solution.
   (b) Name the product, other than magnesium sulfate, of the reaction between magnesium and copper(II) sulfate solution.
   (c) Name the product, other than zinc oxide, when a mixture of copper(II) oxide and zinc is heated together.
   (d) Name the product, other than aluminium oxide, when a mixture of copper(II) oxide and aluminium is heated together.

2. **Discussion**
   Here are a number of points that you may consider when preparing for the discussion.
   - Ensure the class has sufficient background to be able to discuss the topic.
   - Decide on the number of students per group (3–4 is usually suitable) and whether a chairperson and/or note taker will be required.
   - Prepare some points beforehand, but only use them to assist students if they cannot think of points themselves or miss one or two key points. If students have no difficulty generating ideas, you need not provide any points.
   - During group discussions, you may like to move from group to group, listening to what is being said but giving suggestions only if necessary to stimulate discussion.
   - Be flexible with the time. Shorten or lengthen the time according to the need. Keep in mind that your expectations of the time needed may not correspond to the time students actually need.
   - A brief, oral report from each group to the whole class is useful (this also gives students the chance to develop communicative skills.)

   The discussion may include the following points:
   (a) Factors that need to be considered include: relative attractiveness, degree of resistance to rusting, cost and how long the rust prevention can be effective.
   (b) (i) No protection provide no protection against rusting.
   (ii) Painting is cheap but the paint can come off easily.
   (iii) Connecting the pipes to blocks of zinc provides good protection but the zinc blocks need to be replaced.
   (iv) Using chromium-plated steel looks attractive but is expensive.
   (c) Various choices are possible; reasons will depend on the method chosen.

Additional Teaching Material

Additional Exercise 1: What is Bronze?

Objective

- To compare the compositions of different kinds of bronze alloys

Strategy

CIT: sound reasoning [*comparing*]

Bronze is a widely used alloy. Some of the different types of bronzes are given in the table below.

Name of bronze	Composition of bronze	Example of use
bell metal	78% copper; 22% tin	bells
coinage bronze	95% copper; 4% tin; 1% zinc	copper coins 
phosphor bronze	80% copper; 10% tin; 9% antimony; 1% phosphorous	springs of clocks
aluminium bronze	89% copper; 8% aluminium; 2% tin; 1% zinc	propellers of big ships 
lead bronze	83% copper; 14% tin; 3% lead	bearings for machines
silicon bronze	88% copper; 5% tin; 5% nickel; 2% silicon	corrosion-resistant containers for chemicals

Study the table carefully.

Compare the compositions of the different bronzes and list the ways in which the bronzes are similar and the ways they are different.

You are then to decide a definition for bronze, based on the composition of the alloy.

Use the graphic organiser on the next page to help you.

Comparing

What is the purpose of this comparison? →

Factors

How are they the same?

Factors

How are they different?

Conclusion →

Additional Teaching Material

Additional Exercise 2: Reactivity Series and the Thermite Reaction

Objective

- To investigate the reactions between metals and metal oxides, and to relate them to the reactivity series

Strategy

CIT: sound reasoning [*analysing*]

Some metals react with metal oxides in reactions known as **thermite reactions**. During the process, a lot of heat is given out. One common thermite reaction is the reaction between aluminium and iron(III) oxide to produce iron. This reaction is used for welding railway lines together as shown in the photographs below (Figures 1 and 2).

Figure 1 Molten iron is formed from aluminium and iron(III) oxide.

Figure 2 Gaps between the rails joined together tightly when the iron cooled.

A mixture of aluminium powder and iron(III) oxide is ignited. The iron is formed in the molten state because of the heat produced in the reaction. The molten iron flows into the gap between the rails and, on cooling, welds the rails tightly together.

The thermite reaction can be demonstrated in the laboratory using the following setup (Figure 3). A magnesium ribbon fuse is used to ignite the mixture.

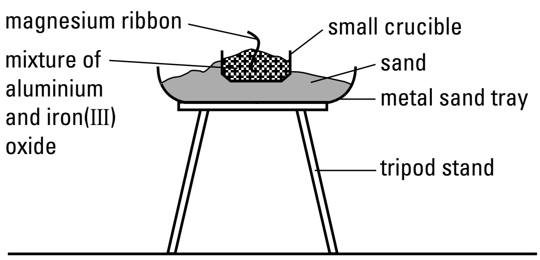


Figure 3 Demonstrating the thermite reaction in the laboratory

Questions

1. Write the chemical equation for the reaction between aluminium and iron(III) oxide powder. Include appropriate state symbols.

2. The thermite reaction is also a displacement reaction. Explain.

3. In the laboratory demonstration, why is the reaction carried out in a sand tray?

4. For safety reasons, a magnesium fuse rather than a match is used to ignite the mixture. Suggest why.

5. If this reaction is demonstrated in front of a class, suggest one other safety precaution that must be taken.

6. The table below shows the results of investigations between other metals and metal oxides. A tick '✓' indicates a reaction took place and a cross '✗' indicates no reaction.

Metal	Symbol	Metal oxide				
		bismuth(III) oxide	**calcium oxide**	**cobalt(II) oxide**	**tin(IV) oxide**	**zinc oxide**
bismuth	Bi	✗	✗	✗	✗	✗
calcium	Ca	✓	✗	✓	✓	✓
cobalt	Co	✓	✗	✗	✓	✗
tin	Sn	✓	✗	✗	✗	✗
zinc	Zn	✓	✗	✓	✓	✗

(a) Place the five metals in order of reactivity (most reactive first).

(b) Which reaction was probably most vigorous? Give a reason for your answer.

(c) Construct the chemical equation for the reaction between zinc and tin(IV) oxide.

Additional Teaching Material

Additional Experiment 1: Reaction of Metal Oxides with Carbon

Aim

- To compare the ease of reaction of metal oxides with carbon

Apparatus and materials

- Bunsen burner
- tripod and wire gauze
- spatulas (4)
- metal caps (from soft drink bottles) (3)
- carbon powder
- copper(II) oxide
- iron(III) oxide
- zinc oxide

Key Competencies

CIT: comparing, inferring
ICS: communicating effectively [*tables, equations*]; collaboration [*working as a team, peer review*]

Safety Warnings

Introduction

In this experiment, you will compare the ease with which the following metal oxides can be changed to the metals by heating with carbon:

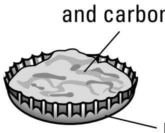
(i) copper(II) oxide
(ii) iron(III) oxide
(iii) zinc oxide

Wear safety googles.

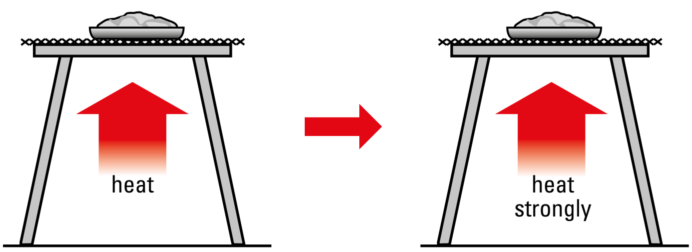
Procedure

1. Remove the plastic disc from the metal cap of a bottle.

2. Mix 2 spatula measures of a metal oxide with 2 spatula measures of carbon powder in the metal cap.



3. Heat the mixture gently (a) at first and then strongly (b).



Do not look directly at the mixture. The mixture may jump out when heated strongly.

4. Allow the cap to cool. Then examine the residue. Look for any evidence of a metal. Record your observations in the table below.

5. Repeat Steps 1 to 4 with each of the other two metal oxides.

Results

Fill in the table below.

Metal oxide	Observations	Does reaction occur?
Copper(II) oxide		
Iron(III) oxide		
Zinc oxide		

Questions

1. In which case does a reaction occur most easily?

2. Based on the experimental results, try to arrange the three metal oxides in increasing ease of the change from the oxide to the metal.

3. Write a balanced chemical equation for the reaction of copper(II) oxide with carbon.

Additional Teaching Material

Additional Experiment 2: Investigating the Decomposition of Metal Carbonates

Aim

- To investigate if there is a relationship between the ease of decomposition and the position of the metal in the reactivity series

Apparatus and materials

- Pyrex glass test-tube
- test-tube
- delivery tube
- limewater
- retort stand
- boss and clamp
- stopwatch
- measuring cylinder (10 cm^3)
- metal carbonate powders
- – copper(II) carbonate
- – zinc carbonate
- – calcium carbonate
- – potassium carbonate

Key Competencies

CIT: creativity [*planning an experiment, defining the problem, inferring, evaluating*]
ICS: communicating effectively [*diagrams, tables, IT software, written report*]; collaboration [*working as a team, peer review*]

Safety Warnings

Defining the Problem

State clearly what you are trying to find out and briefly describe your general approach for the investigation.

Plan

1. **Variables**
   State the control variables in this investigation.

2. **Procedure**
   Describe your method. Be sure to explain how to make a fair comparison.

3. **Safety Precautions**
   What safety precautions, if any, need to be taken in your experiment?

Peer Review

Pass your plan to one or more other groups. Get them to make suggestions on how to improve your original plan. After making any necessary changes, carry out the experiment.

Results

In the space below, record your observations in an appropriate format.

Metal carbonate	Time
Copper(II) carbonate	
Zinc carbonate	
Calcium carbonate	
Potassium carbonate	

Conclusion

Intepret your results and draw a conclusion to answer the question.

____

____

Evaluation

If you were to repeat the experiment with the same compound, suggest some possible ways to improve the experiment.

____

____

____

____

Report

As a group, prepare a written group report on your investigation (using a Word Processor). Be sure to include the aim, procedure, results and conclusion together with other points you think may be interesting.

Last day for handing in the report: ______________________________

Additional Teaching Material

Additional Experiment 3: Problems on Rusting

Aim
- To solve problems related to rusting

Apparatus and materials
- Depend on the design of the experiment

Key Competencies
CIT: creativity [*planning an experiment, defining the problem, making a fair comparison, inferring, evaluating*]
ICS: communicating effectively [*diagrams, tables, IT software, presentation*]; collaboration [*working as a team, peer review*]

Safety Warnings


Introduction
A group of students noted that objects made of iron placed or found near the sea or in places affected by acid rain appear to rust more quickly. They also wanted to know the best way to prevent these objects from rusting. Therefore, they asked two questions about rusting.

1. Do salt water and acid rain make iron objects rust faster?
2. What is the best method to stop iron from rusting? Using paint, grease, a plastic covering, a layer of copper or a layer of magnesium?

Choose one of these questions to investigate.

Our group has chosen Question:

Carefully discuss with your group how to answer the question. Here are some points you will need to pay special attention to.

- How will you carry out a fair test (i.e., control the variables)?
- What will you measure or observe?
- How long will you leave your experiment to obtain results?

Defining the Problem
State clearly what you are trying to find out and briefly describe your general approach for the investigation.
To find out whether iron nails placed in salt water and acid rain rust more quickly than iron nails placed in tap water. The experiment requires nails to be placed in salt water, acid and just water under controlled conditions.

Plan
1. **Apparatus and materials**
List the apparatus, chemicals and other materials you will need.

2. **Safety precautions**
What safety precautions, if any, need to be taken in your experiment?

3. **Procedure**
   Describe your method. Be sure to explain how you will control variables to ensure a fair comparison. Include diagrams of your apparatus.

Peer Review

Pass your plan to one or more other groups. Get them to make suggestions on how to improve your original plan. After making any necessary changes, carry out the experiment.

Observations

Record all your observations.

Conclusion

Interpret your results and draw a conclusion to answer the question.

Evaluation

If you were to repeat the experiment, suggest some possible ways to improve your procedure.

Presentation (Optional)

Your teacher may ask you to give a brief presentation to your class of your experiment and your findings. In your group (and using suitable software if you want), prepare a talk with points such as aim, method, results and conclusion together with other points you think may be interesting. Then make your presentation with each member of the group contributing.

Answers

Additional Exercise 1:

Comparing

What is the purpose of this comparison? → To work out a definition for bronze based on its composition

Factors	How are they the same?
Pure metal or mixture	All are mixtures (alloys).
Elements	All contain copper and tin.
Main elements	They all contain more copper than any other element.

Factors	How are they different?
Elements	Each bronze contains different elements.
Elements	Some bronzes consist of metals while some consist of metals and non-metals.
Percentage of copper	Percentage is different in every type of bronze.
Percentage of tin	Percentage is different in every type of bronze.

Conclusion → All bronzes contain copper and tin and the main element is copper.

Additional Exercise 2:

1. $2A\mathit{l}(s) + Fe_2O_3(s) \longrightarrow A\mathit{l}_2O_3(s) + 2Fe(\mathit{l})$
2. The aluminium replaces the iron(III) oxide.
3. E.g. The sand tray absorbs the heat produced.
4. Using a fuse enables the demonstrator to move well away from the apparatus before the thermite reaction begins.
5. E.g. Place a safety screen between the apparatus and the class./More the class well away from the apparatus./Have a fire extinguisher ready in case of an accident.
6. **(a)** Calcium, zinc, cobalt, tin, bismuth

   (b) Calcium with bismuth(III) oxide as these two metals are furthest apart in the reactivity series.

   (c) $2Zn(s) + SnO_2(s) \longrightarrow 2ZnO(s) + Sn(\mathit{l})$

Additional Experiment 1:

Results

Metal oxide	Observations	Does reaction occur?
Copper(II) oxide	Brownish solid formed	Yes
Iron(III) oxide	No apparent change/Silvery solid formed.	No/Yes
Zinc oxide	No apparent change.	No

Questions

1. The reaction of copper(II) oxide
2. Increasing ease of reaction: Copper(II) oxide, iron(III) oxide, zinc oxide.
3. $2CuO(s) + C(s) \longrightarrow 2Cu(s) + CO_2(g)$

Additional Experiment 2:

Defining the Problem

Most metal carbonates decompose when heated. The products are a metal oxide and carbon dioxide gas. The carbon dioxide can be detected with limewater. If a metal carbonate is steadily heated, the time that is taken for a white precipitate to form with limewater is a measure of the speed of decomposition of the metal carbonate. The shorter the time, the more easily it decomposes. We can find the time it takes to decompose each metal carbonate and compare how easily they decompose.

Plan

1. The control variables are the mass of solid, the volume of limewater and the Bunsen flame used.
2. Weigh out a known mass of metal carbonate, say 1 g. Place the metal carbonate in the Pyrex test-tube in the apparatus. Place 4 cm^3 of limewater in the test-tube. Place a Bunsen flame under the Pyrex test-tube. Start timing. Record the time taken for the first sight of a white precipitate formed with limewater. Repeat with other metal carbonates in turn.
3. E.g. Heat the solids in the test-tube gently at first, so that the gas is not formed too quickly. Be careful not to crack the heating test-tube. Turn off the Bunsen burner when it is not needed.

Results

Metal carbonate	Time
Copper(II) carbonate	45 seconds
Zinc carbonate	100 seconds
Calcium carbonate	970 seconds
Potassium carbonate	does not decompose

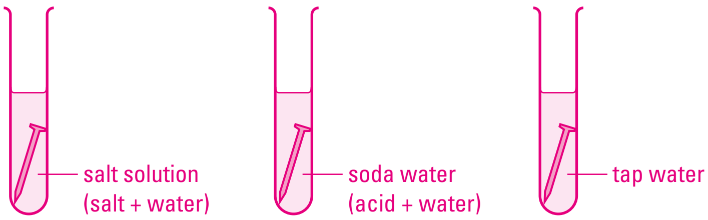
Conclusion

From the analysis of results obtained, there is a relationship and that is the more reactive the metal, the less easily the metal carbonate decomposes when heated.

Additional Experiment 3:

Plan

1. E.g. 1 test-tube rack, 3 test-tubes, 3 iron nails, soda water (to simulate acid rain), seawater or salt solution, tap water.
2. Handle rusty nails with care.
3.
   1. Set up three test-tubes as shown below. Test-tube C is a control — all variables are the same as in test-tubes A and B except for the condition being investigated, that is, the substance that may affect the speed of rusting.
   2. Leave the three test-tubes to stand for three days. Compare the degree of rusting of the iron nails during the three days in all the test tubes.



A
- iron
- water
- air
- salt solution

B
- iron
- water
- air
- soda water ("acid rain")

C
- iron
- water
- air

Observations

E.g. There is more rusting of the iron nails in test-tubes A and B than in test-tube C.

Conclusion

Salt water and acid rain do speed up the process of rusting.