14 Extraction and Uses of Metals

Introduction

There are three related sub-themes in this chapter. First, students are introduced to metal ores and how metals are extracted from them; links are made between the method of extraction and the reactivity series. Second, the uses of metals and how these uses depend on properties are investigated. Finally, the limited reserve of metals and ways of conserving them, including recycling, are studied.

Chapter Opener (page 207)

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

What is an ore (or a metal ore)?

Answer: A metal ore is a rock from which a useful metal is obtained.

What metal is used to make the bodies and wings of most aircraft? What properties of the metal make it useful?

Answer: Aircraft are made of aluminium which is extracted using electrolysis. The aluminium alloys are strong, lightweight and corrosion-resistant. (Refer to Section 14.3 of the Textbook to see the link between the uses of metals and their properties.)

There is a need to conserve metals. What is the reason for this?

Answer: There are limited amounts of metal ores in the Earth. Refer to Section 14.4 of the Textbook for a discussion on metal conservation and recycling of metals.

2. Carry out an 'Inquiry Preview.'

Stimulation

Introduce the topic by showing the class some samples of metal ores such as bauxite, haematite and malachite. Let the class know that metals can be extracted from these ores. During the introduction, explain the terms rock, mineral and metal ore. Then go through the steps in the extraction of a metal from a metal ore as shown in Figure 14.1 on page 208 of the Textbook.

For example,

bauxite (ore) ⟶ aluminium oxide (mineral) ⟶ aluminium (metal)

Learning Outcomes

After completing this chapter, students should be able to:

- describe the ease of extracting metals from their ores by relating the metals to their positions in the reactivity series
- relate the uses of metals to their properties
- describe and explain the essential reactions in the extraction of iron from haematite ore in a blast furnace
- describe steels as alloys with iron, carbon and other elements and how controlled use of these additives changes the properties of the iron
- state uses of different types of steel including mild steel and stainless steel
- describe metal ores as a finite resource and hence elaborate on the need to recycle metals
- discuss some social, economic and environmental issues of recycling metals

Teaching pointers

14.1 How are Metals Obtained from Ores? (page 208)

1. Ask the class the following questions to revise the key ideas needed in studying this chapter:

(a) What is the order of the main metals in the reactivity series?
(b) Where in the reactivity series are
  (i) the most reactive metals, and
  (ii) the least reactive metals?
(c) Name metals that are found as free elements in the Earth. Are these metals very reactive or not?

Answers:
(a) Refer to Figure 13.10 on page 195 of the Textbook.
(b) **(i)** The most reactive metals are found at the top of the reactivity series.
  (ii) The least reactive metals are found at the bottom of the reactivity series.
(c) Examples of metals that are found as free elements in the Earth include copper, mercury, silver, gold and platinum. These metals are very unreactive.

Note: Students may not be aware of all these metals.

2. Ensure that students are able to distinguish between a rock, a mineral and a metal ore. Some students may have the misconception that a metal ore is the mineral in a rock rather than the rock itself. Thus bauxite is a metal ore, a rock from which aluminium is obtained. Bauxite contains one main mineral — aluminium oxide (75% or more by mass) and other compounds. The aluminium oxide is not the ore.

Thus a metal ore = a rock = a useful mineral + waste mineral(s).

3. Discuss the names of metal ores and the main minerals in them. You may carry out an analysis of the names of some metal ores. For example:
   - rock salt (salt = sodium chloride)
   - magnesite (magnesi = from magnesium)
   - limestone (lime = term for calcium compounds)
   - haematite (haem- = of blood)
   - magnetite (from magnet)
   - bauxite (from the village of Les Baux in France)

   Relate the words haematite and haemoglobin. Haematite has a reddish colour like blood.

Skills Practice (page 209)

1. Gold, silver, copper, platinum and mercury are examples.
2. Haematite – iron(III) oxide Fe_2O_3. Magnetite – iron(II, III) oxide Fe_3O_4.
3. HgS.

Notes for Teachers

Notes on metal ores
- Bauxite is about 75% aluminium oxide and 25% iron(III) oxide (hence its red colour).
- Haematite is 85% or more iron(III) oxide.
- Galena is about 15% lead(II) sulfide.
- Copper pyrite is also called copper pyrites and chalcopyrite.
- Free iron is found in meteorites that have fallen onto the Earth from space.
- The names of some ores tell us something about them. For example, the iron ore magnetite is magnetic. (See 'More on bauxite' below.)

More on bauxite

In 1821, P. Berthier discovered a hard, reddish, clay-like material containing 52% aluminium oxide near the village of Les Baux in southern France. Using the name of the village, he called it bauxite, which is the most common ore of aluminium. The reddish colour of bauxite is due to the presence of iron(III) oxide in the rock.

Teaching pointers

14.2 What are Methods of Extracting Metals? (page 209)

1. The method of extraction of a metal from its ore and the position of the metal in the reactivity series is another important pattern in Chemistry.
2. Note: In the mining industry, the overall cost of extraction is a major factor in the choice of method. Thus aluminium could be extracted by heating aluminium oxide with coke. But the cost of getting the high temperatures make the process uneconomical compared with electrolysis. In contrast, using coke to extract iron from iron(II) oxide is cheaper than carrying out electrolysis on the molten ore.
3. Coke is always used in the extraction of less reactive metals whenever possible as it is cheaper than other forms of carbon.
4. The blast furnace gets its name from the hot air that is blasted into it to burn the coke (carbon). Blast furnaces can reach heights of 60 metres or more. They run continuously 365 days of the year. If stopped, the molten steel and slag inside a furnace would solidify and have to be chipped out by hand in order to restart the furnace again.

5. The heat produced in the blast furnace reactions is used to heat the air blasted in from the side. Waste gases produced can cause air pollution as they contain carbon monoxide and sulfur dioxide. The sulfur dioxide causes acid rain.
6. An additional experiment on the extraction of a metal from an ore is provided at the end of this chapter. Refer to the notes below on this experiment. The worksheet may be photocopied and distributed to the class.
7. Two additional activities on the discovery of metals are also provided at the end of the chapter:
   - An additional "Chemistry in Society". This shows a pattern relating the discovery of metals to their position in the reactivity series (i.e. 'the lower the position of a metal in the reactivity series, the earlier it was discovered') and exceptions to this pattern.
   - Additional Exercise 1 on the discovery of metals. This may be used in conjunction with the "Chemistry in Society" material.

Skills Practice (page 211)

1. **(a)** Reduction of metal oxide with coke.
   (b) Physical methods only as platinum is found as a free element in the Earth.
   (c) Reduction of metal oxide with coke.
   (d) Electrolysis.
2. Bismuth is likely to be located at the bottom of the reactivity series, near copper and silver.
3. The blast furnace gets its name from the hot air that is blasted into it to burn the coke (carbon).
4. $Fe_3O_4(s) + 4CO(g) \longrightarrow 3Fe(l) + 4CO_2(g)$

Additional Experiment 1: How Can We Obtain Copper from a Copper Ore?

In this experiment, students plan and carry out an investigation to extract copper from malachite. Although malachite is actually basic copper(II) carbonate $CuCO_3 \cdot Cu(OH)_2$, the copper(II) hydroxide will not affect the results of the experiment.

Suggested teaching and learning sequence
This experiment could be spread over two single periods as follows:

Lesson 1 (1 period)
The teacher introduces the activity and groups begin the planning of their investigation.

Preparation before lesson 2
Groups complete their plan, discuss it with the teacher and make any necessary changes.
Lists of apparatus and materials are handed to the laboratory technician.

Lesson 2 (1 period)
In the laboratory, groups carry out their experiment.

Follow-up activity
Groups prepare a written report.

Notes for Teachers

Discovery of metals

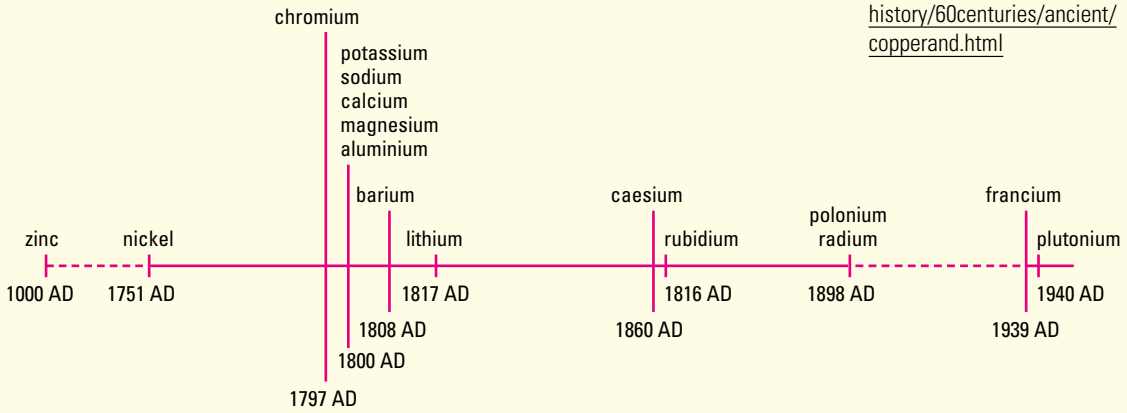
Only dilute hydrochloric acid is used in the reaction with metals as all the chlorides formed in the reactions are soluble in water. Dilute nitric acid is not used as it does not behave like a typical acid. It reacts with metals, including copper, to form nitrogen monoxide gas, NO, instead of hydrogen. 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.

IT Link

Copper — history
http://www.copper.org/education/history/60centuries/homepage.html

Copper — extraction
http://www.copper.org/education/production.html

Copper in ancient China
http://www.copper.org/education/history/60centuries/ancient/copperand.html



Metal	francium	nickel	radium	barium	chromium	lithium	plutonium	rubidium	caesium	polonium
Year of Discovery	1939	1751	1898	1808	1797	1817	1940	1861	1860	1898

Literature and the extraction of aluminium

In 1857, the English novelist, Charles Dickens became interested in the extraction of aluminium and wrote the following:

"Within the course of the last two years a treasure has been divined, unearthed and brought to light … what do you think of a metal as white as silver, as unalterable as gold, as easily melted as copper, as tough as iron, which is malleable, ductile, and with the singular quality of being lighter that glass? Such a metal does exist and that in considerable quantities on the surface of the globe."

Notes:

- Aluminium was first discovered in 1825 by Hans Christian Oersted, the Danish chemist and physicist, though only in minute amounts.
- In 1854, a French chemist extracted aluminium from the reaction of liquid sodium with aluminium chloride. This process produced large quantities of aluminium but was very expensive. It was this sample of aluminium that Dickens was referring to. The French Emperor, Napoleon III, had some aluminium cutlery made for state banquets. These cutlery cost much more than gold cutlery.
- Dickens described aluminium as a metal that is white/silvery in appearance, unreactive, has a low melting point, strong, malleable, ductile and has a low density. The metal ore is very abundant in the Earth's crust.
- Should the name of the metal be aluminium or aluminum? In 1808, Sir Humphry Davy proposed the name alumium for the metal (even before it had been discovered). He later changed this to aluminum and in 1812 settled on aluminium. By 1857, both spellings were in use. Dickens commented at the time that he felt both names were too difficult to pronounce.

Teaching pointers

14.3 What are the Uses of Metals? (page 211)

1. In Chapter 13, students saw how the properties of a metal depend on its structure. In this section, they see examples of how the uses of a metal depend on its properties.
2. In Exercise 14.1 of the Theory Workbook, students analyse data on properties of metals and use it to explain why metals are used for particular purposes.
3. The steel-making process is one of the major uses for oxygen. Ensure that students appreciate how the amount of carbon in a steel alloy affects its properties and therefore its uses.
4. Two additional activities on the uses of metals are provided at the end of the chapter:
   - Additional Exercise 2 on steels.
   - An additional "Chemistry in Society" on the uses of titanium alloys.

(page 211)

Mystery Clue

Aluminium, as a metal, is a good conductor of heat and so conducts heat away quickly from the airship. Also, aluminium is shiny and so is a good reflector of heat.

Skills Practice (page 212)

1. **(a)** Aluminium has a low density thus allowing javelins to be lightweight and therefore be thrown further.
   (b) Gold is very resistant to corrosion.
   (c) Mercury has a low melting point (–39 °C) and is a liquid at room temperature. It is sensitive to small changes in temperature.
   (d) Steel is strong and cheap.
   (e) Copper is resistant to corrosion and is not too expensive. It does not react with water.
   (f) Aluminium is malleable (can be easily formed into foil) and is a good conductor of heat.
2. **(a)** Iron
   (b) This is stainless steel. It does not rust and is used to make cutlery.

(page 212)

Mystery Clue

Its high strength

Teaching pointers

14.4 Is Recycling Metals Important? (page 213)

1. The estimates in Figure 14.8 are not to be regarded as precise. Different estimates are available (see Figure 1 in Exercise 14.2 in the Theory Workbook).
2. Reserves of metals are dependent on the price. An increase in price of the metal may make it worth extracting. Hence the metal may be used up more quickly.
3. Most iron and aluminium ores are close to the Earth's surface and are obtained by open-cast mining. This causes environmental problems such as leaving large areas of wasteland, creating waste material and causing the destruction of ecosystems.
4. Using objects made of other materials instead of metals helps to conserve metals. An example is the use of optical (glass) fibres in place of copper cables. But in some cases, metals cannot be replaced. For example, electrical conductors and high-performance alloys for tools, aircraft cannot be replaced with other materials.

5. A problem with recycling is exemplified with aluminium foil. Very little aluminium foil is recycled because of the difficulty in collecting it. Aluminium cans are easier to collect.

6. 'Chemistry in Society' on page 215 of the Textbook describes the recycling of steel and some precious metals in Singapore. Other metals, such as aluminium and lead, are also collected but are not recycled locally. Instead, they are shipped to countries in the region where they are recycled. For example, waste aluminium products, including drink cans, are sent to China. Lead, obtained from old batteries, is sent to the Philippines for recycling.

Additional Exercise 3: Class Debate on the Use and Conservation of Metals

This is a class debate on the use and conservation of metals. The materials can be photocopies and distributed to the class.

Points on holding a debate

1. Prepare the physical environment for the debate. A hall or lecture room with tables for the teams and adjudicators will be needed. Time keeping and other jobs will need to be organised. Get students to help.

2. Decide how the team members will speak. One suggestion is:

   (a) The team captain introduces his team's main points.

   (b) Other members go into greater detail and also argue against points raised by the opposing team.

   (c) The team captain has the final turn to summarise the team's position.

3. Decide the role of the floor audience. It may be useful to allow them to make brief comments after the two teams have finished and while the adjudicators are deliberating.

4. Decide how any judging will be done and by whom. For an inter-class debate, the teachers could be the adjudicators. Alternatively, assign three to five students to this task.

5. Criteria for judging the debate may include:

   - Clarity of presentation,
   - Accuracy or validity of the (chemical) ideas presented,
   - Ability to counter the opposing team's points.

   A 5-point scale is suitable for marking each point. The marks for all the adjudicators are totalled to decide the winner.

6. Include follow-up written work, if necessary. Students who are listening to the debate should record the main points of each of the speakers. This will help them in the follow-up assignment.

Points 'for' and 'against' the motion

You may give the teams the following points to help in their preparation for the debate.

<u>For the affirmative team:</u>

- The Earth's reserves of metals are limited.
- We must use these resources wisely and not squander them.
- Even though recycling bins are provided, many aluminium cans are still thrown away, thus polluting the environment.
- Containers can be made from other materials, such as glass and plastic.

- As recycling aluminium causes problems such as difficulty in getting people to return the used cans, it is therefore more sensible not to use aluminium to make the drink cans in the first place.
- Aluminium ore is obtained by open-cast mining which destroys the environment by leaving large areas of wasteland and causing the destruction of ecosystems.
- Countries where aluminium ore is extracted could earn more revenue by promoting tourism instead of mining metals.

For the negative team:

- Aluminium is suitable to make drink cans because it can be recycled.
- Drink cans use only a fraction of the total amount of aluminium produced.
- Aluminium is very suitable for making the cans because it is strong and light in weight.
- Alternatives to aluminium are not always suitable. For example:
  - Glass containers break easily.
  - Plastic containers are not strong and are more likely to be thrown away, thus polluting the environment.
  - Tin cans are too heavy.
- The cost of alternative materials for cans may be higher.
- The Earth still has large reserves of aluminium.
- Aluminium ore often comes from poor countries, where their people need the jobs and income from the aluminium mining industry.

Approximate time allocation for the debate:

(a)	Introduction by the teacher.	5 min
(b)	Each speaker is called on to speak for a maximum of 3 minutes each.	18 ~ 20 min
(c)	Summary from the two captains.	8 min
(d)	Adjudicators score the debate, announce the winner and give comments. While the adjudicators score the debate, the floor audience could be invited to give their comments of the motion.	10 min

Skills Practice (page 214)

1. (a) Metal recycling is the collection and melting of used metal to form blocks of pure metal that can be used again.

(b) Recycling of metals is carried out to save the limited amount of metal ores, to save the cost of extracting new metals from ores and to help the environment by preventing land pollution.

(c) Reasons may include the following: Fewer metal reserves in the Earth; metals become more expensive; recycling of metals will be cheaper than extracting new metals; an increasing awareness about the need to use the Earth's resources wisely and to protect the environment (from disposal of metal waste).

(d) Recycling can cause air pollution. It also costs money to transport the scrap metals.

2. Steel cans are separated from the aluminium cans with the aid of an electromagnet.

3. Gold is a valuable metal and can be sold for a high price, and is also expensive to extract. Copper, is a cheap metal and can be easily extracted from the ground.

4. Potassium is too reactive. It reacts quickly with air and water and thus its compounds are not worth collecting. Aluminium is recycled because it does not corrode into compounds and only needs to be melted into clean blocks.

Chemistry in Society (page 215)

How are Metals Recycled in Singapore?

Exercise

1. Recycling of drink cans and bottles can be more widely practised in Singapore through more advertising to create public awareness. The refuse collected could be used not only for recycling but also to generate electricity.
2. To deal with the increasing amount of scrap metal, the business can aim to collect back metals. This could be done in bulk to cut down on cost. Most of the metals can be sold to other recycling companies in Singapore or shipped to other countries in the region for recycling. These also help to cut down costs as recycling facilities require capital.

Notes for Teachers

Amount of gold on the Earth

There is so little gold in the Earth's crust that all the gold ever extracted would form a cube with a side of just 18 metres. To appreciate how little this amount is — the gold would be able to fit easily into

(a) 18 MRT carriages, or

(b) an Olympic-size swimming pool.

Recycling and the 3R's in Singapore

Promoting the 3 R's:

One of the programmes started by the Ministry of the Environment is the Waste Minimisation and Recycling Programme, which aims to promote the 3 R's: reduce, reuse and recycle. The programme was initiated as a result of realising that Singapore faces a challenging task of dealing with the increasing amount of waste generated by the population. High-rise buildings, high cost of operating incineration plants and the lack of space for landfills, have resulted in the need for waste minimisation and recycling.

IT Link

Recycling metals

Steel recycling
http://www.scrib.org.uk/recycling_steel/recycling_steel.asp

http://www.scrib.org.uk/recycling_steel/recycling_video.asp [Recycling DVD]

Aluminium recycling
http://recycling.world-aluminium.org/

http://www.ollierecycles.com/uk/html/alumin_how.html

http://www.cansforkids.org/whatwedo.htm

A recycling park

A good example of waste recycling in action in Singapore is the Eco-Recycling Park at Tuas. This site covers 19 hectares, an area as large as 20 football fields. Various businesses in the park recycle industrial waste especially plastics, paper, glass, wood and metal. One company, Citiraya, collects rejected products such as circuit boards, computer parts and mobile phones from electronics manufacturers and extracts precious metals from them. These precious metals include silver, gold and platinum. The company extracts roughly 200 kg of gold per month and makes an annual profit of S$3 million.

Recycling as an alternative to landfills

Singapore has only 682 km^2 of land, therefore it cannot afford to have many landfill sites for waste. The government plans to abolish landfill sites altogether by minimising the amount of waste generated and by recycling as much as possible. All landfill sites on the mainland have been closed; the only site now in use is that at Pulau Semakau, which is 8 km from Singapore.

Solving the Mystery (page 26)

The Hindenburg mystery — what caused the disaster?

Infer
The advantage of helium is that it does not burn. The disadvantage is that it is denser than hydrogen and so does not provide as much lift.

Connect
The gas particles diffuse through the small holes (pores) in the surface of the balloon. On heating, the gas particles move faster and diffuse through the pores more quickly.

Further Thought
The steel frame would have made it too heavy for the denser helium to provide sufficient lift for it to fly. Hence the amount of steel and other materials that increase the weight of an airship need to be reduced in modern airships that use helium.

IT Link

About the Hindenburg disaster

www.answers.com/topic/what-happened-to-the-hindenburg#ixzz1JkUV8rqJ

http://www.airships.net/hindenburg/disaster/myths

http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/*WPCP_007150 [pages 8-10]*

14 Chapter Review

Self-Management

Misconception Analysis (page 217)

1. **False** Some metals, such as silver and gold, occur as free metals in the Earth.

2. **False** Haematite is a metal ore, that is, a rock containing a useful mineral. The mineral in haematite is iron(III) oxide.

3. **True** Metals at the bottom of the reactivity series are found as free metals, those in the middle are extracted using carbon, while those at the top are extracted using electricity.

4. **False** Extraction with carbon is possible, but only at very high temperatures.

5. **False** For example, aluminium is extracted from aluminium oxide using electricity.

6. **True** In a blast furnace, coke, a form of carbon, reacts with carbon dioxide to form carbon monoxide The carbon monoxide then reacts with the iron(III) oxide.

7. **False** All steel alloys contain iron and carbon. But many steel alloys also contain small amounts of other metals.

8. **False** Reserves of metals such as gold may be used up within 50 years. But other metals, such as iron and aluminium, will last much longer.

Practice

Structured Questions (page 218–219)

1. (a) The methods of heating metal oxides with carbon and by electrolysis.
   (b) (i) Physical methods
   (ii) The methods of heating metal oxides with carbon and by electrolysis.
   (c) Gold is extracted by physical methods. Zinc, lead and iron are extracted by heating the metal oxides with carbon. Aluminium and magnesium are extracted by electrolysis.
   (d) The method of electrolysis.

2. (a) PbS
   (b) (i) lead(II) sulfide + oxygen ⟶ lead oxide + sulfur dioxide
   $2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$
   (ii) lead(II) oxide + carbon ⟶ lead + carbon monoxide
   $PbO(s) + C(s) \longrightarrow Pb(l) + CO(g)$
   (c) Heat the galena strongly in a test-tube or metal lid to convert the lead(II) sulfide into lead(II) oxide. Allow the product to cool, mix in an equal amount of carbon powder and heat again. Liquid lead will form as carbon removes oxygen from the lead(II) oxide.

3. (a) Carbon (b) Chromium
(c) Aluminium (d) Zinc
(e) Carbon (f) Oxygen

4. Outer rim: steel
Core: copper, silver

5. (a) (i) Copper is a good conductor of electricity, does not corrode and is ductile.
(ii) Copper is expensive and has a high density.
(b) Sodium is too soft. It reacts with air and water.
(c) Aluminium is used because it has a low density and is a good conductor of electricity (though it is not as good a conductor of electricity as copper).
(d) The steel centre provides the cable with greater strength.

6. (a) Between 1960 and 2000, the number of steel cans has decreased while the number of aluminium cans has increased.
(b) Aluminium was found to be a more suitable material to be used to make cans.
(c) They did so to reduce the usage of metals in order to conserve metals.

Free Response Questions (page 219)

1. Responses may include the following points:
- Metals low in the reactivity series occur as free elements in nature and can be extracted by physical methods. An example of such a metal is gold.
- Metals in the middle of the series are extracted by heating the metal ore with carbon (or carbon monoxide produced from carbon). For example, iron is extracted from haematite/iron(III) oxide by heating with carbon monoxide
- Metals at the top of the series are extracted by passing an electric current through the molten ore. For example, aluminium is extracted by the electrolysis of molten aluminium oxide.

2. Responses may include the following points:
- Problems with the increasing use of metals:
  – There is a limited resource of metal ores.
  – Resources will be used up.
- Solving the problem:
  – Recycle metals.
  – Reuse metals for other purposes.
  – Replace metals with other materials, e.g. plastic, wood, concrete.
  – Reduce the use of metals to conserve them.

3. Recycle the tin cans to extract the tin; use aluminium cans instead of tin cans; encourage the use of more plastic food containers; use other more plentiful metals to coat steel cans; use thinner tin coatings.

Extension (page 219)

1. Using government statistics:
Population = 4 240 300 (as of June 2004)
[Population = 4 425 720 (July 2005 estimated)]
Number of households = 1 097 000 (as of June 2004)
Number of members per household = 3.83
Estimated number of cans used
per week per household ≈ 10
Therefore, number of cans used
per year $\approx 10 \times 52$ weeks $\times$ 1 097 000
$\approx 570\,000\,000$

2. Additional ideas:
Advantages of recycling:
- Provides job opportunities.
- A source of income through the sale of recycled metal.
- Reduces the money spent on importing fresh metal.

Disadvantages of recycling:
- Possible water pollution from the processing of scrap metals.
- Possible air pollution.
- Transportation costs.

Importance of recycling from Singapore's perspective:
- Prevents land pollution.
- Saves cost of importing new metal.
- Provides a source of revenue through the exportation of recycled metals.

For Singapore, the recycling of metals is a worthwhile effort.

Additional

Chemistry in Society

Discovery of Metals

What is the relationship between the discovery of metals and the reactivity series?

Metals are among the most useful materials. The first metals were discovered and used about 8000 years ago. These were gold and silver. Archaeologists divide human history into ages by the main metals that were used. These are the Copper Age, the Bronze Age, and the Iron Age.

The timeline below shows when several metals were first used.

The Three Metal Ages

The discovery and use of metals were important for the development of human civilisations. Archaeologists divide human history into ages by the main metals that were used. These are the Copper Age, the Bronze Age, and the Iron Age.

The Copper Age
(about 4000 BC – 2500 BC)
The first copper metal was probably obtained by accident when rocks containing copper ore were heated in a wood fire. (The wood formed charcoal, a form of carbon, which is needed to extract the copper.) Copper was used to make jewellery, tools and simple weapons.

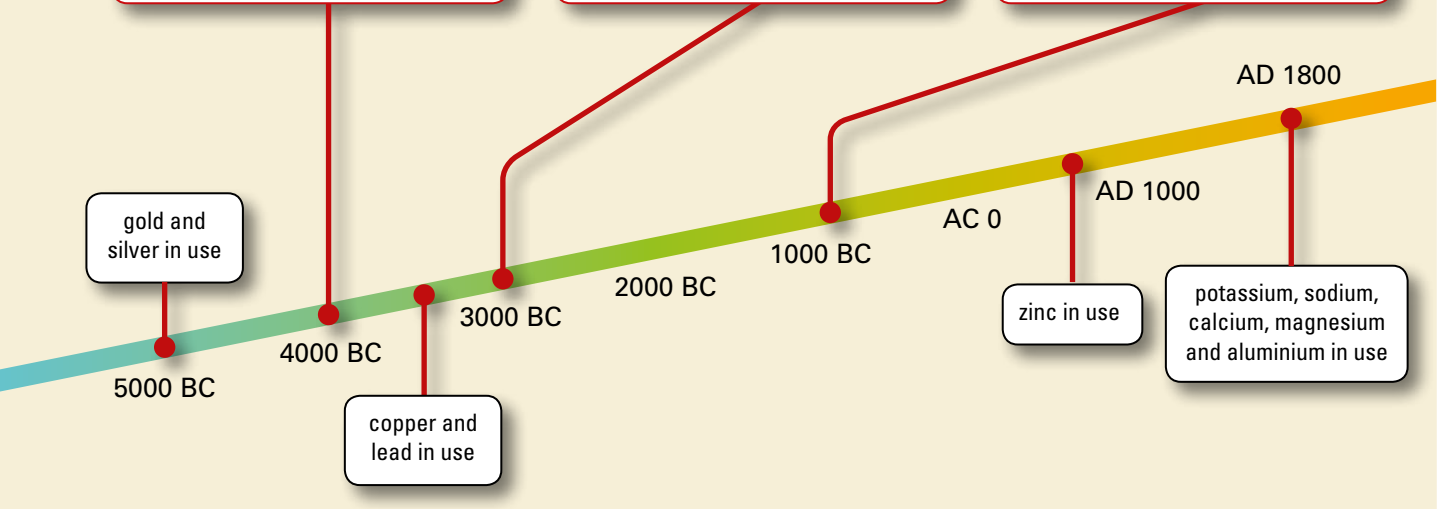
Figure 1 A copper pot

The Bronze Age
(about 3600 BC – 1200 BC)
Copper is a soft metal and does not make good tools. People discovered that when two different kinds of rocks were heated together, a stronger kind of copper was formed. This material was bronze, an alloy of copper and tin. Bronze replaced copper to become the main material used to make things such as cooking pots, bells, armour and swords.

Figure 2 A bronze bell

The Iron Age
(about 1400 BC – now)
Iron is much stronger than bronze and makes sharper tools and weapons (Figure 14.8). Iron became popular as civilisations developed (Figure 14.9). Today, we are still in the Iron Age. Over 90% of the metal used today is iron.

Figure 3 Ancient iron tools



Discovery of Metals and the Reactivity Series

If we reverse the reactivity series, we get the approximate order in which metals were discovered. Metals at the bottom of the reactivity series, such as silver and gold, were discovered free in the Earth in ancient times. The very reactive metals at the top of the reactivity series, such as potassium and sodium, were only discovered recently.

These examples suggest the following general pattern:

The lower the position of a metal in the reactivity series, the earlier it was discovered.

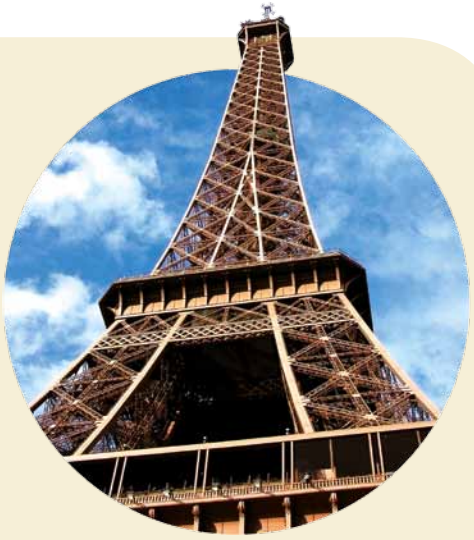


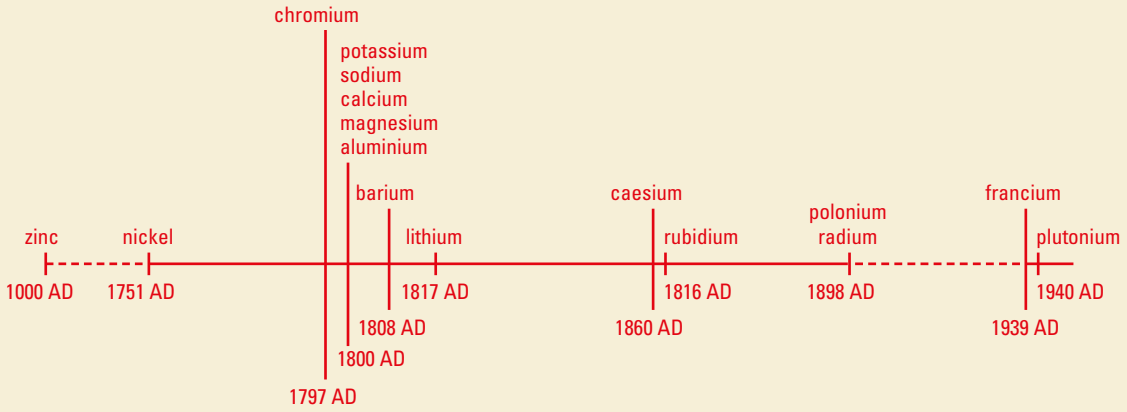
Figure 4 The Eiffel Tower in Paris is made from steel, an alloy of iron.

Exercise

1. The metal manganese was discovered in 1774. What can you infer about
   (a) its position in the reactivity series and
   (b) the method used to extract it?
   [*inferring*]
2. Some metals do not fit the above pattern. Iron was discovered in ancient times. However, we would predict it to be discovered more recently. Explain. [*explaining*]
3. Find the dates of the discovery of other metals. Construct an extended timeline to include these metals.

Answers

1. (a) It would be somewhere in the middle of the reactivity series between zinc (discovered about 1000 AD) and potassium/sodium (discovered in the early 1800s).
   (b) By the reaction of an oxide of manganese with carbon (or carbon monoxide). (Manganese is extracted by the reduction of manganese(IV) oxide with carbon, though other methods are also used.)
2. Because iron is just below zinc in the reactivity series, we might expect it to have been discovered about 1000 AD rather than in ancient times.
3.



Additional

Chemistry in Society

Titanium: The Space Age Metal

What properties does titanium have that make it a useful metal?

Scientists and engineers have always wanted a metal with the strength of steel and the low density and corrosion-resistance of aluminium. That metal exists. It is called titanium.

Titanium alloys are used in modern aircraft engines and air frames the wings of aircraft because of their lightness and strength. They are also used in spacecraft and bicycle frames (Figure 1).

The corrosion-resistance of titanium is exploited in artificial hip replacement joints and in metal pipes and tanks used in chemical industries (Figure 2).

Titanium has also affected the fashion industry. The metal has a very attractive characteristic bloom which is why it is used for jewellery (Figure 3).

Exercise

1. Find titanium in the Periodic Table. What is its symbol? What section of the Periodic Table is it part of? [*identifying, associating*]
2. What properties of titanium make it useful as jewellery? [*inferring, elaborating*]
3. Titanium and its alloys have many other uses. Do a search to find out more of their uses. [*IT search, elaborating*]

Answers

1. Symbol of titanium is Ti. It is a transition metal.
2. Strength; low density; corrosion-resistance
3. Answer depends on students IT search

Figure 1 The body and engines of this new aircraft contain titanium alloys [Boeing-787]

Figure 2 A titanium alloy hip joint

Figure 3 A titanium necklace

Additional Teaching Material

Additional Exercise 1: Discovery of Metals

Objective

- To collect and use information on the years in which various metals were discovered

Key Competency

CIT: sound reasoning [*classifying, predicting*], management of information [*information searching*]

copper urn

bronze helmet

iron dagger

A Discovery of Some Metals

A list of metallic elements is given below. Use the Internet or a CD-ROM encyclopaedia to find out when these metals were first discovered. Write the year next to the name in the table. If the metal was discovered thousands of years ago, and you do not know exactly when, you can write 'a long time ago'.

Metal	Date	Metal	Date	Metal	Date
aluminium		barium		caesium	
calcium		chromium		copper	
francium		gold		iron	
lead		lithium		magnesium	
nickel		plutonium		polonium	
radium		rubidium		silver	
thallium		tin		zinc	

B Classification

Now classify the elements into three groups according to when they were discovered.

Before the year 1000	Between 1000 and 1800	Between 1800 and 1890	After 1890

Questions

Look carefully at the four lists in part **B**.

1. In the list 'before the year 1000', what features do most of the metals have in common?

2. From the list 'between 1800 and 1890'.
(a) What features do these metals have in common?

(b) suggest an explanation for why these metals were only discovered after 1800.

3. What features do the metals in the list 'after 1890' have in common? Why were they only discovered recently even though they are not very reactive?

4. Look at the position of the metal thallium in the four lists, what does this suggest about the chemical reactivity of thallium and how is it extracted from its ore?

5. The metallic element bismuth has been known for thousands of years. What does this fact suggest about the chemical nature of this metal?

_____

_____

Write the title of the CD-ROM or the address of the website from which you have obtained your information.

CD-ROM: _____

Website address: _____

Additional Teaching Material

Additional Experiment 1: How Can We Obtain Copper from a Copper Ore?

Objective

- To plan and carry out an experiment to extract copper from a copper ore

Apparatus and materials

- (Depends on the design of the experiment)

Key Competency

CIT: creativity (planning an experiment), inferring, evaluating
ICS: collaboration (working as a team), peer review, communicating effectively, IT tools (software), written report

Safety Warnings

Introduction

Malachite contains copper(II) carbonate. In this activity, you are to plan and carry out an experiment to extract copper from malachite.

Malachite, a copper ore

Reactions

The extraction of copper from the ore will require two steps. Write a chemical equation for each of the two steps.

Part 1: _____ Reaction: _____

Part 2: _____ Reaction: _____

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 how to get the metal using the two steps. Include diagrams of your apparatus if you think this is helpful.

Step 1: _____

_____

Step 2: _____

_____

Diagram (if any)

4. Peer review

Pass your plan to one or more other groups. Get them to make suggestions on how to improve your original plan.

_____

_____

Results

Describe the appearance of the metal you get.

_____

Evaluation

If you were to repeat the experiment with the same metal compound, list some possible ways to improve your procedure.

_____

_____

_____

Report

As a group, prepare a written group report (using a Word Processor) on how your group extracted the metal. 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 Exercise 2: Steels

Objective

- To compare different kinds of steels

Key Competency

CIT: sound reasoning [*analysing, comparing, classifying*]

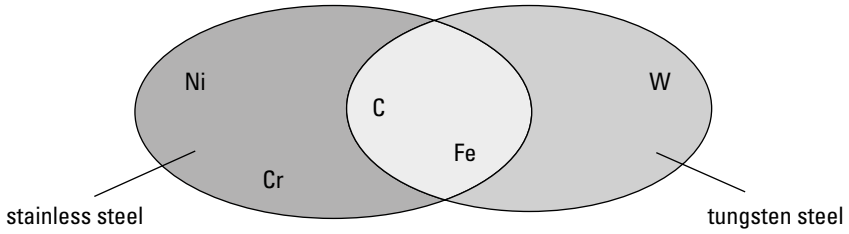
The compositions and uses of some different steel alloys are given in the table below.

Name of steel alloy	Approximate composition	Properties of the steel	Use
mild steel	98.8% iron; 0.5% manganese; 0.5% silicon; 0.2% carbon	fairly hard and strong; but rusts	buses; cars; steel rods for roads
stainless steel	72.4% iron; 18% chromium; 9.5% nickel; 0.1% carbon	resists rusting	cutlery
tungsten steel	94.5% iron; 5% tungsten; 0.5% carbon	exceptionally hard	cutting tools
manganese steel	86% iron; 13% manganese; 1% carbon	exceptionally tough	rock drills
permalloy	21% iron; 78% nickel; 1% carbon	can be strongly magnetised	electromagnets

1. What elements do all the steels contain?

2. **Tungsten steel** and **manganese steel** are both harder and tougher than mild steel. From the table, suggest two differences in composition of these steels that produce this change in properties.

3. The elements present in different steels can be compared using Venn diagrams. A Venn diagram comparing the elements present in **stainless steel** and **tungsten steel** is shown below.



(a) Construct a Venn diagram to compare the elements present in **tungsten steel** and **manganese steel**.

(b) Construct a Venn diagram to compare the elements present in **stainless steel** and **permalloy**.

(c) Construct a Venn diagram to compare the elements present in **mild steel** and **manganese steel**.

Additional Teaching Material

Additional Exercise 3: Class Debate on the Use and Conservation of Metals

Aim

- To carry out a debate on the use and conservation of metals
- To recognise that metal reserves are limited and that there is a need to conserve these reserves

Key Competencies

CL: the need to conserve metals
CIT: sound reasoning
ICS: management of information, communicating effectively [*collaborating with others, debating, writing an essay*]

The Problem

Every year in Singapore and around the world, millions of tonnes of aluminium are used to make drink cans. Once the drinks are consumed, many of the cans are thrown away as waste. If this practice continues, a time may soon come when there is little or no aluminium ore left in the Earth for mining. Some estimates suggest that this may happen within 40 years!

Aluminium can drinks

The Debate

Organise a class debate on the following motion:

'Aluminium should not be used to manufacture drink cans.'

Two teams will be selected — the *proposition* team (which agrees with the motion) and the *opposition* team (which disagrees with the motion). Each team will have three speakers and one extra person to help in the search for information. Other class members will be chosen to be judges, timekeepers, and to prepare the room for the debate. One person will also be chosen to be the chairperson for the debate.

A. Preparation

1. Each team will be given several days to prepare its argument for the debate. You may need to search for ideas from books in the library and from the Internet.

2. Organise the information your team has collected in a way that best represents your side of the debate.

B. The Debate

1. The debate will last for about one hour. Here is how it may be carried out.
- **(a)** Introduction by the teacher and arrangement of the room for the debate.
- **(b)** A speech from each member of both teams. Each speaker has a maximum of 3 minutes.
- **(c)** Each team captain gives a summary of his side's arguments. A maximum of 4 minutes is allowed.
- **(d)** The judges give their comments on the performance of the two teams on:
  - **(i)** how good the arguments were,
  - **(ii)** how well the members of the team spoke, and
  - **(iii)** how well the team members worked together.

  This will take about 10 minutes.
- **(e)** The chairperson announces the result.

2. All students who are *listening* to the debate are to write down the main points of each speaker in the following table.

	Proposition team	Opposition team
Speaker 1		
Speaker 2		
Speaker 3		
Summary speech by the captain		

C. Follow-up Assignment

Take some of the points from the table above made by the speakers in the two teams. Write a short essay describing, with reasons, how well you thought these points helped each team's side of the debate.

Answers

Additional Exercise 1:

A Discovery of some metals

Metal	Date	Metal	Date	Metal	Date
aluminium	1825	barium	1808	caesium	1860
calcium	1808	chromium	1797	copper	a long time ago
francium	1939	gold	a long time ago	iron	a long time ago
lead	a long time ago	lithium	1817	magnesium	1808
nickel	1751	plutonium	1940	polonium	1898
radium	1898	rubidium	1861	silver	a long time ago
thallium	1861	tin	a long time ago	zinc	1746

B Classification

Before the year 1000	Between 1000 and 1800	Between 1800 and 1890	After 1890
copper	chromium	aluminium	francium
iron	nickel	barium	plutonium
gold	zinc	calcium	polonium
lead		caesium	radium
silver		magnesium	
tin		lithium	
		rubidium	
		thallium	

Questions

1. They are not very reactive and are found at the bottom of the reactivity series.
2. **(a)** They are very reactive metals and are found at the top of the reactivity series.
   (b) Electricity is used to extract them. The first battery was not made until about 1800.
3. They are all radioactive. They were only discovered after 1890 when radioactivity was discovered.
4. It is very reactive and must be extracted by electrolysis.
5. It is very unreactive and is easy to extract from its ore.

CD-ROM: World Book Encyclopedia

Website address: www.chemicalelements.com

Note:
Zinc may be classified as a 'before the year 1000' element depending on the reference source.

Additional Experiment 1:

Reactions

Part 1: $CuCO_3(s) \longrightarrow CuO(s) + CO_2(g)$
Reaction: decomposition

Part 2: $2CuO(s) + C(s) \longrightarrow 2Cu(s) + CO_2(g)$
Reaction: reduction

Plan

1. E.g. Metal caps from soft drink bottles, Bunsen burner, tripod, wire gauze, spatulas, malachite/copper(II) carbonate powder, carbon powder.

3. Step 1: Place some malachite/copper(II) carbonate in a metal cap. Heat strongly to change it into solid copper(II) oxide.

   Step 2: Allow the cap to cool. Then add some powdered carbon to the cap. Mix with the copper(II) oxide. Heat the mixture to obtain copper metal.

Results

Copper is a shiny, brownish metal.

Additional Exercise 2:

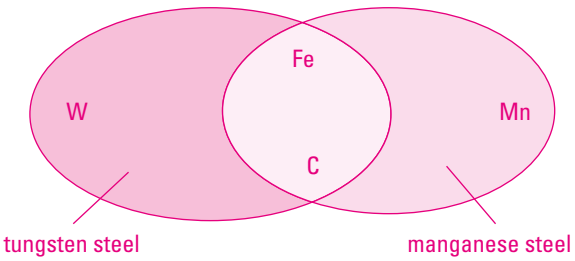
1. Iron and carbon

2. Tungsten steel and manganese steel have larger percentages of other elements.

   Tungsten steel and manganese steel have larger percentages of carbon.

3. **Note:** 'Stainless steel' area includes Ni, Cr, C and Fe while the 'tungsten steel' area includes W, Fe and C.

   (a)



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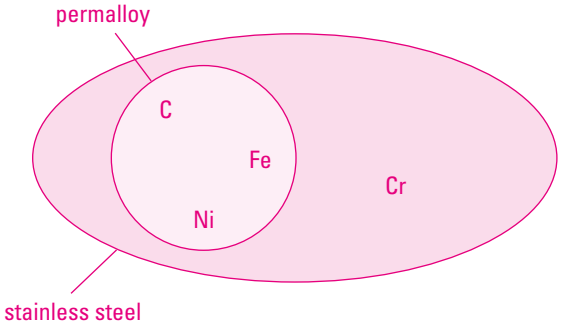

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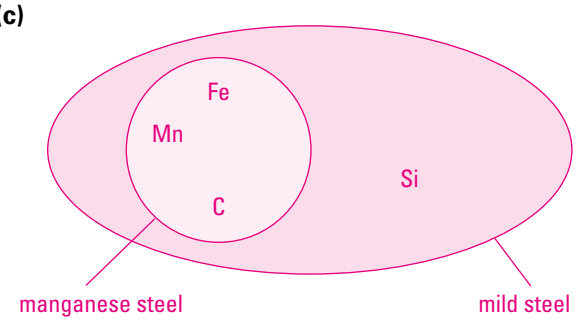

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