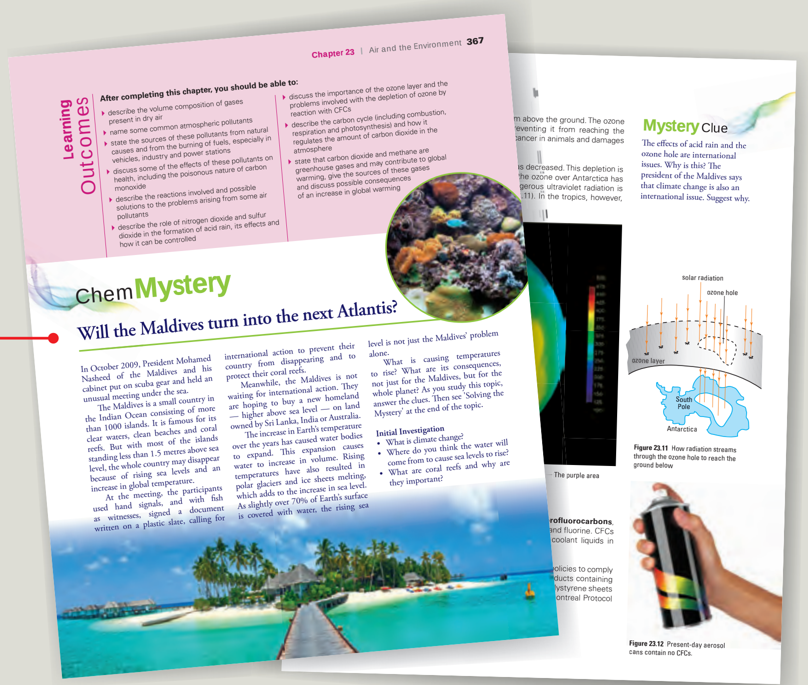
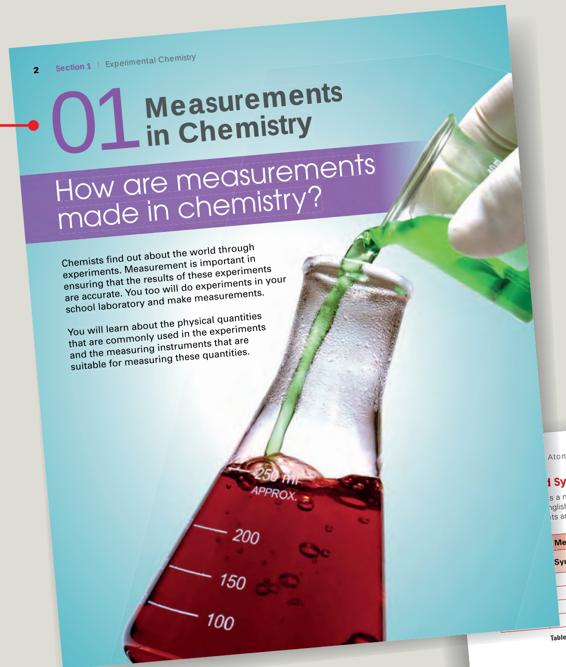
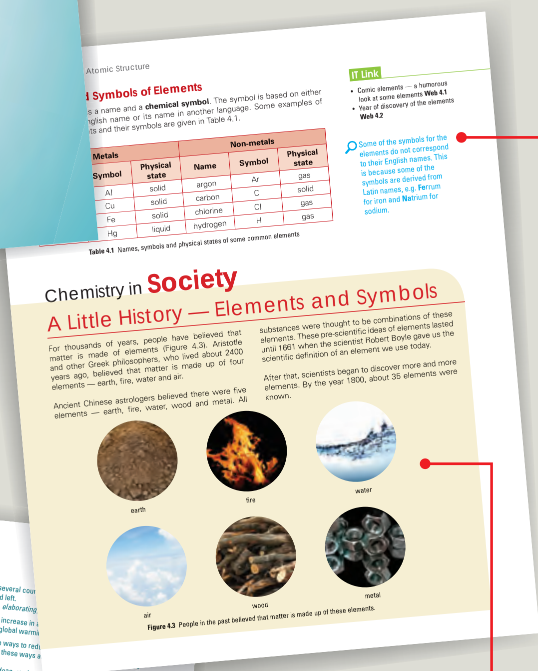
Features



Chapter Opener — presents a Big Question to set the focus for the chapter. The guiding questions and topical background provide students with a head start in grasping important concepts of chemistry through critical thinking.



ChemMystery — merges the concepts of study with real-life incidents which have occurred in human history, both in the distant past and in recent times. **Mystery Clues** are interspersed across one or more chapters belonging to the same section, to assist students in formulating the answer(s) to the Mystery.

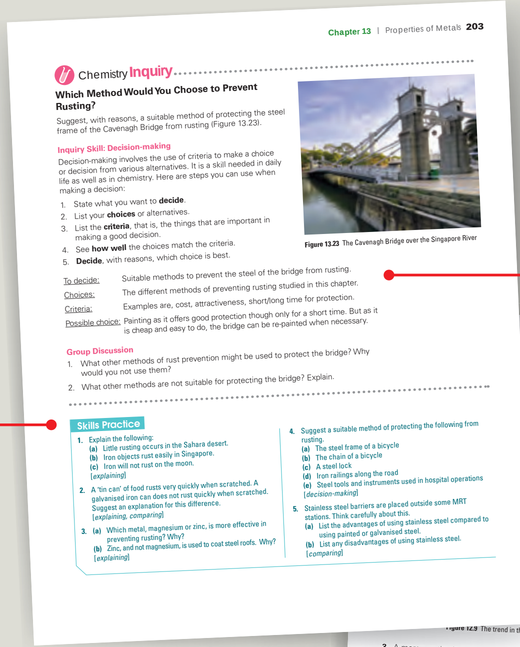


Notation — points out information about chemistry, which includes one of the following:

- a word analysis of chemistry terms to help students understand the meaning of these terms
- means to help students to remember chemistry concepts learnt and
- interesting facts that point out the relevance of chemistry to everyday life.

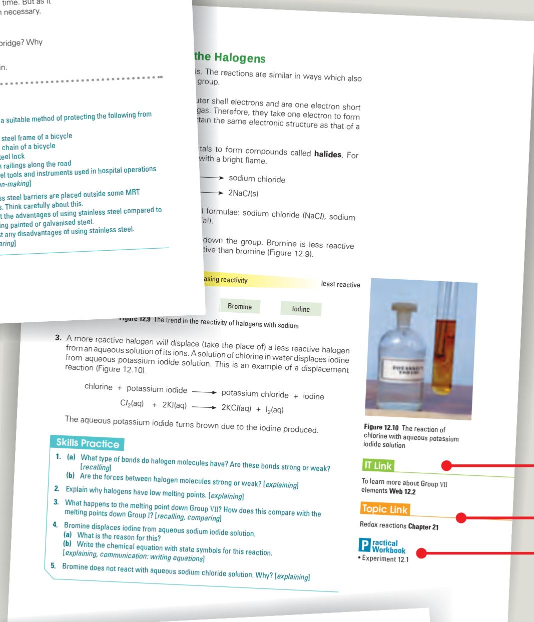
Solving the Mystery — found at the end of the concluding chapter, relates the study concepts involved by way of an in-depth explanation of the Mystery.

Chemistry in Society — presents applications of chemistry concepts through varied contexts to engage students. It helps them relate the study of chemistry to their everyday lives. The Exercise at the end of this feature promotes class participation and facilitates the application of the 21st Century Competencies.



Chemistry Inquiry — encompasses guided steps for students to solve a variety of chemistry problems using an inquiry-based approach. Questions are designed to facilitate group discussion and support an investigative approach to concept learning.

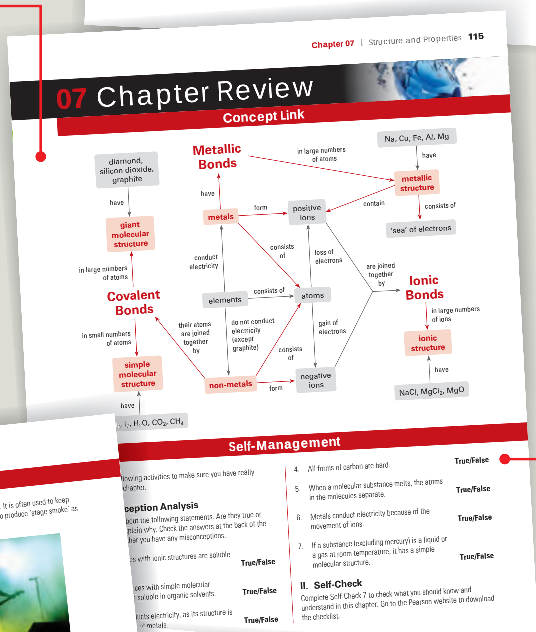
Skills Practice — supplements content development within the text. This feature is located at appropriate junctures within the chapters. The questions aid students in the application of chemistry concepts.



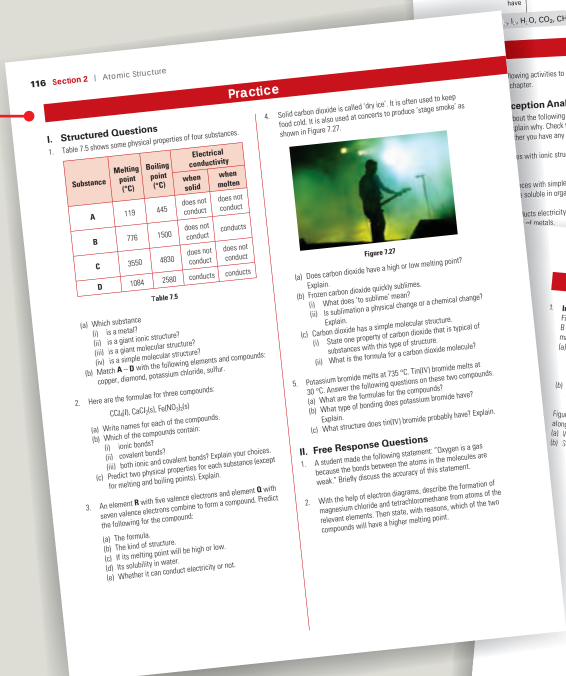
IT Link — invites students to participate in IT-based activities or explore websites relevant to the topic. The web codes mentioned, e.g. Web 12.2, refer students to relevant website addresses listed at the back of the book.

Topic Link — refers students to relevant sections in the textbook to help them recall concepts learnt.

Workbook Link — refers students to the theory workbook exercises for reinforcement of concepts or to the practical workbook for relevant experiments.

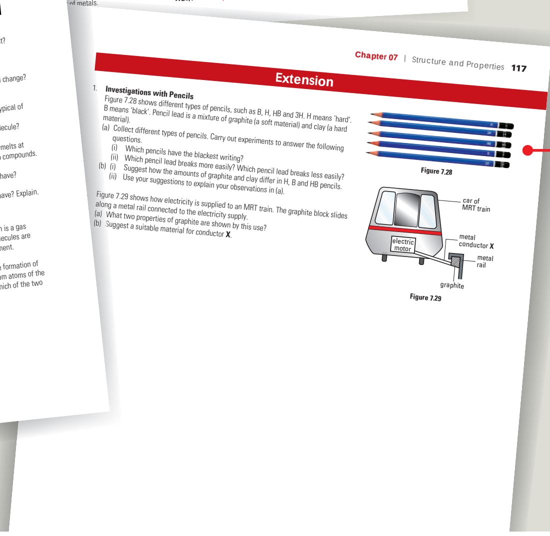


Concept Link — provides an overall view of the concepts learnt in the chapter and highlights the links between concepts taught in different chapters.



Practice — provides questions which are challenging and tests students' ability to apply and integrate concepts learnt.

Self-management — encourages students to be independent and responsible learners. Here, they can correct any misconceptions they may have, be aware of points they should know, and understand and reflect on what they have learnt.



Extension — provides opportunities for students to go beyond the syllabus by finding out more and thinking critically.

Contents

Introduction: Chemistry as an Inquiry x

Section 1 Experimental Chemistry

01 Measurements in Chemistry 2

ChemMystery: A lake divided — how did a railroad affect the Great Salt Lake? 3

1.1 What are the Basic Physical Quantities Used in Experiments? 4

1.2 How are Physical Quantities Measured in Experiments? 4

1.3 What are the Apparatus Set-ups for Some Simple Experiments? 8

02 Purification of Substances 13

2.1 What is a Pure Substance? 14

2.2 How are Pure Substances Obtained? 15

2.3 What is Chromatography? 22

2.4 How Do We Check the Purity of Substances? 25

Solving the Mystery: A lake divided — how did a railroad affect the Great Salt Lake? 26

Section 2 Atomic Structure

03 Kinetic Particle Theory 30

ChemMystery: Why do pollen grains move about in water? 31

3.1 What is Matter and What are Its Different States? 32

3.2 How Did the Kinetic Particle Theory of Matter Come About? 33

3.3 What are the Particulate Models of Matter? 37

3.4 How Does the Kinetic Particle Theory Explain Changes in State? 39

04 Elements, Compounds and Mixtures 48

4.1 What are Elements? 49

4.2 What are Elements Made of? 53

4.3 What are Compounds? 55

4.4 What are Compounds Made of? 57

4.5 What are Mixtures? 58

Solving the Mystery: Why do pollen grains move about in water? 61

05 Structure of Atoms 66

ChemMystery: What role did iodine have in the Fukushima nuclear disaster? 67

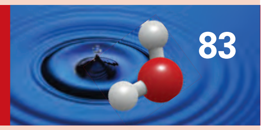
5.1 What Makes Up an Atom? 68

5.2 Atomic Structure 69

5.3 How are Electrons Arranged in an Atom? 74

5.4 How are Ions Formed from Atoms? 76

06 Chemical Bonds 83



6.1 What Holds Atoms Together? 84

6.2 How are Ionic Bonds Formed? 85

6.3 How are Covalent Bonds Formed? 89

6.4 What Do Giant Molecular Structures Look Like? 95

6.5 How are Metallic Bonds Formed? 96

07 Structure and Properties 101

7.1 Structure and Physical Properties 102

7.2 Structure and Physical Properties of Simple Molecular Substances 103

7.3 Structure and Physical Properties of Giant Molecular Substances 105

7.4 Structure and Physical Properties of Ionic Compounds 107

7.5 Structure and Physical Properties of Metallic Structures 110

7.6 Identifying the Structure of a Substance 112

7.7 Key Ideas 113

Solving the Mystery: What role did iodine have in the Fukushima nuclear disaster? 114

Section 3 Chemical Calculations

08 Relative Masses of Atoms and Molecules 118

ChemMystery: Producing iron — how does the chemist produce 30 000 tonnes of iron? 119

8.1 Do Atoms Have Mass? 120
8.2 What is Relative Atomic Mass? 121
8.3 What are Relative Molecular Mass and Relative Formula Mass? 123
8.4 How Do We Calculate Percentage Composition? 124

09 Counting Atoms: The Mole 129

9.1 How Do We Count Particles in Chemistry? 130
9.2 How are Moles and Number of Particles Related? 131
9.3 What is Molar Mass? 132
9.4 What are the Different Kinds of Chemical Formulae? 135
9.5 What is the Molar Volume of Gases? 138
9.6 Why Does the Concentration of Solutions Matter in Chemistry? 141

10 Calculations Using Chemical Equations 147

10.1 How Do We Construct Chemical Equations? 148
10.2 Calculations from Equations 151
10.3 How Do We Calculate Volumes of Reacting Gases from Equations? 156
10.4 What are Limiting Reactants? 157
10.5 How are Percentage Yield and Percentage Purity Calculated? 158

Solving the Mystery: Producing iron — how does the chemist produce 30 000 tonnes of iron? 160

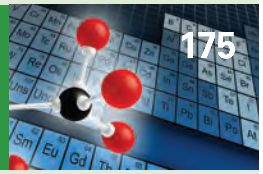
Section 4 Periodicity

11 The Periodic Table 164

ChemMystery: What place does praseodymium have in our world? 165

11.1 What is the Idea Behind the Periodic Table? 166
11.2 How Did the Modern Periodic Table Come About? 166
11.3 What Patterns Can be Found in the Periodic Table? 169
11.4 What is the Periodic Table Used for? 170

12 Group Properties and Transition Elements 175



12.1 Where are the Major Groups Positioned? 176
12.2 What are the Group I Elements? 176
12.3 What are the Group VII Elements? 179
12.4 What are the Group O Elements? 181
12.5 What are the Transition Elements? 182

Solving the Mystery: What place does praseodymium have in our world? 185

13 Properties of Metals 189

ChemMystery: The Hindenburg mystery — what caused the disaster? 190

13.1 What are the Physical Properties of Metals? 191
13.2 What are the Chemical Properties of Metals? 192
13.3 What is the Reactivity Series? 195
13.4 What are Some Applications of the Reactivity Series? 197
13.5 What is Rusting? 200

14 Extraction and Uses of Metals 207

14.1 How are Metals Obtained from Ores? 208
14.2 What are the Methods for Extracting Metals? 209
14.3 What are the Factors that Affect the Choice of Metals? 211

14.4 Is Recycling Metals Important? 213

Solving the Mystery: The Hindenburg mystery — what caused the disaster? 216

Section 5
Chemistry of Reactions

15 Acids and Bases 220


ChemMystery: What is in the toxic red sludge? 221

15.1 What are Some Common Acids? 222

15.2 Why is Water Important for Acids? 225

15.3 What are Bases and Alkalis? 230

15.4 How are Indicators and pH Related? 232

15.5 What are Ionic Equations? 237

16 Neutralisation and Salts 243


16.1 What is Neutralisation? 244

16.2 What Occurs During Neutralisation? 244

16.3 How are Oxides Classified? 246

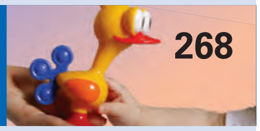
16.4 How is Neutralisation Applied in Daily Life? 248

16.5 What are Salts? 250

17 Ammonia 260


17.1 What are Some Uses of Ammonia? 261

17.2 How is Ammonia Manufactured? 262

18 Chemical Analysis 268


18.1 What are the Uses of Chemical Analysis? 269

18.2 What Physical Tests Can be Used to Identify Substances? 269

18.3 How Can Ions be Identified? 271

18.4 How Do We Test for Gases and Water? 276

18.5 What is Volumetric Analysis? 277

Solving the Mystery: What is in the toxic red sludge? 281

19 Energy from Chemicals 285


ChemMystery: How does a reusable heat pack work? 286

19.1 What Happens to Energy During a Change? 287

19.2 What are Exothermic and Endothermic Changes? 287

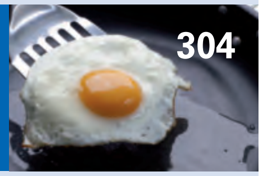
19.3 How Can Enthalpy Changes be Represented? 291

19.4 How are Chemical Bonds Related to Heat Energy? 292

19.5 What is Activation Energy? 294

19.6 How is Hydrogen Used as a Fuel? 297

Solving the Mystery: How does a reusable heat pack work? 300

20 Speed of Chemical Reactions 304


ChemMystery: Why did the Kinzua Bridge collapse? 305

20.1 What Can We Observe About the Speed of Chemical Reactions? 306

20.2 How Can We Measure the Speed of a Reaction? 306

20.3 How Can Differences in Speeds of Reactions be Explained? 310

20.4 What Factors Affect the Speed of Chemical Reactions? 311

21 Redox Reactions 324


21.1 What are Oxidation and Reduction? 325

21.2 Oxidation and Reduction as Gain or Loss of Oxygen 326

21.3 Oxidation and Reduction as Gain or Loss of Hydrogen 328

21.4 Oxidation and Reduction as Gain or Loss of Electrons 330

21.5 What is Oxidation State? 333

21.6 Oxidation and Reduction as Increase or Decrease in Oxidation State 336

21.7 How Can We Test for Oxidising and Reducing Agents? 338

21.8 Are All Reactions Redox Reactions? 339

22 Electrolysis 344

22.1 How is Electrolysis Used in Daily Life? 345
22.2 What is Electrolysis? 346
22.3 What Happens During Electrolysis of Molten Ionic Compounds? 347
22.4 What Happens During Electrolysis of Aqueous Solutions of Ionic Compounds? 350
22.5 What are Some Industrial Applications of Electrolysis? 355
22.6 How Do Simple Electric Cells Work? 358
Solving the Mystery: Why did the Kinzua Bridge collapse? 361

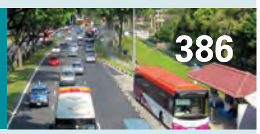
Section 6 The Atmosphere

23 Air and the Environment 366

ChemMystery: Will the Maldives turn into the next Atlantis? 367
23.1 What Affects the Quality of Our Air? 368
23.2 What is the Composition of Air? 368
23.3 What is Air Pollution? 370
23.4 How Can We Reduce Air Pollution? 376
23.5 What is the Carbon Cycle? 378
23.6 What is Global Warming? 380
Solving the Mystery: Will the Maldives turn into the next Atlantis? 382

Section 7 Organic Chemistry

24 Fuels and Crude Oil 386



ChemMystery: Go green! How can we drive environmentally-friendly cars? 387
24.1 Why are Fuels Needed? 388
24.2 What are Petroleum and Natural Gas? 388
24.3 How is Petroleum Made Into Useful Products? 391
24.4 What Issues Arise from the Uses of Fossil Fuels? 394

25 Alkanes and Alkenes 398

25.1 What are Organic Compounds? 399
25.2 How Can We Classify Organic Compounds? 399
25.3 What are Alkanes? 400
25.4 What are Alkenes? 405
25.5 What are Isomers? 410
25.6 What Foods Contain Unsaturated Compounds? 412
25.7 The Cracking of Alkanes 413

26 Alcohols, Carboxylic Acids and Esters 418

26.1 What are Alcohols? 419
26.2 How Do We Manufacture and Use Ethanol? 420
26.3 What are the Reactions of Ethanol? 423
26.4 What are Carboxylic Acids? 424
26.5 What are Esters? 427
26.6 Key Summaries 429

27 Macromolecules 434

27.1 How Common are Plastics in Daily Life? 435
27.2 How are Plastics Formed? 436
27.3 What is Addition Polymerisation? 438
27.4 What is Condensation Polymerisation? 441
27.5 What Problems Does Disposal of Plastics Cause? 445
Solving the Mystery: Go green! How can we drive environmentally-friendly cars? 447

Answers 451
Index 453
Acknowledgements 456
Web Links 457
Word Analysis 458
The Periodic Table of Elements 459

Introduction:
Chemistry as an Inquiry

What is Chemistry?

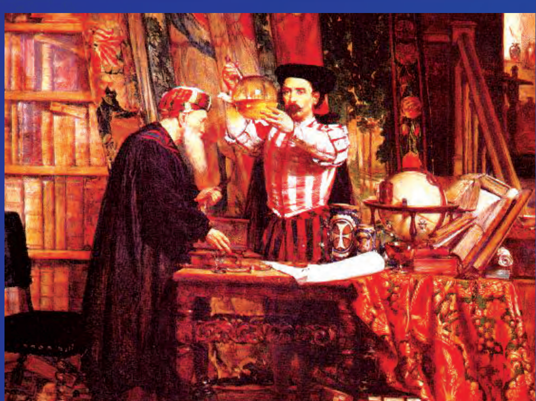
Chemistry is the study of matter. A person who specialises in chemistry is called a **chemist**.

This is the Earth as seen from outer space. The Earth, and everything in it, is made of matter.

Chemistry is believed to have originated in Egypt. The word *chemistry* comes from the Greek word *chemeia*, which refers to the art of using metals in Egypt.

The early history of chemistry is mainly about the extraction and use of metals. More than 2000 years ago, people in Egypt and other countries were using gold, silver, copper, iron and bronze.

For over 1000 years, from the 5th to the 16th century, the search for ways to change cheap metals into gold was the main interest of people called *alchemists* (rather than chemists). In the next century, most of their time was spent making drugs. The alchemists collected a lot of information about the properties of many substances. They also invented a lot of the apparatus used in laboratories today.



Alchemists at work

Chemistry as we know it today developed in Europe in the 17th century. One chemist, often regarded as the 'Father of Chemistry', was Robert Boyle. Boyle was the first to develop modern ideas of elements and compounds and to use the scientific method as a method for acquiring knowledge.

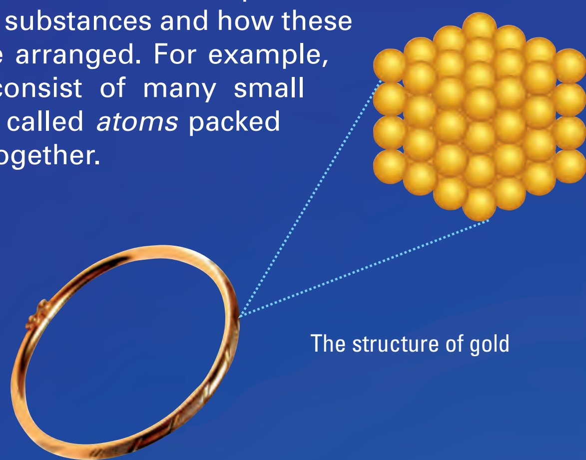
Robert Boyle (1627–1691)

What Do Chemists Investigate?

Chemists investigate (i.e. learn about) substances. This includes the *structure* of substances, the *properties* of substances and the *changes* within substances.

Structure of Substances

Structure refers to the parts that make up substances and how these parts are arranged. For example, metals consist of many small particles called *atoms* packed closely together.



The structure of gold

Properties of Substances

The word 'property' means 'what something is like.' Chemists classify properties into **physical properties** and **chemical properties**.

The *physical properties* of a substance are those that can be observed or measured without the substance changing into another substance.

The *chemical properties* of a substance describe the change of a substance into another substance.

Examples of physical properties are colour, smell, taste, hardness, density, conduction of electricity, solubility in water (or other solvents), melting point and boiling point.

Iron is converted to iron oxide (rust) in the presence of oxygen and water. Magnesium burns in oxygen to form magnesium oxide.

Changes in Substances

Chemists classify changes in substances as **physical changes** and **chemical changes**.

A *physical change* is a change in which no new substances are formed.

Examples of physical changes are melting, freezing, evaporation, boiling, condensation and dissolving.

Ice melting — a physical change

Burning of a match — a chemical change

A *chemical change* is a change in which one or more new substances are formed.

The rusting of iron and the burning of a match are examples of chemical changes.

What is the Scientific Method?

Science is not just a collection of facts or ideas about matter. It is a special way of thinking and finding out about the world. This special way is often called the **scientific method**.

In the scientific method, the scientist:

1. *makes observations* and *asks questions*,
2. *looks for patterns*,
3. *seeks explanations*, and
4. *carries out experiments*.

To observe, we use our senses. Observations we make about nature (which include measurements) are called *facts* or *data*.

For example,

- A candle burns with a luminous flame.
- At sea level, the boiling point of water is 100 °C.

Scientists also look for patterns among different facts. Many important patterns are known as laws.

For example,

- All sugar dissolves in water (a pattern).
- Like poles of a magnet always repel (law of magnetism).

Finally, scientists seek explanations for observations and patterns as well as answers to their questions.

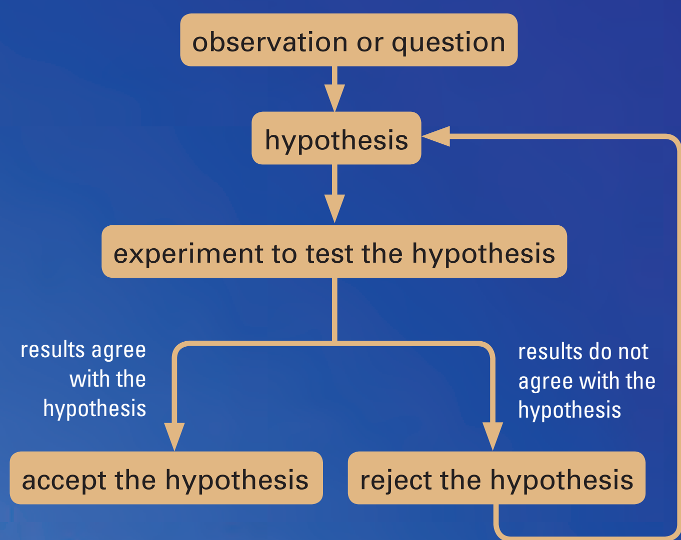
For example,

- Observation: A candle burns with a luminous flame. Why?
- Question: How does iron rust?

To do this, scientists begin by guessing what the answer or explanation might be. An educated guess based on observation is called a hypothesis. A hypothesis is a suggested answer to a question or explanation for an observation.

Scientists then test a hypothesis by conducting an **experiment**. If the results of the experiment show that the hypothesis does explain the facts or answer the question, the scientists accept the hypothesis. If the experiment shows that the hypothesis is wrong, they reject it. A new hypothesis is then suggested and further experiments are done to test it.

The flow chart summarises the steps followed in the scientific method.



The scientific method

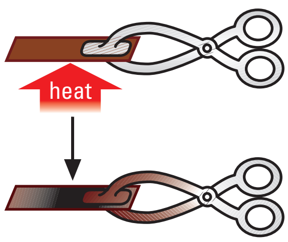
Using the Scientific Method

The example below shows an investigation of the effect of heat on copper.

Observation

We heat a piece of copper in a Bunsen flame. We observe that the colour of the copper changes from brown to black. The same result occurs when other pieces of copper are heated. There is a pattern in the observations.

Pattern: Copper becomes black when heated in air.



Explanation

We ask, "Why did this happen?" The black colour makes us think of soot which is also black. Therefore, we make the following hypothesis.

Hypothesis: Soot from the Bunsen burner flame covers the surface of the copper.

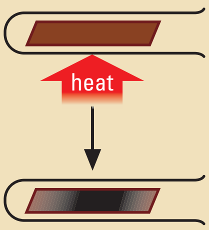
Prediction

We can make the following prediction based on this hypothesis.

Prediction: If we heat the copper so that the flame does not touch it, the copper will not become black.

Experiment

To test the prediction, we carry out the experiment as shown in the diagram below.



We observe that the copper turns black again when heated. Therefore, our hypothesis is wrong. We reject the hypothesis and suggest another.

Second Hypothesis

We know the copper is heated in air. Perhaps, the copper reacts with the air. Therefore, we suggest the new hypothesis.

Hypothesis: Copper turns black because it reacts with air.

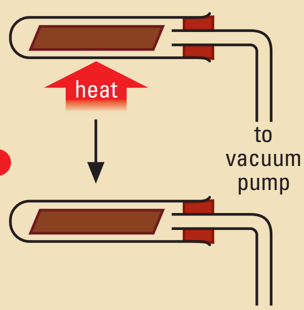
Prediction

From the second hypothesis, we can make a prediction.

Prediction: The colour will not change if we heat the copper in a vacuum.

Second Experiment

To test the prediction, we use the set-up shown below. We use a vacuum pump to remove air from the tube. Then we heat the test tube.



We observe that the colour of the copper remains brown. As the result agrees with the second hypothesis, we accept the hypothesis as an explanation for the observation.

Conclusion

From the results of the experiment, we draw the following conclusion.

Conclusion: When heated in air, copper turns black because it reacts with the air.

Theories and Models

Theories: If a hypothesis or a set of hypotheses explains facts satisfactorily and is widely accepted, it is called a **theory**. Here are some theories that you will learn about in this course:

- *Kinetic particle theory of matter* (Chapter 3)
- *Atomic theory* (Chapter 5)
- *Ionic theory and the theory of bonding* (Chapter 6)

A theory is a hypothesis or a set of hypotheses that has been tested and can explain many scientific facts.

Models: Theories are general and cover many ideas. To explain *particular* ideas, **models** are constructed. A model can be in the form of words, diagrams, physical models or mathematical formulae. For example, the kinetic particle theory applies to all matter, while the diagram on page x is a particle model for solid gold.

Limitations of the Scientific Method

The scientific method is used to acquire an understanding of nature but it has some limitations. Two limitations are mentioned below.

1. **Scientific knowledge is not fixed — it is always tentative**

   In science, a theory explains known facts. If there are new facts that it cannot explain, the theory is then modified to explain them. If this is not possible, scientists discard the theory for new ones. Therefore, scientific knowledge is never fixed but is always changing and improving.

2. **Science cannot answer all questions**

   Science has answered many questions about nature. However, science cannot provide answers to all questions or solve all problems. For example, although scientists can predict the strength of a typhoon and the path it will take, they cannot prevent it from happening. In addition, scientists cannot answer moral questions or solve many problems that people have. In fact, these are not part of the study of science.

In this course, you will see how ideas, theories and models in chemistry have been changed and improved when they were not able to explain new facts.

Why Study Chemistry?

There are several reasons why we study chemistry. Here are some of them.

1. Firstly, a basic knowledge of chemistry can help us in many ways in our daily life.
   - We can learn something about home safety. For example, knowing how to use gas safely and handling chemicals properly by reading their hazard warning labels.
   - We can become better-informed consumers. For example, by reading the labels on cans of food or medicine, we know what we are buying.
   - We can learn about ways to protect the environment. For example, we learn to recycle metals and plastics instead of dumping them on used land; to use clean fuels in vehicles, industries and power stations so that we reduce air pollution.
2. Secondly, through studying chemistry, we can acquire useful skills. These include skills for thinking, problem solving, being creative, working with others and communication. These skills will be useful throughout our lives and can be applied in our work.
3. Thirdly, chemistry is required for many fields of study. For example, courses in pharmacy and medicine require applicants to have a knowledge of chemistry.

Learning Outcomes

After completing this chapter, you should be able to:

- explain, with examples, why pure substances are needed
- suggest methods of separation and purification given information about components of mixtures
- describe methods for separation and purification
- interpret chromatograms including comparison with 'known' sample and the use of R_f values
- explain the need to use locating agents in the chromatography of colourless compounds
- deduce from the given melting point and boiling point, the identities of substances and their purity
- explain that the measurement of purity in substances used in everyday life is important

2.1 What is a Pure Substance?

A **pure substance** is a single substance not mixed with anything else.

White sugar is a **pure substance**. No other substance is present. A crystal is also a pure substance. Crystals of copper(II) sulfate prepared in the laboratory are pure (Figure 2.1). In nature, very few substances are pure. Most substances are impure and in the form of mixtures.

Figure 2.1 Crystals of copper(II) sulfate are pure.

A **mixture** consists of two or more substances that are not chemically combined together.

Seawater is a **mixture** as it contains water, salt and other dissolved solids. Milk is a mixture of fats and other solids in water (Figure 2.2).

Figure 2.2 Milk is a mixture of fats and other solids in water.

Many industries need pure substances to make products such as foods, medicines, computer chips and chemicals (Figures 2.3 to 2.5).

Figure 2.3 In the pharmaceutical industry, medicines must be pure. Impurities can be dangerous as they may poison people.

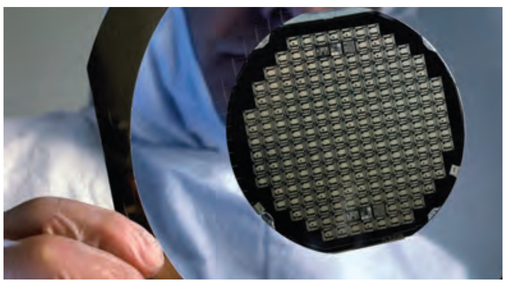


Figure 2.4 In the computer industry, silicon is used to make silicon chips. Extremely pure silicon (99.999 999% pure) has to be used.

Figure 2.5 Chemicals used in analysis of substances must be pure to ensure that the analysis results are accurate.

Mystery Clue

When sodium chloride is extracted from the Great Salt Lake, it is not a pure substance. Explain why.

Skills Practice

1. How can you tell that white sugar is pure by simply looking at it? [*inferring*]
2. List some other examples found in daily life that are
   (a) pure substances, and
   (b) mixtures.
   [*recalling, elaborating*]
3. Air is a mixture of gases. Name these gases. [*recalling*]
4. The chemicals we use in the laboratory should be pure. Suggest a reason. [*evaluating*]

Figure 2.6 Stones in water

2.2 How are Pure Substances Obtained?

Mixtures can be easily separated into pure substances. This process is called **purification**. It is done by using physical methods without chemical reactions. Several methods of purification are discussed as follows.

Decanting

Look at Figure 2.6 on the right. How can you remove the stones from the water? The easiest way to do this is to just pour off the water. This is called decanting (Figure 2.7).

Decanting separates an insoluble solid from a liquid by pouring off the liquid from the container.

Decanting is also common in daily life. For example, when cooking, we often pour off water from foods by decanting.

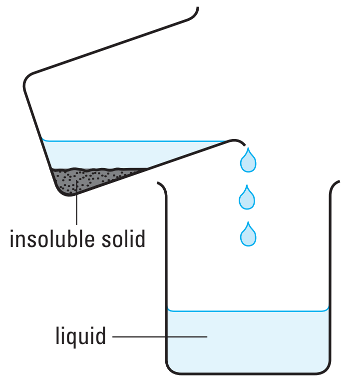


Figure 2.7 Decanting by pouring off the liquid from the container

Filtration

When we want to separate small solid particles, such as sand, from water, we use a method called **filtration**.

Filtration is used to separate an insoluble solid from a liquid.

A simple way of doing this is shown in Figure 2.8.

The mixture is poured into a filter paper. A liquid passes through small holes in the filter paper. The insoluble solid cannot pass through and is trapped in the filter paper.

The solid collected in the filter paper is called the **residue**. The liquid passing through the filter paper is called the **filtrate**.

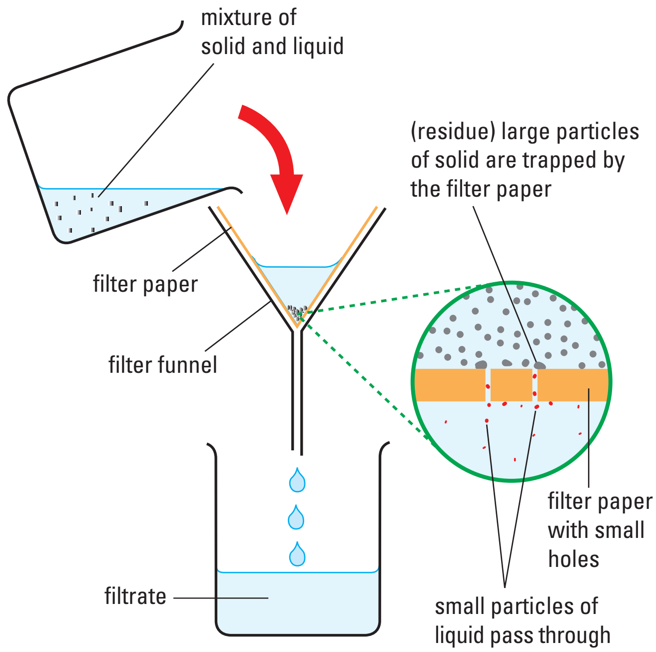


Figure 2.8 Filtration

Uses of filtration

Apart from being used in the laboratory, filtration is also used in our bodies as well as in our daily lives.

- **Nose:** The human nose filters particles from the air to ensure that the air we breathe in is clean.
- **Kidneys:** Our kidneys use filtration to separate wastes (and extra water) from our blood. The waste and water then pass out of the body as urine.

- **Water filtration:** Much of Singapore's drinking water comes from rain water collected in local reservoirs and from rivers in Johor, Malaysia. At water purification plants (Figure 2.9), large filters are used to remove sand and mud from water. The filters in these plants do not use filter paper, but consist of layers of sand, gravel and pebbles (Figure 2.10).

Figure 2.9 A water purification plant at Bukit Timah

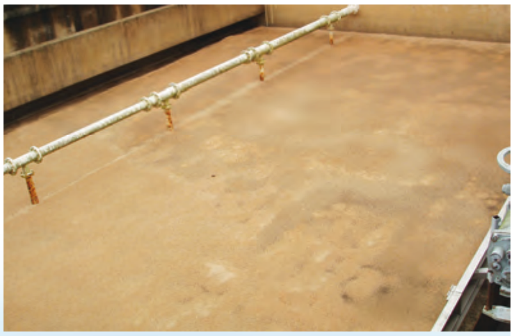


Figure 2.10 Sand filter in a water purification plant

Evaporation

How can we separate common salt from a salt solution?

Common salt dissolves in water to form a salt solution. We cannot use filtration to separate salt from its solution as the dissolved salt passes through the filter paper. To obtain common salt from a salt solution, we use a method called **evaporation** (also called evaporation to dryness). During evaporation, the solution is heated and water changes into steam. When all the water has evaporated, solid salt remains as a residue.

Evaporation is used to separate dissolved solids from a solution.

In some countries, salt is obtained by evaporating seawater in large open areas called 'salt pans' (Figure 2.11). Heat from the Sun slowly evaporates the water in the pans, leaving behind solid salt.

Figure 2.11 Salt pans

Separating two solids

A mixture of two solids can be separated by combining filtration and evaporation if one solid is soluble in a solvent and the other is insoluble. In the example above, suppose the salt is mixed with sand. As sand is insoluble in water, it is first removed by filtration. The salt is then obtained by evaporation.

Problems with evaporation

Evaporation has two disadvantages:

1. Some solids decompose when heated. Sugar is an example. If a sugar solution is evaporated to dryness at a high temperature, the solid sugar obtained decomposes to black carbon.
2. With evaporation, any soluble impurities will also be present in the solid residue.

Crystallisation

The best method to obtain a pure solid from a solution is **crystallisation**.

Crystallisation separates a dissolved solid from a solution, forming pure crystals of the substance. One way to carry out crystallisation is to heat a solution to evaporate off the solvent until a saturated solution is obtained. The hot, saturated solution is then allowed to cool. As it cools, pure crystals of the dissolved solid (solute) form. The impurities remain in the solution.

Figure 2.12 shows the main steps involved to obtain crystals from a solution.

Mystery Clue

Explain why the water in the Great Salt Lake became so salty and why deposits of solid salt form on the shores of the lake.

Practical Workbook

• Experiment 2.1

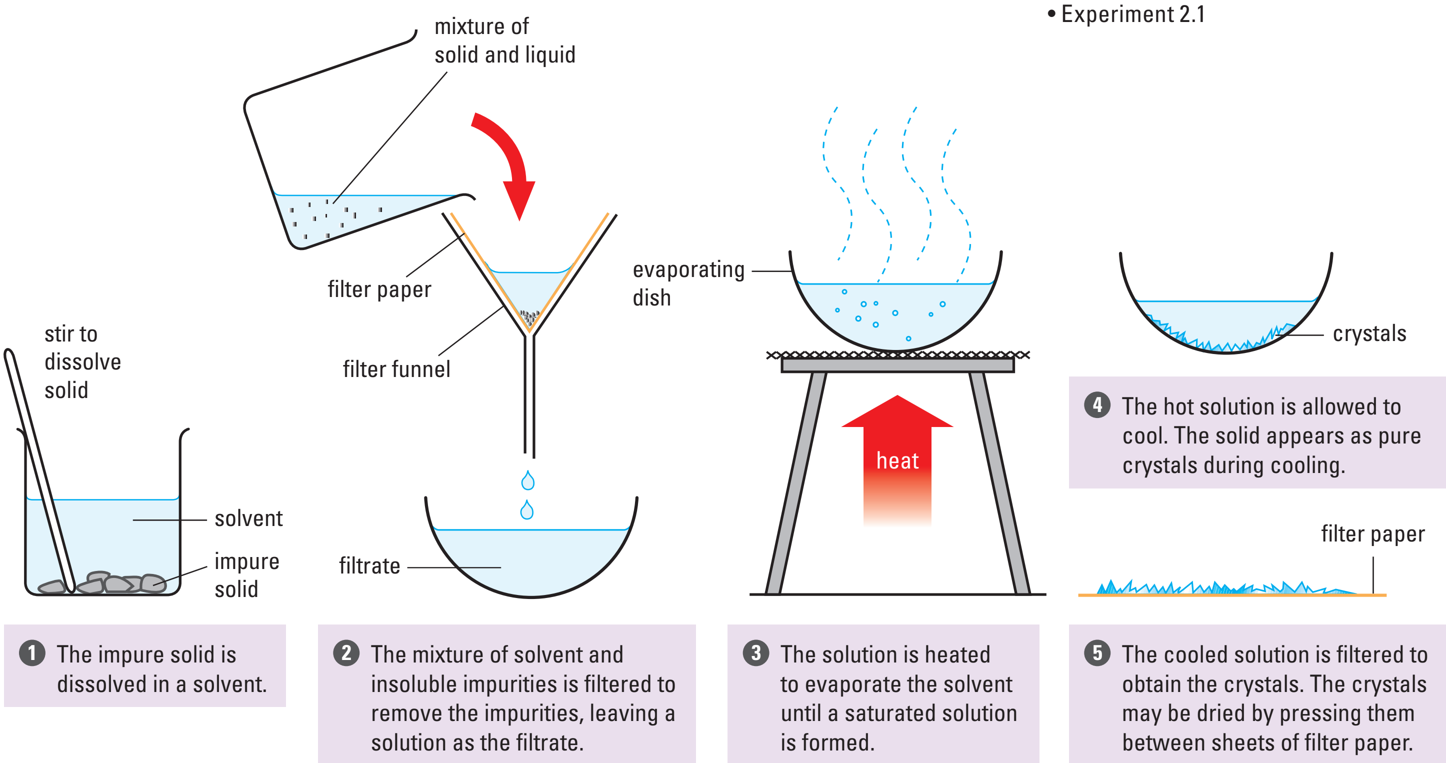


Figure 2.12 Purification by crystallisation

Why are crystals formed?

Crystallisation occurs because the solubility of most solutes decreases as the temperature decreases. That is, less solute can dissolve in a solution at a lower temperature than at a higher temperature. As a hot solution cools, it eventually becomes saturated, that is, it can hold no more solute. The extra solute, that cannot be dissolved, separates as pure crystals. Impurities, if present in small amounts, remain in the solution.

Crystallisation from a solution is the most common method used by chemists to purify solids. Pure sugar is obtained this way.

Crystallisation without a solvent

Some solids can be purified by melting them. The hot liquid is then cooled slowly. Pure crystals form as the liquid freezes. This is crystallisation without a solvent. This is how crystals of rock, such as quartz, are produced from molten rock in the Earth (Figure 2.13).

Topic Link

Crystallisation is an important step in the preparation of soluble salts.
Chapter 16

Figure 2.13 Pure quartz crystals