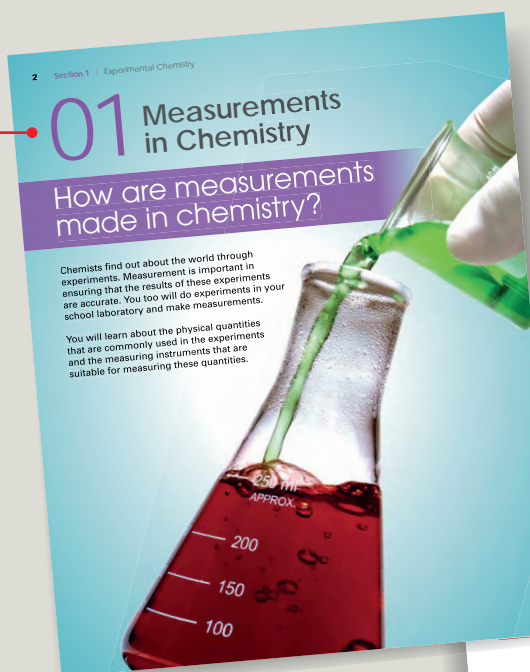


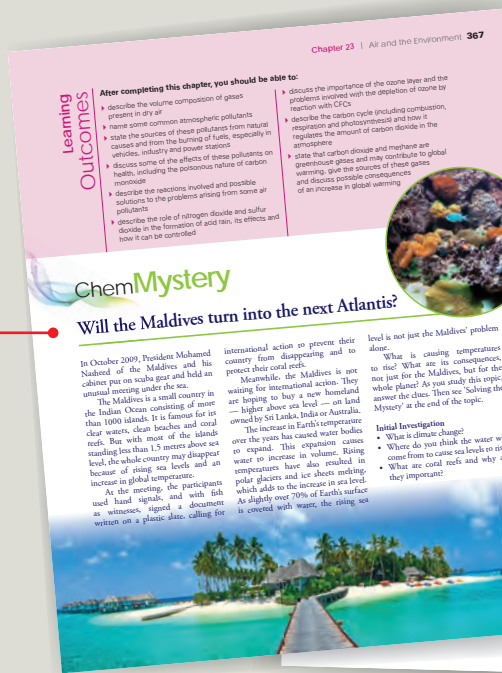
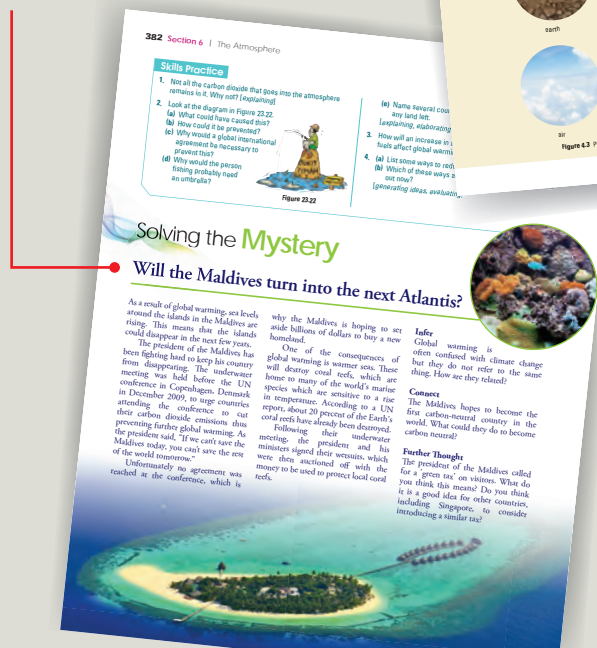


Features

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.

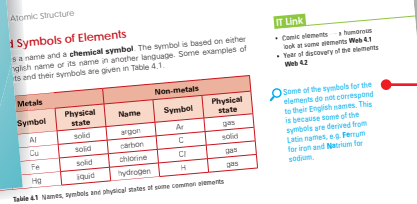


Solving the Mystery — found at the end of the concluding chapter, relates the study concepts involved by way of an in-depth explanation of the Mystery.



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:

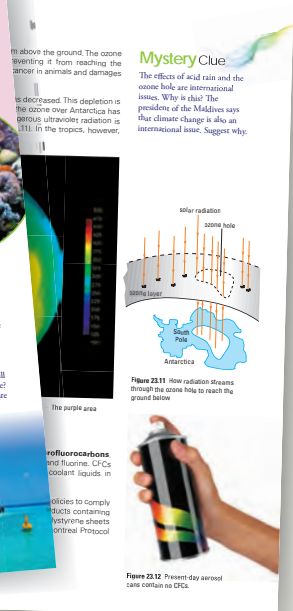
- a word analysis of chemistry terms to help students understand the meaning of these terms
- means to help students to remember chemistry concepts learnt and
- interesting facts that point out the relevance of chemistry to everyday life.

Chemistry in Society

A Little History — Elements and Symbols



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.



7 Chemistry Inquiry

Which Method Would You Choose to Prevent Rusting?

Suggest, with reasons, a suitable method of protecting the steel frame of the Cavenagh Bridge from rusting (Figure 13.23).

Inquiry Skill: Decision-making

Decision-making involves the use of criteria to make a choice or decision from various alternatives. It is a skill embedded in daily life as well as in chemistry. Here are steps you can use when making a decision:

1. State what you want to **decide**.
2. List your **choices** or alternatives.
3. List the **criteria**, that is, the things that are important in making a good decision.
4. Give **how well** the choices match the criteria.
5. **Decide**, with reasons, which choice is best.

To decide: Suitable methods to prevent the steel of the bridge from rusting.

Choices: The different methods of preventing rusting studied in this chapter.

Criteria: Examples are, cost, attractiveness, short/long time for protection.

Possible choice: Painting as it offers good protection though only for a short time. But as it is cheap and easy to do, the bridge can be re-painted when necessary.

Group Discussion

1. What other methods of rust prevention might be used to protect the bridge? Why would you not use them?
2. What other methods are not suitable for protecting the bridge? Explain.

Skills Practice

1. Explain the following:
 - (a) Life rusting occurs in the Sahara desert.
 - (b) Iron objects rust easily in Singapore.
 - (c) Iron will not rust on the moon. [explaining]
2. A tin can of food rusts very quickly when scratched. A polished can does not rust quickly when scratched. Suggest an explanation for this difference. [explaining, comparing]
3. (a) Which metal, magnesium or zinc, is more effective in preventing rusting? Why? [explaining]
 (b) Zinc and not magnesium, is used to coat steel rods. Why? [explaining]
4. Suggest a suitable method of protecting the following from rusting:
 - (a) The steel frame of a bicycle
 - (b) The chain of a bicycle
 - (c) A steel lock
 - (d) Iron railings along the road
 - (e) Steel tools and instruments used in hospital operations [decision-making]
5. Stainless steel barriers are placed across some MRT stations. Think carefully about this:
 - (a) List the advantages of using stainless steel compared to using painted or galvanized steel.
 - (b) List any disadvantages of using stainless steel. [comparing]



Figure 13.23 The Cavenagh Bridge over the Singapore River

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.

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.

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.

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.

The Halogens

The reactions are similar in ways which also group:

After all electrons and are one electron short (s). Therefore, they take one electron to form the same electronic structure as that of a noble gas.

to form compounds called **halides**. For example: sodium chloride (NaCl), sodium iodide (NaI).

Formulae: sodium chloride (NaCl), sodium iodide (NaI).

down the group. Bromine is less reactive than chlorine (Figure 12.9).

Reactivity Chlorine is more reactive than bromine.



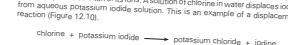
Figure 12.10 The reaction of chlorine with aqueous potassium iodide solution

To learn more about Group VII elements Web 12.2

Topic Link Chapter 21

Practical Workbook Experiment 12.1

2. A more reactive halogen will displace (take the place of) a less reactive halogen from an aqueous solution of its ions. A solution of chlorine in water displaces iodine from aqueous potassium iodide solution. This is an example of a displacement reaction (Figure 12.10).



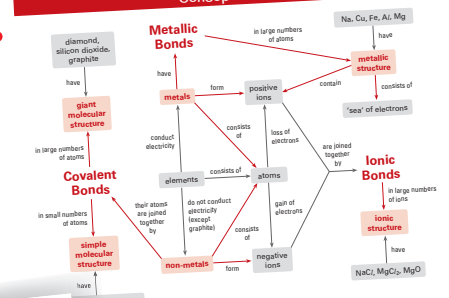
The aqueous potassium iodide turns brown due to the iodine produced.

Skills Practice

1. (a) What type of bonds do halogen molecules have? Are these bonds strong or weak? [explaining]
 (b) Are the forces between halogen molecules strong or weak? [explaining]
2. Explain why halogens have low melting points. [explaining]
3. What happens to the melting point down Group VII? How does this compare with the melting points down Group I? [explaining, comparing]
4. Bromine displaces iodine from aqueous sodium iodide solution.
 - (a) What is the reason for this?
 - (b) Write the chemical equation with state symbols for this reaction. [explaining, communicating, writing equations]
5. Bromine does not react with aqueous sodium chloride solution. Why? [explaining]

07 Chapter Review

Concept Link



Practice

1. Structured Questions

Table 7.5 shows some physical properties of the substances.

Substance	Melting point (°C)	Boiling point (°C)	Electrical conductivity when solid	Electrical conductivity when molten
A	119	445	does not conduct	does not conduct
B	776	1590	does not conduct	conducts
C	3550	4830	does not conduct	does not conduct
D	1084	2580	conducts	conducts

1. (a) Which substance is a metal?
 (b) Which substance is a giant ionic structure?
 (c) Which substance is a simple molecular structure?
 (d) Which substance is a giant molecular structure?
 (e) Which substance is a simple molecular structure with a high melting point?
 (f) Which substance is a simple molecular structure with a low melting point?

2. Here are the formulae for three compounds: CCl_4 , CaF_2 , FeSO_4 .

(a) Write names for each of the compounds.
 (b) Which of the compounds contain:
 (i) ionic bonds?
 (ii) covalent bonds?
 (c) Which of the compounds contain:
 (i) both ionic and covalent bonds? Explain your choices.
 (ii) both ionic and covalent bonds? Explain your choices.
 (iii) Predict two physical properties for each substance (except for melting and boiling points). Explain.

3. An element R with five valence electrons and element Q with seven valence electrons combine to form a compound. Predict the following for the compound:

- (a) The formula.
- (b) The kind of structure.
- (c) If its melting point will be high or low.
- (d) Its solubility in water.
- (e) Whether it can conduct electricity or not.

4. Solid carbon dioxide is called 'dry ice'. It is often used to keep food cold. It is also used at concerts to produce 'stage smoke' as shown in Figure 7.27.

(a) Does carbon dioxide have a high or low melting point? Explain.

(b) Frost on carbon dioxide quickly sublimates. Explain.

(c) What does 'sublimation' mean? Explain.

(d) Carbon dioxide has a simple molecular structure. Explain.

(e) State one property of carbon dioxide that is typical of substances with this type of structure.

(f) What is the formula for a carbon dioxide molecule?

5. Potassium bromide melts at 735 °C. Tin(IV) bromide melts at 20 °C. Answer the following questions on these two compounds:

- (a) What are the formulae for the compounds?
- (b) What type of bonding does potassium bromide have? Explain.
- (c) What structure does tin(IV) bromide probably have? Explain.

II. Free Response Questions

1. A student made the following statement: 'Oxygen is a gas because the bonds between the atoms in the molecules are weak.' Briefly discuss the accuracy of this statement.

2. With the help of electron diagrams, describe the formation of magnesium chloride and sodium chloride from atoms of the relevant elements. Then state, with reasons, which of the two compounds will have a higher melting point.



Figure 7.27

Self-Management

Doing activities to make sure you have really learnt.

ception Analysis

State the following statements. Are they true or false? Explain why. Check the answers at the back of the book if you have any misconceptions.

1. Metals conduct electricity because of the movement of ions. **True/False**

2. If a substance (including mercury) is a liquid of molecular structure, it has a simple molecular structure. **True/False**

3. All forms of carbon are hard. **True/False**

4. When a molecular substance melts, the atoms in the molecules separate. **True/False**

5. Metals conduct electricity because of the movement of ions. **True/False**

6. Metals conduct electricity because of the movement of ions. **True/False**

7. If a substance (including mercury) is a liquid of molecular structure, it has a simple molecular structure. **True/False**

II. Self-Check

Complete Self-Check 7 to check what you should know and understand in this chapter. Go to the Pearson website to download the checklist.

Extension

1. Investigations with Pencils

Figure 7.28 shows different types of pencils, such as B, H, HB and 3H. H means 'hard' and B means 'black'. Pencils lead is a mixture of graphite (a soft material) and clay (a hard material).

(a) Cut the different types of pencils. Carry out experiments to answer the following questions:

- (i) Which pencils have the blackest markings?
- (ii) Which pencil lead breaks more easily? Which pencil lead breaks less easily?
- (iii) Suggest how the amounts of graphite and clay differ in H, B and HB pencils. Use your suggestions to explain your observations in (i).

Figure 7.29 shows how electricity is supplied to an MRT train.

(a) Why is a metal rail connected to the electricity supply?

(b) What are the purposes of graphite in the system shown in Figure 7.29?

(c) Suggest a suitable material for contact X.

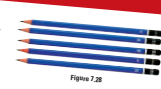


Figure 7.28

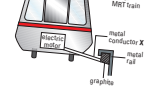


Figure 7.29

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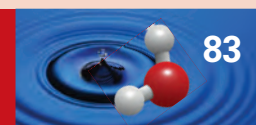
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Introduction:

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



Robert Boyle (1627–1691)

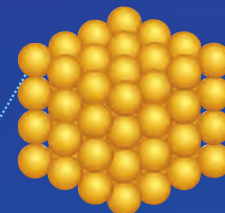
Chemistry as we know it today developed in Europe in the 17th century. One chemist, often regarded as the 'Father of Chemistry', was Robert Boyle. Boyle was the first to develop modern ideas of elements and compounds and to use the scientific method as a method for acquiring knowledge.

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.



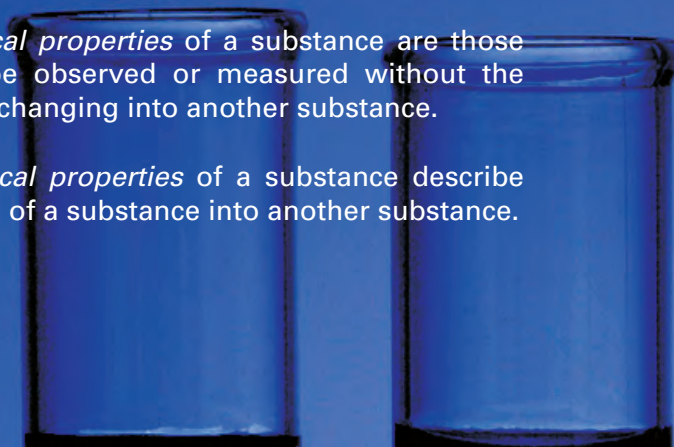
The structure of gold

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.

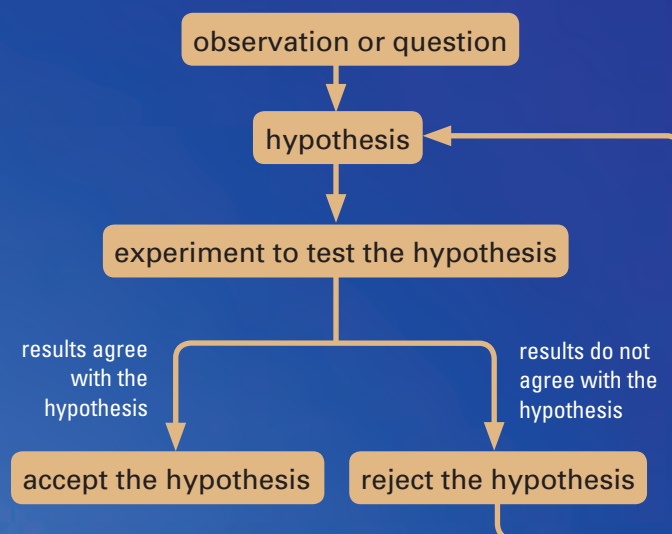
For example,

- 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

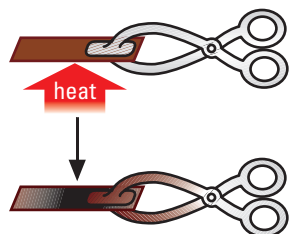
Using the Scientific Method

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.



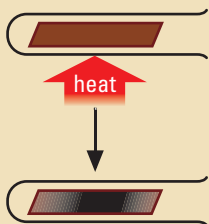
Explanation

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.

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.

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.

Prediction

From the second hypothesis, we can make a prediction.

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

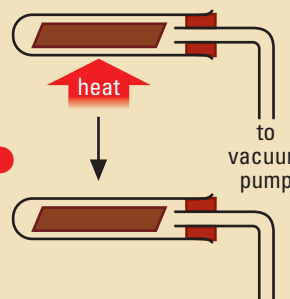
Second Hypothesis

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.

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.

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).

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



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



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



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

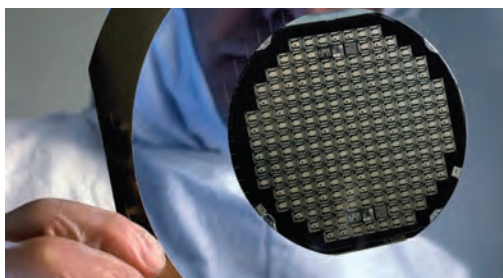


Figure 2.4 In the computer industry, silicon is used to make silicon chips. Extremely pure silicon (99.999 999% pure) has to be used.



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*]

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.

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**.

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.



Figure 2.6 Stones in water

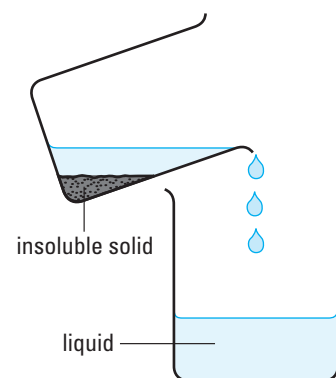


Figure 2.7 Decanting by pouring off the liquid from the container

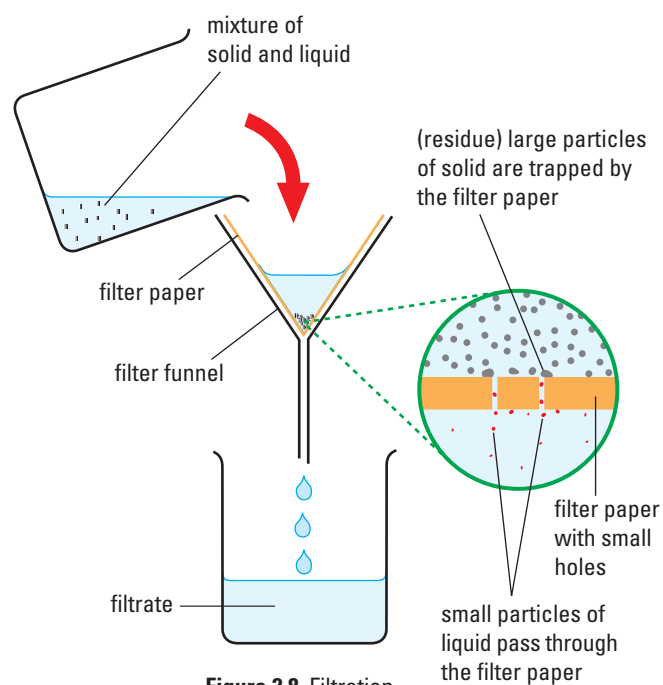


Figure 2.8 Filtration

- **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).

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 2.9 A water purification plant at Bukit Timah



Figure 2.10 Sand filter in a water purification plant



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.

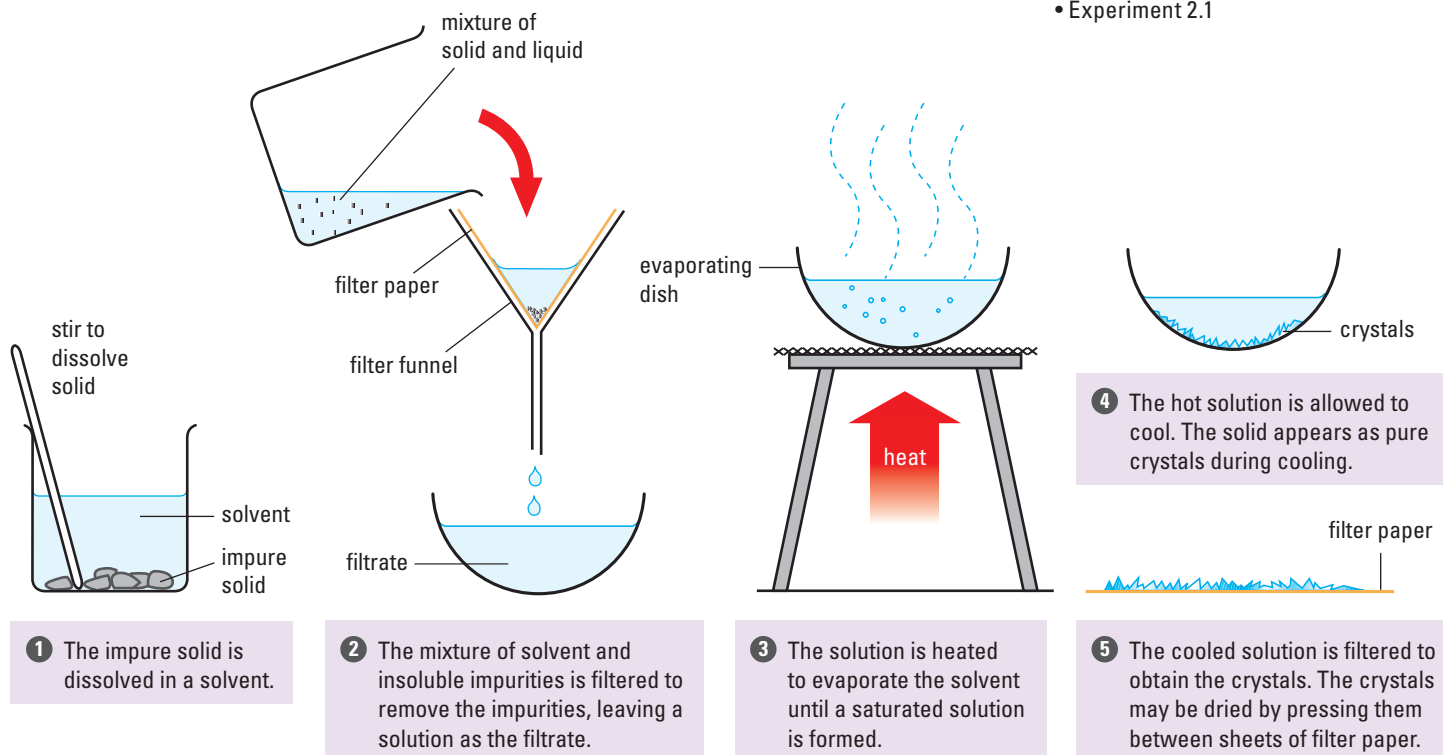


Figure 2.12 Purification by crystallisation

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).

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

Topic Link

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

Chapter 16



Figure 2.13 Pure quartz crystals