15 Acids and Bases

Introduction

Acids and alkalis are involved in many chemical processes, which range from industrial processes to biological processes, from reactions in the laboratory to reactions at home. In this chapter, students learn about the properties of acids and bases/alkalis, acid-alkali/base indicators, the pH scale as a measure of acidity and alkalinity and the strengths of acids and alkalis. The knowledge gained in this chapter forms the basis for subsequent work on neutralisation, salts and acid-base volumetric analysis.

Chapter Opener (page 220)

1. Begin the chapter by discussing the following questions. Precise answers are not needed at this stage.

   What are the names of some acids? What properties do they have in common?

   Answer: Some of the acids commonly found in the laboratory are hydrochloric acid, sulfuric acid and nitric acid. Acids have a sour taste; are hazardous; turn blue litmus paper red; react with some metals to produce hydrogen gas; react with carbonates to produce carbon dioxide gas; react with metal oxides and hydroxides to produce a salt and water.

   What is an acid-base indicator? What are some indicators used in the laboratory?

   Answer: An indicator is a substance that is has different colours in an acids and alkalis. Litmus, phenolphthalein and pH paper are indicators.

   What is an ionic equation and how does it differ from a chemical equation?

   Answer: An ionic equation is an equation for reactions involving ions in aqueous solutions.

2. Carry out an 'Inquiry Preview.'

Stimulation

Introduce this topic by bringing a variety of common foodstuffs and drinks that contain acids to class. Get students to taste the foods and to describe the taste of acids as sour. (Note: Do not use foods or drinks that contain a lot of sugar as this will mask the sour taste.) Ask students the following questions which serve as an introduction to the ideas to be taught in this chapter.

- Name some acids that you have already studied. [See Section 15.1 on page 249 of the Textbook.]
- How can we test for the presence of an acid? [The presence of an acid can be tested by using indicators. For example, acids turn blue litmus red.]
- What is the taste of acids? Why do we not taste substances in the laboratory? [Acids taste sour. Substances may be harmful.]
- What gas is formed when an acid reacts with a metal? [Hydrogen gas]
- Are acids harmful? What would you do if some acid spills onto your hand? [Acids are hazardous. Wash the acid off by placing the hand under running water from a tap.]

As an optional homework exercise, students could carry out the information search in Exercise 15.1A of the Theory Workbook.

Learning Outcomes

After completing this chapter, students should be able to:

- define acids and alkalis in terms of the ions they produce in aqueous solution and their effects on indicators
- describe the characteristic properties of acids in reactions with metals, bases and carbonates
- state some uses of acids including sulfuric acid
- describe the characteristic properties of bases in reactions with acids, metal ions and ammonium compounds
- describe the difference between strong and weak acids and alkalis in terms of the extent of ionisation
- describe the pH scale as a measure of relative acidity and alkalinity
- construct ionic equations

Teaching pointers

15.1 Common Acids (page 222)

1. Many sweets contain ascorbic acid which gives them a sour taste. Fizzy drink powder is usually a mixture of citric acid and tartaric acid. Link the names of citrus fruits such as oranges, lemons and grapefruit to the presence of citric acid.
2. You may mention that the three common laboratory acids are called mineral (or inorganic) acids as they can be obtained from minerals in the ground.
3. Link the concentration of laboratory acids to the idea of concentration and its units which were introduced in Chapter 9.
4. Get students to notice that the formulae for all the laboratory acids contain hydrogen. Students will learn in Section 15.2 that it is the presence of hydrogen ions that give acids their acidic properties. They will also learn that acids such as ethanoic acid, CH_3COOH, have both ionisable and non-ionisable hydrogen atoms.

5. All acids have a sharp and sour taste. This is what most people mean when they say something is acidic. This taste is often associated with acidic fruits such as lemons, limes and star fruits. The taste of an acid is due to the presence of hydrogen ions, $H^+(aq)$. You may distribute acidic sweets among the students to let them experience the sour taste (but do not do so if the lesson is conducted in the laboratory).
6. Demonstrate the effect of acids on blue litmus paper.
7. Restrict the discussion on the reaction of metals with acids to dilute hydrochloric acid and dilute sulfuric acid as dilute nitric acid does not react like a typical acid. Point this out to students so that they do not use nitric acid when answering questions related to the reaction of metals with acids during the examinations.
8. The properties of acids discussed in this chapter come into the changing definition of an acid over time, which will be investigated in Exercise 15.2B of the Theory Workbook. An alternative version of this, in the form of a flow chart, is contained in Additional Exercise 1 which is found at the end of the chapter. The worksheets may be photocopied and distributed to the class.

Skills Practice (page 225)

1. The 5 mol/dm³ acid is more concentrated; it has more solute (acid) in each unit volume (dm³) of solution.
2. Copper does not react with dilute hydrochloric acid or dilute sulfuric acid as it is below hydrogen in the reactivity series.
3. **(a)** Bubbles of a colourless gas (hydrogen) are produced very slowly.
   (b) Bubbles of a colourless gas (carbon dioxide) are produced.
4. **(a)** $Mg(s) + H2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2(g)$
   (b) $MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$
   (c) $Cu(OH)_2(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + 2H_2O(l)$
   (d) $ZnCO_3(s) + 2HNO3(aq) \longrightarrow Zn(NO_3)2(aq) + CO_2(g) + H_2O(l)$
   (e) $2NaHCO_3(s) + H_2SO_4(aq) \longrightarrow Na2SO_4(aq) + 2CO_2(g) + 2H_2O(l)$
5. **(a)** Acids do not react with glass. Also, as glass is transparent, it enables us to see how much acid is in the bottle.
   (b) Copper, unlike aluminium, does not react with dilute acids. Therefore, cooking with vinegar or other acids will not corrode a copper pot.

Notes for Teachers

Discovery of strong mineral acids

There is some uncertainty as to when the three strong mineral acids, sulfuric acid, nitric acid and hydrochloric acid, were first discovered. The discovery of these strong acids probably happened in the Middle East during the 9th Century through the work of Muslim alchemists. The acids were 'rediscovered' in Europe in the 13th Century, based on translations of the earlier Arabic documents.

Sulfuric acid: This was made by heating vitriols which contain copper(II) sulfate, $CuSO_4.5H_2O$ (blue vitriol) and iron(II) sulfate, $FeSO_4.7H_2O$ (green vitriol). The vitriols decompose to the metal oxides, giving off water and sulfur trioxide which combine to produce dilute sulfuric acid. The acid was then called oil of vitriol, among other names.

Nitric acid: This was probably the first mineral acid to be discovered. It is made by distilling both saltpetre (potassium nitrate, KNO_3) and vitriols together. The vitriols form sulfuric acid which reacts with the saltpetre.

Hydrochloric acid: This was known as spirit of salt. The acid was probably made by heating common salt or sal ammoniac (ammonium chloride) with sulfuric acid. It was also discovered that the gas produced in the reaction (hydrogen chloride) had to be dissolved in water.

This discovery of these acids was the most important advancement in Chemistry after the successful production of iron from its ore some three thousand years before. Many chemical reactions could be carried out with the aid of these strong mineral acids. These reactions could not be carried out by the earlier Greeks and Arabs as the strongest acid they had at their disposal at that time was vinegar.

Teaching pointers

15.2 Why is Water Important for Acids? (page 225)

1. In Experiment 15.2A of the Practical Workbook, students investigate the role of water in the properties of acids using citric acid. The Textbook uses the example of hydrogen chloride which is conceptually easier to explain and to represent in diagrams, but is more difficult to handle in an experiment.
2. Perhaps prepare some hydrogen chloride and dissolve it in methylbenzene (toluene), a non-aqueous solvent. Add a piece of blue litmus paper and a piece of magnesium to this solution. Repeat with hydrochloric acid, i.e. a solution of hydrogen chloride in water.
3. You may want to demonstrate that hydrogen gas is formed when electricity passes through an acid solution, using apparatus such as that shown in Figure 15.16 on page 225 of the Textbook. However, as students have not yet studied the electrolysis of dilute acids, they will have to accept for the moment that acids contain hydrogen ions.
4. The positive ion in acid solutions is actually the hydroxonium ion, H_3O^+. However, do not mention this ion to the students. Use the simplified form of $H^+(aq)$ instead.
5. For dibasic and tribasic acids, ionisation actually occurs in steps. Consider sulfuric acid:

   Step 1: $H_2SO_4(l) \longrightarrow H^+ (aq) + HSO_4^-(aq)$

   Step 2: $HSO_4^-(aq) \longrightarrow H^+ (aq) + SO_4^{2-}(aq)$

   However, when discussing basicity, there is no need to refer to this stepwise ionisation of acids. For convenience, just use the overall equation.

   $$H_2SO_4(l) \longrightarrow 2H + (aq) + SO_4^{2-}(aq)$$
6. Emphasise that not all the hydrogen atoms in an acid necessarily form hydrogen ions. For example, in ethanoic acid, only one of the hydrogen atoms forms a hydrogen ion.
7. **Note:** In inorganic acids, the ionisable hydrogen is written first in the formula. For example, hydrochloric acid is written as **H**C*l*. In organic acids, the ionisable hydrogen is written last. For example, ethanoic acid is written as CH_3COO**H**.
8. Get students to look at the label on a bottle or packet of fizzy powder and identify the solid acids present in it. Due to the chemical complexity of the formulae for these acids, students are not expected to know the chemical equations. Add some of these solid acids to water and observe the gas produced.

   Get the class to explain the reaction.

9. Optional: you may discuss the chemistry concepts involved in baking a cake. Demonstrate the rising of a cake using a commercial cake mix. See 'Notes for Teachers' on the next page.

10. In Activity 15.1 of the Theory Workbook, students will see how the definition of an acid has undergone many changes as new facts or theories about acids show the existing definition to be wrong or inadequate.

11. At room temperature, 1 mol/dm^3 ethanoic acid solution is about 0.4% ionised, i.e. for every 100 ethanoic acid molecules, four molecules are ionised to give hydrogen ions.

12. Carbonic acid also contains a few HCO_3^-(aq) ions due to the reaction of CO_3^{2-}(aq) ions with water. **Note:** Students do not be need to know this point at 'O' Level.

13. Demonstrate the differences in reactivity of strong and weak acids by adding a piece of magnesium to each of two test tubes containing dilute hydrochloric acid and dilute ethanoic acid. Compare the rate at which gas is evolved.

14. Students often confuse the terms 'strong' and 'weak' with 'concentrated' and 'dilute'. Differentiate clearly the meaning of these terms. Use Figure 15.20 on page 228 of the Textbook in your explanation.

15. The equation for the dissociation of ethanoic acid contains a double arrow. Discuss briefly with the class that such reactions are reversible and proceed in both directions. (Students will learn more about reversible reactions when studying the Haber Process in Chapter 17.)

Chemistry Inquiry (page 227)

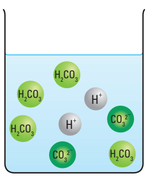
What is the Basicity of Ethanoic Acid?

Group Discussion

1. Refer to the definition on page 226.
2. (a) $H_3PO_4(aq) \longrightarrow 3H^+(aq) + PO_4^{3-}(aq)$
   (b) Tribasic.

Skills Practice (page 228)

1. The double arrow shows that the reaction is reversible/proceeds in both directions. (Students will learn more about reversible reactions when studying the Haber process in Chapter 17.)

2. 

Note: Water molecules are not drawn but are represented by the background shading.

3. A strong acid is one that is completely ionised in water. A weak acid is one that is only partially ionised in water.

4. **(a)** Hydrogen ions, H^+ (aq) and sulfate ions, SO_4^{2-}(aq).
(b) Hydrogen ions, H^+ (aq), ethanoate ions, CH_3COO^-(aq) and ethanoic acid molecules, CH_3COOH(aq).
(c) Hydrogen ions, H^+ (aq) and nitrate ions, NO^{3-}(aq)

5. **(a)** Carbon dioxide gas
(b) The reaction with nitric acid will be faster as nitric acid is a strong acid.

Chemistry in Society (page 229)

Everybody's Favourite Acid

Exercise

1. No. Strawberries contain less citric acid and thus would not be as equally effective in removing rust.
2. (a) Citric acid is found in many fruits, which are thought to be an important part of a healthy diet. This meant that these fruits, which people consume all this while, could actually be harmful.

   (b) The impact would be greater because the internet allows for information to be spread to a larger group of people in a very short amount of time.

   (c) When obtaining information from external sources, we need to verify and cross-check with other authoritative sources to ensure that the information is accurate.

Notes for Teachers

The Chemistry of baking a cake

Baking powder is used in the making of a cake. It consists of either sodium hydrogencarbonate (also known as baking soda) or a mixture of sodium hydrogencarbonate and a solid acid (tartaric acid). To make a cake, baking powder is mixed with flour and water and heated. The following reactions occur.

- If baking powder contains only sodium hydrogencarbonate, the equation is as follows:

$$2NaHCO_3(s) \longrightarrow Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

- If both sodium hydrogencarbonate and an acid are present, they react in the presence of water to produce carbon dioxide gas.

The carbon dioxide gas produced spreads through the flour or cake mixture, causing the cake to 'rise'.

Teaching pointers

15.3 What are Bases and Alkalis? (page 230)

1. The word alkali comes from the Arabic word 'al-qily' which means 'to roast in a pan'. Originally, the roasted ashes of marine plants gave sodium or potassium carbonate. The ashes were mixed with slaked lime to give solutions of sodium hydroxide or potassium hydroxide. This technique was in use more than 1100 years ago.
2. You may show the class some household products that contain alkalis, e.g. cleaning liquids such as window cleaner (which contain ammonia solution), over cleaner (which contain sodium hydroxide) and soaps (which contain sodium salts of organic acids). See also the examples in Figure 15.31 on page 231 of the Textbook. Students might feel the more dilute ones to note the slippery feel of alkalis.
3. Sodium hydroxide is a more commonly used alkali than potassium hydroxide as it is cheaper to manufacture. Sodium hydroxide is known as caustic soda (caustic = burning/corrosive; soda = compound containing sodium). Potassium hydroxide is known as caustic potash (potash = compound containing potassium).

4. Precipitation reactions: Emphasise that solid precipitate contains ions. Link this idea to the study of solid ionic structures in Chapters 5 and 7. It is not necessary to consider the solubility of the precipitates in excess alkali here. Solubility of metal ions in excess alkalis will be investigated in Chapter 18, when tests are carried out to identify the metal ions.
5. At this stage, write all equations as chemical equations and not ionic equations. Ionic equations will be introduced in Section 15.5.
6. Ammonia solution, a weak alkali, has no NH_4OH molecules. The solution consists of ammonia molecules, ammonium ions and hydroxide ions. Hence the term 'ammonium hydroxide', once used for ammonia solution, is incorrect.

(page 231)

Mystery Clue

Concentrated sodium hydroxide is hazardous as it burns the skin and other body tissues. To treat an alkali spill on the body, wash it under a tap with large amounts of water. (Refer to the table for "First Aid in the Laboratory" on page 3 of the Practical Workbook. Also note the warning included with Experiment 15.3 on page 79 of the Practical Workbook.)

Skills Practice (page 232)

1. Two common alkalis are sodium hydroxide and ammonia solution. Sodium hydroxide is found in oven and floor cleaners while ammonia solution is found in window cleaners.
2. **(a)** $ZnCl_2(aq) + 2NaOH(aq) \longrightarrow Zn(OH)_2(s) + 2NaCl(aq)$
   (b) $CuSO_4(aq) + 2NaOH(aq) \longrightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$
   (c) $FeCl_2(aq) + 2KOH(aq) \longrightarrow Fe(OH)_2(s) + 2KCl(aq)$
   (d) $Fe(NO_3)_3(aq) + 3KOH(aq) \longrightarrow Fe(OH)_3(s) + 3KNO_3(aq)$
3. $(NH_4)_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2NH_3(g) + 2H_2O(l)$
4. **(a)** is a dilute solution of a strong alkali.
   (b) is a concentrated solution of a strong alkali.
   (c) is a dilute solution of a weak alkali.
   (d) is a concentrated solution of a weal alkali.

Notes for Teachers

Treatment of alkali burns
Concentrated alkalis are often more destructive than acids as they can penetrate skin tissue and adhere to the surface of our eyes. Treatment includes flushing with water to wash off the chemical. After that, vinegar or another mildly acidic substance mixed with water can be put on the burn to neutralise any alkali that is left and to lessen the pain. If the damage is severe, the patient should be taken immediately to a hospital or medical clinic.

For alkalis that get into the eye, the patient should hold his or her head under a tap and flush the eye with running water for approximately 20 minutes. It is important to gently hold the eyelids apart while washing in order to rinse underneath the lids and to wash away as much of the chemical as possible. Using a dry cloth is helpful because the lids are difficult to hold back when they are wet.

The following website provides more information on the treatment of alkali burns:
http://www.stlukeseye.com/conditions/ChemicalBurn.html

(page 231)

Mystery Clue

The alkali would react with solution containing lead(II) ions to form lead(II) hydroxide which would be present in the sludge.

Teaching pointers

15.4 How are Indicators and pH Related? (page 232)

1. Students were introduced to indicators in their lower secondary science course. Demonstrate the colours of phenolphthalein, methyl orange and litmus in both acids and alkalis. Do not mention the pH values at which these indicators change colour. Phenolphthalein and/or methyl orange will be used later in titrations.
2. As an interesting homework exercise, students can make and use a red cabbage or other natural indicators. See 'Notes for Teachers' on the next page.
3. If the school has a garden, get students to grow hydrangeas in acidic and alkaline soils to obtain the different coloured flowers. Acidic soil can be prepared by adding compost or ammonium sulfate. Adding lime will give an alkaline soil. Check the pH of the soil before using it to grow the flowers.
4. To show the relationship between the difference in acidity and pH, you may first devise a 'pSour' scale (see 'Notes for Teachers' on the next page). This scale links an increase in sourness to an increase in acidity and then to an increase in the concentration of $H^+(aq)$ ions . The pH scale can be accepted as a range of numbers without defining it. The 'H' in pH refers to H^+ ions. As it is a logarithmic scale, a change of 1 pH unit changes the acidity (or concentration of H^+ ions) by 10 times.
5. You may like to set up and demonstrate the use of a pH meter and/or pH sensor connected to a computer. Compare the pH values obtained with those obtained using Universal indicator paper or solution.
6. An additional experiment is included at the end of this chapter to test for the pH values of common substances, note that the pH of distilled water may not be exactly 7 as it usually contains dissolved carbon dioxide making it slightly acidic. The method used in the experiment to measure the pH of soil is very simple and prone to inaccuracies. For a more accurate measure, refer to the 'Notes for Teachers' below.
7. As the section on the importance of pH is concrete and relevant to everyday life, it is very useful for academically less able students. Test some of the substances, such as saliva, foods preserved in acidic solutions, perm solutions, shampoos and hair conditioners with indicator paper.
8. Medical research has shown high rates of throat cancer amongst groups of people who consume large amounts of vegetables pickled in acid solutions. This is a very serious problem in some parts of China.
9. Hair is made from proteins. Water and weakly alkaline solutions break some of the weak bonds between the protein molecules in adjacent strands of hair, allowing the shape of hair to be changed.

(page 234)

Mystery Clue

The pH of the sludge would be about 13 as it contains concentrated sodium hydroxide. This alkali burns human tissue.

Skills Practice (page 237)

1. Acids are corrosive or irritants and may harm tissue in the mouth.
2. (a) Sour milk consists of lactic acid, which gives it a sour taste.
   (b) Sour milk has a pH 3 ~ 4, as lactic acid is a weak acid.
3. Mei Ling is correct. The red litmus paper will remain red with water and other neutral substances. To be sure that a substance is acidic, we must observe a change in colour. Therefore we should also test the solution with blue litmus paper.
4. The solution with pH 1 is strongly acidic.
   The solution with pH 4 is weakly acidic.
   The solution with pH 7 is neutral.
   The solution with pH 9 is weakly alkaline.
   The solution with pH 13 is strongly alkaline.
5. Cola – pH 4
   Distilled water – pH 7
   Seawater – pH 8
   Liquid soap – pH 10
   Lemon juice – pH 3
6. pH paper is red in dilute hydrochloric acid, yellow in lemonade and green in distilled water.

Notes for Teachers

Fun with natural indicators

The acidity or alkalinity of household products can be tested by using one or more plant extracts as indicators. Suitable plants to be used are red cabbage, Coleus leaves and the petals of hibiscus and blue morning glory flowers. To obtain the extract, first cut the plant into small pieces, then crush the pieces using a mortar and pestle or cut them using a blender. Add a little water or alcohol. Continue crushing or blending until all the colour comes out. Filter to obtain only the liquid. Use a known acid (e.g. vinegar) and a known alkali (e.g. ammonia) to obtain the colour of the indicator in acids and alkalis. The indicator can then be used to test various substances.

Note: To be useful as an indicator, the extract must have a deep colour. Deep red is usually the best. Avoid using yellow or pale-coloured petals. For hibiscus, the extract is purple. It is red in acids and green in alkalis. Red cabbage is pink in acids and green in alkalis.

From 'pSour' scale to pH scale

To introduce the idea of differences in acidity, get students to compare the taste of distilled water, unsweetened carbonated drink, lemon juice and an unsweetened soft drink. Ask students to place these substances in increasing order of sourness. As sour taste indicates acidity, an increase in sourness means an increase in acidity. As acidity is caused by H+(aq) ions, an increase in sourness gives a decrease in pH values. The pH scale can be extended to include alkalis.

The origin of the pH scale

The pH scale was introduced in 1909 by the Danish biochemist, S.P.L. Sorenson. He devised the scale to measure the concentration of hydrogen ions in solutions. The higher the concentration of hydrogen ions, the higher is the acidity. According to Sorenson, the "actual degree of acidity" refers to the concentration of hydrogen ions. However, the term he used then was not 'pH'. Rather, he referred to the readings as the 'hydrogen ion component' and the designated 'pH' as the numerical value of the components. The letter 'p' in pH is derived from the German word 'potenz' meaning power or exponent of, in this case, 10. Refer also to Exercise 15.1C which refers to the origin of the pH scale.

pH in the garden

Here are the optimum pH values for the growth of some plants:

Bananas	5.0 – 7.0
Beans	5.5 – 7.5
Carrots	6.5 – 7.5
Hibiscus	6.0 – 7.0
Lettuce	6.0 – 7.0
Peas	6.5 – 7.5
Potatoes	4.5 – 6.0
Rice	5.0 – 6.0
Watermelons	6.5 – 7.0

Finding the pH value of soil

The method used in Experiment 15.4B is prone to inaccuracies. Here is a more accurate method:

1. Grind the soil with a mortar and pestle. Place the soil in a boiling tube to a depth of about 2 cm. Add an equal amount of distilled water and a few drops of Universal indicator solution.
2. Add one spatula measure of barium sulfate. Stopper the boiling tube and shake. Allow the mixture to settle for a few minutes.
3. Compare the colour of the barium sulfate suspension with a pH colour chart.

IT Link

Website on student research relating to red cabbage indicator:
http://youth.net/nsrc/sci/sci041.html#anchor388332

Website on student research relating to pH and plant growth [see number 7]:
http://youth.net/nsrc/sci/sci.002.html

Website on student research comparing the pH of orange juices [see number 11]:
http://youth.net/nsrc/sci/sci.008.html

Website on student research comparing the acidity of juices [see number 6]:
http://youth.net/nsrc/sci/sci.016.html

Website on student research comparing the acidity of apples and oranges [see number 7]:
http://youth.net/nsrc/sci/sci.019.html

Teaching pointers

15.5 What are Ionic Equations? (page 237)

1. The jump from writing full equations to writing ionic equations is very great for most students. Thus, introduce ionic equations only at this stage of the course and use only reactions and chemical equations that students are already familiar with.
2. Students can use the ionic formula cards on pages 92 and 93 of this Teacher's Resource File to help them write ionic equations. To show what happens to the particles represented in reactions, prepare coloured, transparent two-dimensional plastic models of atoms and ions (such as in Figure 15.45 on page 238 of the Textbook) and project them on an overhead projector. Include spectator ions that are not involved in the reaction as well. Then remove these ions to leave the ionic equation.
3. Emphasise that in ionic equations, we only write ions
   (a) for ionic compounds,
   (b) if the ions in the compound are free to move independently of each other (i.e. when the compound is in molten or aqueous state), and
   (c) if the ions are actually involved in the reaction.

   Thus, the formula of a precipitate is written in full as it is a solid and the ions are not free to move.
4. Point out that the same ionic equation can represent different reactions as spectator ions are not included in the ionic equation. For example, in the reaction of magnesium with dilute hydrochloric acid and dilute sulfuric acid, both acids have H^+(aq) ions which take part in the reactions. The Cl^-(aq) and SO_4^{2-}(aq) ions are not involved in the reaction and thus are not included in the ionic equation.

Chemistry Inquiry (page 239)

What is the Ionic Equation for the Reaction Between Calcium Carbonate and a Dilute Acid?

Group Discussion

1. E.g. sulfuric acid, nitric acid and ethanoic acid. The sulfate ion $SO_4^{2-}(aq)$, nitrate ion $NO_3^-(aq)$ and ethanoate ion $CH_3COO^-(aq)$ do not react.
2. $Cu(OH)_2(s) + 2H^+(aq) \longrightarrow Cu_2+(aq) + 2H_2O(l)$

Skills Practice (page 240)

1. $Mg(s) + 2H^+(aq) \longrightarrow Mg^{2+}(aq) + H_2(g)$
   The ionic equation for the reaction between magnesium and sulfuric acid is the same as that for the reaction between magnesium and hydrochloric acid. The $Cl^-(aq)$ and $SO_4^{2-}(aq)$ ions are only spectator ions. As they are not involved in the reaction, they are omitted from the ionic equation.
2. (a) $Zn(s) + 2H^+(aq) \longrightarrow Zn^{2+}(aq) + H_2(g)$
   (b) $MgO(s) + 2H^+(aq) \longrightarrow Mg^{2+}(aq) + H_2O(l)$
   (c) $Fe^{3+}(aq) + 3OH^-(aq) \longrightarrow Fe(OH)_3(s)$
   (d) $Cu(s) + 2Ag^+(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$
   (e) $Cl_2(g/aq) + 2I^-(aq) \longrightarrow 2Cl^-(aq) + I_2(aq)$

15 Chapter Review

Self-Management

Misconception Analysis (page 240–241)

1. **True** This is the definition of an acid. In aqueous solution, acids have hydrogen ions.
2. **True** As it is the hydrogen ion in an acid that reacts, the acid must be in the form of an aqueous solution.
3. **False** Copper(II) hydroxide in an insoluble base. Alkalis are soluble bases.
4. **False** For example, many foods contain acids which are not harmful. Laboratory acids and alkalis, especially the concentrated solutions, are harmful.
5. **True** Acids have pH values less than 7; the lower the pH value, the more acidic it is.
6. **False** The strength of an acid/alkali refers to its degree of ionisation; a strong acid or alkali is 100% ionised. The concentration of an acid/alkali refers to the amount of solute per unit volume. Thus we can have a concentrated solution of a weak acid, for example a 10 mol/dm^3 solution of ethanoic acid.
7. **True** This is part of the ionic theory of acids and alkalis proposed by the Swedish chemist, Arrhenius.
8. **False** Litmus paper can only indicate whether a substance is acidic or alkaline.

Practice

Structured Questions (page 241–242)

1. (a)

Reaction number	Reagent X	Reagent Y	Gas produced
1	dilute hydrochloric acid	magnesium	hydrogen
2	dilute sodium hydroxide solution	ammonium sulfate	ammonia
3	dilute sulfuric acid	magnesium carbonate	carbon dioxide

   (b) The pH of the solution would be 7.
   (c) $2H_2SO_4(aq) + MgCO_3(s) \longrightarrow MgSO_4(aq) + CO_2(g) + H_2O(l)$

2. (a) Copper(II) oxide and magnesium hydroxide are bases. Sodium hydroxide and calcium hydroxide are alkalis.
   (b) Alkalis are soluble bases.
   (c) (i) Hydroxide ion, $OH^-(aq)$
   (ii) Alkaline solutions conduct electricity and so the hydroxide part of the compound must be an ion. / Alkalis form precipitates of hydroxides with metal ions.

(iii) A strong alkali completely ionises in water to give hydroxide ions. A weak alkali only partially ionises in water. Therefore the concentration of hydroxide ions is greater in a solution of a strong alkali.

3. (a) The first answer is correct.
The second answer is correct.
The third answer should be: Copper(II) hydroxide is formed.
Since sodium hydroxide is used, copper(II) oxide cannot be formed. Besides, copper(II) oxide is black and not blue.
The fourth answer should be: The colourless solution is sodium sulfate.
The sodium ions and the sulfate ions form sodium sulfate which is dissolved in the solution.
(b) (i) $CuSO_4(aq) + 2NaOH(aq) \longrightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$
(ii) $Cu^{2+}(aq) + 2OH^-(aq) \longrightarrow Cu(OH)_2(s)$
(c) Copper(II) nitrate or copper(II) chloride solution

4. (a) (i) An alkali is a soluble base.
(ii) Two examples of alkalis are sodium hydroxide and ammonia solution. Two examples of bases are lead(II) oxide and magnesium(II) hydroxide.
(iii) E.g. $PbO(s) + 2HCl(aq) \longrightarrow PbCl_2(aq) + H_2O(l)$
(b) E.g. $NH_4Cl(s) + NaOH(aq) \longrightarrow NaCl(aq) + NH_3(g) + H_2O(l)$

Free Response Questions (page 242)

1. Responses may include the following points:
   - An aqueous solution of citric acid turns the colour of indicator paper to its acidic colour. Explanation:
     – Water is needed for an acid to exhibit acidic properties.
     – Citric acid powder has no water and thus has no acidic properties.
   - An aqueous solution of citric acid reacts slowly with magnesium metal to form bubbles of gas. Explanation:
     – The gas is hydrogen. / Metals react with acid solutions to give hydrogen gas.
     – Citric acid solution forms H+(aq) ions which react with the magnesium metal.

2. Responses may include the following points:
   - Acid and hydrogencarbonate react to give carbon dioxide gas and water.
   - Balanced equation: $2NaHCO_3(s) + H_2SO_4(aq)$ $Na_2SO_4(aq) + 2CO_2(g) + 2H_2O(l)$
   - The gas forces the water out of the extinguisher.
   - The mixture of carbon dioxide gas and water extinguishes the fire.

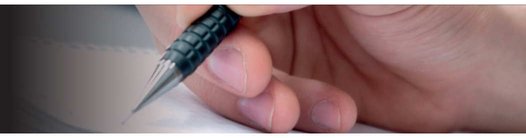
3. Responses may include the following points:
Step 1: Add Universal Indicator paper to the four solutions.
– The two acids change the colour of the indicator to red.
– The two alkalis change the colour of the indicator to blue or purple.
Step 2: Add either acid to the two alkaline solutions. The reaction that gives off a gas indicates that the alkaline solution is sodium carbonate. The other alkali must be ammonia solution.
Step 3: Add sodium carbonate solution to the two acids. A gas (carbon dioxide) is evolved. The acid that gives a faster reaction (more bubbles of gas given off per unit time) is dilute nitric acid.
The other acid must be ethanoic acid.

Extension (page 242)

1. Different plants require soils of different pH values to grow well. For a list of pH values best suited for plant growth, refer to the following website: http://www.ces.ncsu.edu/depts/hort/consumer/quickref/soil/pHplants.html

   Farmers try to maintain the optimum pH values of the soil for their types of plants. One of the most common problems is an overly acidic soil. This could be due to acid rain. To remove excess acid from soil, farmers sometimes spread slaked lime (or aqueous calcium hydroxide) or powdered limestone (solid calcium hydroxide). This process is known as liming.

2. Refer to Figure 15.44. Universal Indicator paper will show most shampoos to be slightly alkaline. Most hair conditioners are mildly acidic and are used to neutralise any excess alkali remaining in the hair after shampooing. Strong acids and alkalis are not used in shampoos and hair conditioners such as solutions are harmful to the skin and eyes.



Additional Teaching Material

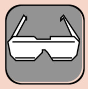
Additional Exercise 1: The pH Scale

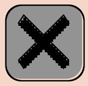
Aim
- To measure the pH values of some domestic substances using pH paper

Key Competencies
CIT: sound reasoning [*estimating, inferring, comparing, explaining, predicting*]
ICS: communicating effectively [*collaborating with others, group discussion, oral presentation*]

Apparatus and materials
For Part A
- test tube
- pH paper
- spotting tile
- pH colour chart
- dropper
- common domestic substances in the table on the next page
- distilled or deionised water

For Part B
- mortar and pestle
- Universal Indicator solution
- test tube and stopper
- filter paper
- dropper
- samples of different soils
- filter funnel

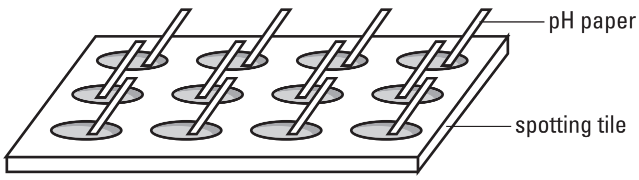
Safety warnings



bleaching solution, liquid detergent

A The pH of Common Substances

Procedure
Most of the substances in this experiment are liquids or solutions. If the substance to be tested is a solid, add about 2 cm^3 of distilled water to a small amount of the substance. Shake to mix.

1. Place a small piece of pH paper in each of the cavities in a spotting tile.



2. (a) Add a drop of each solution to the pH paper.
(b) Using a pH colour chart, estimate the pH value of each substance.

Results
Record the pH colours and values in the table below.

Substance	Colour of pH paper	pH value	Strongly acidic/Weakly acidic/ Neutral/Weakly alkaline/ Strongly alkaline
lemon juice			
vinegar			
bleaching solution			
liquid detergent			
glass cleaner			
toothpaste			
soda drink			
sugar			
table salt			
distilled water			
tap water			
fresh milk			
sour milk			
soap			
baking soda			
tea			

B Measuring the pH of Soil

Procedure
Bring to your laboratory samples of soils collected from different places, e.g. gardens, pot plants, hillsides, beach, swamp, your school.

1. (a) Grind a soil sample into a powder using a pestle and mortar.
(b) Transfer two spatulas full of soil into a test tube. Then half fill the test tube with distilled water.

2. (a) Stopper the test tube and shake for about 1 minute.
(b) Filter to remove the soil particles. Collect the filtrate in a test tube.
(c) Add three drops of Universal Indicator solution to the filtrate.
(d) Determine the pH value from a pH colour chart.
(e) Record the result in the table below.

3. Repeat Steps 1 and 2 with the other soils.

Results

Source of soil	pH value

Discussing your findings
Compare your finding with those of other groups. Do all groups get similar pH values for similar kinds of soils? If not, groups could repeat the tests where pH values differ. If there are still different results, suggest possible reasons.

Project (Optional)

1. Obtain some seeds of a plant.
   Plant the seeds in each type of soil.
   Predict if the plants would grow well in each soil.
   Water the soils and observe the plants as they grow.
   Check to see if your predictions are correct.

2. Your teacher may ask you to give a brief oral presentation (no more than five minutes) to your class of your findings. In you talk, include the aim, predictions, method and results together with other points you think may be interesting.

Answers

Additional Exercise 1:

Results

Substance	Colour of pH paper	pH value	Strongly acidic/Weakly acidic/ Neutral/Weakly alkaline/ Strongly alkaline
lemon juice	orange	~3	weakly acidic
vinegar	orange	~3	weakly acidic
bleaching solution	purple	~12	weakly alkaline
liquid detergent	–	variable	weakly alkaline
glass cleaner	dark blue	~11	weakly alkaline
toothpaste	blue	~10	weakly alkaline
soda drink	pale orange	~4	weakly acidic
sugar	green	7	neutral
table salt	green	~7	neutral
distilled water	green	7	neutral
tap water	yellow/green	5–7	weakly acidic
fresh milk	yellow/green	6	weakly acidic
sour milk	pale orange	4–5 (approx)	weakly acidic
soap	green/blue	8~9	weakly alkaline
baking soda	green/blue	~8	weakly alkaline
tea	orange/yellow	4–5	weakly acidic