BLACK HOLE FORCES IN USE TO MOVE TEETH

CHEMICAL REACTIONS OCCUR WHEN FOOD IS ADDED
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CHEMICAL REACTIONS IN LIVING AND NON-LIVING SYSTEMS

Chemical reactions are everywhere

When we think about chemical reactions, it is easy to only think about those that occur in a science laboratory. However, in reality there are chemical reactions everywhere. Our bodies rely on chemical reactions to function. In fact, our bodies work to ensure that these reactions can occur where and when they are needed. Chemical reactions are also frequently occurring in the non-living environment. The rusting of a building, a campfire, the acidification of oceans, the burning of fossil fuels and the erosion of limestone by acid rain: these are all chemical reactions. In this chapter you will look more closely at the reactions of acids and combustion reactions in both living and non-living systems.
SHOWCASE: INVESTIGATING CHEMICAL REACTIONS

During this showcase you will investigate one of the following topics related to chemical reactions.

- What is the effect of acid rain on plant growth?
- Which metals react with acids?
- Which chips produce the most energy?
- Which brand of vinegar is the most acidic?
- Which soft drink is the most acidic?
- Does the ripeness of a lemon change its acidity?

1. Choose one of the above topics.
2. Conduct some research to find out about the chemical reaction related to the topic.
3. Develop a hypothesis relating your independent and dependent variables.
4. Design an investigation to fairly test your hypothesis.
5. Conduct your investigation, recording your data.
6. Analyse your results and method.
7. Relate your findings to your everyday life and the relevant chemical reactions.
8. Present your report as a poster.

By the end of this chapter you will be able to:

- define and give examples of acids, bases and indicators
- describe the properties of acids and bases
- list key indicators and state their colours in acidic, alkaline and neutral solutions
- describe the pH scale
- describe neutralisation
- describe the reaction between an acid and a metal hydroxide or metal oxide
- describe the reaction between an acid and a carbonate or hydrogen carbonate
- describe the reaction between an acid and a metal
- describe combustion
- describe exothermic and endothermic reactions
- describe the combustion of hydrocarbons
- explain the role of cellular respiration and of photosynthesis in biological processes.
7.1 Acids, bases and indicators

What is an acid?
You have already heard about some acids. You may have made sherbet and used citric acid. Or you may have heard about DNA – deoxyribonucleic acid. Or you may have used hydrochloric acid in an experiment at school.

The definition of an acid has changed several times over the last 250 years as more information has become available. Initially the definition was based on observable properties. French scientist Antoine Lavoisier (1743–94) was one of the first to try to establish what an acid is. He noticed that when a non-metal reacted with oxygen, the compound would form an
acids. Therefore, he proposed that acids contained oxygen. In 1815, English chemist Humphry Davy observed that all acids contained hydrogen. He also observed that metal oxides were basic, not acidic and therefore not all compounds containing oxygen were acids.

In 1884, Svante Arrhenius, a Swedish chemist, refined the definition on the basis of the products of acids and bases in water. He proposed that acids produce hydrogen ions in water while bases produce hydroxide ions in water. While this definition has since been further refined by scientists such as Johannes Bronsted, Thomas Lowry and Gilbert N. Lewis, Arrhenius’ definition is still used today. This definition will be used in this chapter.

Given that an acid produces a hydrogen ion (H⁺) when it forms a solution in water, it makes sense that an acid contains hydrogen atoms. We can represent what happens when the acid forms a solution in an equation. For example, the ethanoic acid (CH₃COOH) found in vinegar will form ethanoate (CH₃COO⁻) and a hydrogen ion (H⁺):

\[
\text{CH}_3\text{COOH(aq)} \rightarrow \text{CH}_3\text{COO}^-(aq) + \text{H}^+(aq)
\]

**Activity 7.1.1**

**Different acids**

There are many different acids. Acids are found in our bodies and our food. In this activity you will become familiar with some of these acids. Use the Internet to complete each of the following tasks.

1. For each of the following acids, find the chemical formula, where it is found and what it is used for.
   - a) Citric acid
   - b) Ethanoic acid
   - c) Sulfuric acid
   - d) Carbonic acid
   - e) Ascorbic acid
   - f) Folic acid

2. The following acids are found in living things. Briefly outline why they are important.
   - a) Nucleic acid
   - b) Amino acid
   - c) Hydrochloric acid
   - d) Uric acid

3. Find the names and formulas of five other acids.

**What is a base?**

Bases are also found around the home; for example, bleach, which has the chemical name sodium hypochlorite (NaOCl). Sodium hydroxide (NaOH) (caustic soda or Drano) is another common base found in the home and school laboratory. Hydroxides, oxides and carbonates are other common bases found in the school laboratory.
Chemically, a base is the opposite of an acid. According to Arrhenius’ definition, a base will form hydroxide ions (OH\(^{-}\)) in solution. In some cases, the hydroxide ion was in the base to start with, and is simply separated when the base dissolves. For example, sodium hydroxide (NaOH) will form sodium ions (Na\(^{+}\)) and hydroxide ions (OH\(^{-}\)):

\[
\text{NaOH(aq)} \rightarrow \text{Na}^{+}(aq) + \text{OH}^{-}(aq)
\]

In other bases, the hydroxide ion is formed when the base reacts with water. Ammonia is an example of this. When it dissolves, the ammonia reacts with water, forming hydroxide ions:

\[
\text{NH}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{NH}_4^{+}(aq) + \text{OH}^{-}(aq)
\]

What is neutral?

When something is neither acidic nor basic, it is described as neutral. Distilled or de-ionised water is neutral, as is a solution of table salt (sodium chloride, NaCl).

What is an indicator?

Indicators are chemical substances that are different colours in acidic or basic solutions (Figure 7.4). The many natural indicators include red cabbage and hydrangea flowers. Other indicators are special compounds only found in science laboratories. Some indicators commonly found in the school laboratory are phenolphthalein, methyl orange, bromothymol blue (Figure 7.5) and universal indicator. Each of these indicators has its own specific colours in acids and bases.

![Figure 7.3 Bases in the home](image1)

![Figure 7.4 a) The colour of indicator paper shows the pH of the liquid. b) Universal indicator exhibits several colour changes.](image2)

![Figure 7.5 Bromothymol blue is a different colour in acidic (left) and basic (right) solutions.](image3)
Indicators found in the science laboratory

In this experiment, you will observe the colour of different indicators in acids, bases and neutral solutions and then use these colours to classify common household substances.

What are the risks in doing this experiment? How can you manage these risks to stay safe?

<table>
<thead>
<tr>
<th>Risk description</th>
<th>Safety measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid and sodium hydroxide solution can be harmful if they come in contact with skin or eyes.</td>
<td>Wear safety glasses while performing this experiment. Wash your hands thoroughly at the end of the experiment.</td>
</tr>
</tbody>
</table>

Materials

- 0.1 M dilute hydrochloric acid solution
- distilled water
- 0.1 M dilute sodium hydroxide solution
- phenolphthalein indicator
- methyl orange indicator
- bromothymol blue indicator
- universal indicator
- household substances such as shampoo, lemonade, milk, bleach, bread, juice from a lemon and a bathroom creamy cleanser
- seven test tubes
- test-tube rack
- permanent marking pen

Method

Part A. Colours of different indicators

1. Place three test tubes in the test-tube rack and number them 1–3.
2. Place approximately 1 mL of hydrochloric acid into test tube 1.
3. Place approximately 1 mL of distilled water into test tube 2.
4. Place approximately 1 mL of sodium hydroxide into test tube 3.
5. Place approximately 3 drops of phenolphthalein into each test tube and record the colour of the solution.
6. Dispose of the chemicals according to your teacher’s instructions and rinse each test tube.
7. Repeat steps 2–6 for the remaining indicators

Part B. Household substances – acid, base or neutral?

8. Place four test tubes in the test-tube rack and number them 4–7.
9. Place approximately 1 mL of the first household substance into each of the test tubes.
10. Place approximately 3 drops of phenolphthalein into test tube 4 and record the colour of the solution.
11. Repeat step 10 for the other indicators, using the remaining test tubes.
12. Discard the chemicals according to your teacher’s instructions and rinse each test tube.
13. Repeat steps 9–12 for the remaining household substances.

Results

Record your observations in the tables like those shown here.

Part A. Colours of different indicators

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Colour in hydrochloric acid (acid)</th>
<th>Colour in distilled water (neutral)</th>
<th>Colour in sodium hydroxide (base)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolphthalein</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methyl orange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bromothymol blue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universal indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part B. Household substances – acid, base or neutral?

<table>
<thead>
<tr>
<th>Household substance</th>
<th>Colour in Acid, base or neutral?</th>
</tr>
</thead>
<tbody>
<tr>
<td>phenolphthalein</td>
<td></td>
</tr>
<tr>
<td>methyl orange</td>
<td></td>
</tr>
<tr>
<td>bromothymol blue</td>
<td></td>
</tr>
<tr>
<td>universal indicator</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

1. Justify which of these indicators was the most useful for classifying substances as acids, bases or neutral.
2. Discuss any patterns in the type of substances that are acids, bases or neutral.

The pH scale

pH means ‘the power of hydrogen’. The pH scale, which gives an indication of how acidic or basic a substance is, usually ranges between 0 and 14.

- A substance with a pH less than 7 (pH < 7) is classified as acidic.
- The lower the pH, the more acidic the substance.
- A substance with a pH of 7 (pH = 7) is classified as neutral.
- A substance with a pH greater than 7 (pH > 7) is classified as basic.
- The higher the pH, the more basic the substance.

Sometimes you need to know not only whether the substance is acidic or basic but also how acidic or how basic it is. This is when you use the pH scale. A substance that has a pH of 3 is more acidic than a substance that has a pH of 5. Similarly, a substance that has a pH of 12 is more basic than a substance that has a pH of 9.

Scientists sometimes use pH meters or probes to measure pH, instead of indicators. pH meters are pieces of equipment that can be inserted into the substance to record its pH. Old pH meters used an analogue scale. Today, most pH meters have a digital scale. pH probes are similar to pH meters, except they connect to a computer so that readings can be taken continuously.

Figure 7.6 The pH scale
Figure 7.7 a) A pH meter and b) a pH probe

Understanding pH

As well as indicating which substance is more acidic or more basic, the pH scale tells you mathematically how much more acidic or basic a substance is. Each division on the pH scale is a difference of 10 times in the acidity. So, a substance that has a pH of 3 is 10 times more acidic than a substance that has a pH of 4.

In this experiment you will use a pH meter or probe to compare the pH values of solutions of different acidity.

What are the risks in doing this experiment? How can you manage these risks to stay safe?

| Hydrochloric acid and sodium hydroxide solution can be harmful if they come in contact with skin or eyes. | Wear safety glasses while performing this experiment. Wash your hands thoroughly at the end of the experiment. |

Materials

• 1, 0.1, 0.01 and 0.001 M hydrochloric acid
• 1, 0.1, 0.01 and 0.001 M sodium hydroxide
• distilled water
• nine test tubes
• test-tube rack
• permanent marker
• pH meter or probe

Method

1. Place 1 mL of each solution into a test tube, labelling it with the type of solution and the concentration (e.g. 1 M).
2. Into the ninth test tube, place 1 mL of distilled water.
3. Use the pH meter or pH probe to determine the pH of each solution. Record this in a results table.
4. Dispose of the chemicals according to your teacher’s instructions.

Results

Record your results in a well-organised table.

Discussion

1. Describe what happened to the pH of hydrochloric acid as the concentration decreased.
2. Describe what happened to the pH of sodium hydroxide as the concentration decreased.
3. Predict some areas of the experiment that may have limited the accuracy of your results. Describe how these could be improved if this experiment was conducted again.

Conclusion

Summarise your findings regarding the concentration of acids and bases and their pH values.
Physical properties of acids and bases

The physical properties of acids and bases allow you to classify chemicals into their appropriate group. They also allow you to choose the most appropriate substance for a specific purpose. Table 7.1 summarises the key properties.

Table 7.1 The physical properties of acids and bases

<table>
<thead>
<tr>
<th>Property</th>
<th>Acid</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taste</td>
<td>Sour</td>
<td>Bitter</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>Conductor</td>
<td>Conductor</td>
</tr>
<tr>
<td>Colour of litmus (an indicator)</td>
<td>Red</td>
<td>Blue</td>
</tr>
</tbody>
</table>

Remembering

1. Define the following glossary terms: acid, base, hydrogen ion, hydroxide ion, indicator, neutral, pH and physical property.

Understanding

2. Name three acids and outline their uses.
3. Describe the purpose of an indicator.

Applying

3. Predict whether lemons are acidic or basic. Explain the reason for your answer.
4. Describe the differences between an acid and a base.
5. Classify each of the following compounds as acid, base or neutral.
   a. Malic acid
   b. HCl
   c. Magnesium hydroxide
   d. Distilled water
   e. Carbonic acid
   f. Ammonia
   g. Sodium chloride (NaCl) solution
6. Nitric acid (HNO₃) will form nitrate (NO₃⁻) and a hydrogen ion (H⁺) in solution. Represent this in an equation.
7. Give two reasons why it is important to understand acids and bases.

Analysing

8. Most indicators exhibit only two colours. Universal indicator has a range of colours. Suggest a reason for universal indicator having so many colours.

Evaluating

9. Which are more useful for identifying the pH of substances: pH probes or indicators? Justify your choice.
10. When carbon dioxide dissolves in water the following reactions occur:
    
    \[
    \text{CO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{CO}_3(aq) \\
    \text{H}_2\text{CO}_3(aq) \rightarrow \text{HCO}_3^-(aq) + \text{H}^+(aq)
    \]
    
    Predict whether the pH would be less than 7, approximately 7 or greater than 7. Use your understanding of acids and bases to justify your prediction.
7.2 Reactions of acids and bases

Adapting pH has many important applications. Different organisms or even parts of organisms need different chemical environments. For example, our eyes have a pH of 7.2. Hence, the pH of a swimming pool should be checked regularly to ensure that the pH is maintained at 7.0–7.6. If the pH is not in this range, then chemicals should be added to the pool to adjust the pH to bring it back to this range.

The pH of an aquarium is also important. Most freshwater fish require a pH of 6.8–7.5 and most saltwater fish require a pH of 8.2–8.4. Products are available for adjusting the pH but they should be used according to the manufacturer's instructions.

In both these examples, the chemicals added undergo a chemical reaction to adjust the pH. There are some key reactions that acids and bases undergo. In the reactions that we will be considering, the products are neutral. Therefore, we say that the acid and base have been neutralised.

**Acids reacting with metal oxides or metal hydroxides**

Metal oxides and metal hydroxides are both bases. A metal oxide is a compound made of a metal and oxygen; for example, magnesium oxide (MgO). A metal hydroxide is a compound made of a metal and hydroxide; for example, sodium hydroxide (NaOH). When these compounds dissolve in water, they will form hydroxide ions, making them bases.
When an acid reacts with either a metal oxide or a metal hydroxide, they will produce a salt and water. ‘Salt’ is a general term used to describe compounds that are composed of both metals and non-metals. The salt is made up of the metal from the base and the part of the acid left after the hydrogen has been removed. Both the salt and water are neutral; therefore this is a neutralisation reaction.

We can summarise the reaction between an acid and a metal oxide or metal hydroxide as:

\[
\text{acid + metal oxide/metal hydroxide} \rightarrow \text{salt + water}
\]

You will often see this reaction written as:

\[
\text{acid + base} \rightarrow \text{salt + water}
\]

This is because metal oxides and metal hydroxides are the more commonly known bases. To name the salt produced in this reaction, the first part of the name comes from the first name of the base (the metal) while the last part of the name comes from the acid.

- Hydrochloric acid forms chlorides.
- Nitric acid forms nitrates.
- Sulfuric acid forms sulfates.

\[
\begin{align*}
\text{Hydrochloric acid} & + \quad \text{sodium hydroxide} & \rightarrow & \quad \text{sodium chloride} & + \quad \text{water} \\
\text{Sulfuric acid} & + \quad \text{potassium hydroxide} & \rightarrow & \quad \text{potassium sulfate} & + \quad \text{water}
\end{align*}
\]

**Figure 7.10** Naming salts of bases

**An example in a non-living system**

A common acid–base reaction that you may have already performed is between hydrochloric acid and sodium hydroxide. The salt produced is sodium chloride (NaCl). This reaction can be represented by the following equations.

Word equation:

\[
\text{hydrochloric acid} + \text{sodium hydroxide} \rightarrow \text{sodium chloride} + \text{water}
\]

Chemical equation:

\[
\text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}
\]

An indicator can show when the solutions are neutralised. The colour of the indicator will depend on which one you are using. If it is an indicator with only two colours, the point of neutralisation will be shown when there is a change in colour.

**An example in a living system**

Antacid tablets and gels are used to treat indigestion, heartburn or acid reflux. The stomach contains hydrochloric acid, which is important in digestion. However, if this acid moves up into the oesophagus, it will cause damage, resulting in the pain associated with indigestion. Antacids work by neutralising the acid, therefore reducing the acidity of the fluid. There are a variety of types of antacid tablets and gels on the market. Some common brands, including Mylanta and Gastrogel, use the active ingredients of aluminium hydroxide (Al(OH)₃) and magnesium hydroxide (Mg(OH)₂).
Neutralisation reaction

<table>
<thead>
<tr>
<th>What are the risks in doing this experiment?</th>
<th>How can you manage these risks to stay safe?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid and sodium hydroxide solution can be harmful if they come in contact with skin or eyes.</td>
<td>Wear safety glasses while performing this experiment. Wash your hands thoroughly at the end of the experiment.</td>
</tr>
</tbody>
</table>

**Aim**

To neutralise an acid by adding a base.

**Materials**

- 10 mL of 0.5 M sodium hydroxide (NaOH)
- 10 mL of 0.5 M hydrochloric acid (HCl)
- distilled water
- universal indicator and colour chart
- plastic pipette or dropper
- two 10 mL measuring cylinders
- five test tubes
- test-tube rack

**Method**

1. Place about 1 mL of the sodium hydroxide into a test tube. Label the test tube to identify what is in it. Add a couple of drops of universal indicator. What colour is the indicator? Use the colour chart to identify the pH of the solution. Record the colour and pH of the solution.
2. Repeat step 1 for the hydrochloric acid.
3. Repeat step 1 for the distilled water.
4. Keep the three labelled test tubes from steps 1–3 to compare your other test tubes with.
5. Measure 2 mL of hydrochloric acid, and pour this into a clean test tube. Add a couple of drops of universal indicator to the solution.
6. Measure 4 mL of sodium hydroxide. Use the plastic pipette to carefully add sodium hydroxide from the measuring cylinder to the acid solution, one drop at a time. When the solution turns green, or is the same colour as your distilled water test tube, you have completed the neutralisation reaction. What volume of base did you need to add?
7. Repeat steps 5 and 6, using 2 mL of sodium hydroxide and adding hydrochloric acid drop by drop.

**Results**

Record your data in a suitable table.

**Discussion**

1. What do you think would happen if you added too much base in step 6? Test this to see if your prediction was correct.
2. How could you make the solution neutral again? Justify your answer. Test this to see if your prediction was correct.
3. What do you think would happen if you added too much acid in step 7? Test this to see if your prediction was correct.
4. How could you make the solution neutral again? Justify your answer. Test this to see if your prediction was correct.
5. Predict the volume of sodium hydroxide that would be required to neutralise 3 mL of hydrochloric acid. Test this to see whether your prediction is correct.
6. Suggest how the volumes of the solutions required for neutralisation are related.
7. Suggest some factors that may affect your answer to question 6.
8. Outline how well the method allowed the neutralisation reaction to be investigated.
9. Outline ways in which the method could be improved.

**Conclusion**

What conclusions can you make about the neutralisation reaction between sodium hydroxide and hydrochloric acid?
Acids reacting with carbonates or hydrogen carbonates

Another reaction that will neutralise an acid is the reaction of an acid with a carbonate or hydrogen carbonate. This reaction will produce a salt, water and carbon dioxide. We can summarise this reaction by the general equation:

\[
\text{acid} + \text{carbonate (or hydrogen carbonate)} \rightarrow \text{salt} + \text{water} + \text{carbon dioxide}
\]

During this reaction you can observe bubbles of a colourless, odourless gas due to the production of carbon dioxide. If the carbonate is a solid, it will disappear or reduce in size as it reacts. If an indicator is added, then it is also possible to observe a colour change as the acid is neutralised.

Many gases are colourless and odourless. The limewater test is used to confirm that a gas is carbon dioxide. When carbon dioxide is bubbled through a solution of limewater (calcium hydroxide), the solution turns milky white.

**Examples in a non-living system**

One example of an acid reacting with a carbonate occurs when acid rain falls on a limestone building. Limestone is calcium carbonate. The sulfuric acid in acid rain reacts with the limestone, causing the limestone to gradually disintegrate.

Word equation:

\[
\text{calcium carbonate} + \text{sulfuric acid} \rightarrow \text{calcium sulfate} + \text{carbon dioxide} + \text{water}
\]

Chemical equation:

\[
\text{CaCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(aq) + \text{CO}_2(g) + \text{H}_2\text{O(l)}
\]
Acids are transported by road in tankers, a bit like petrol tankers. If there is a road accident and the acid leaks from the tank, then bicarbonate of soda is used to neutralise the acid spill. Although other chemicals, such as sodium hydroxide, would also neutralise the acid, bicarbonate of soda is not corrosive and therefore it is safe to transport and handle. Science laboratories also have a supply of bicarbonate of soda in a ‘spill kit’. In the event of an acid spill, your teacher will spread the solid over the acid, neutralising the acid and making it safe to clean up.

Word equation:

sodium hydrogen carbonate + hydrochloric acid → sodium chloride + carbon dioxide + water

Chemical equation:

\[
\text{NaHCO}_3(\text{s}) + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})
\]

You also utilise the reaction between an acid and a carbonate when we make, and eat, sherbet in Experiment 7.2.3. Sherbet is made of icing sugar, citric acid and sodium hydrogen carbonate, also known as bicarbonate of soda or sodium bicarb. The sugar gives the sherbet sweetness, while the acid and sodium hydrogen carbonate react to make the fizz.

**Figure 7.13** Limestone contains calcium carbonate.

**Experiment 7.2.3**

Fun with sherbet: science in the kitchen

In this experiment you will make some sherbet and then perform some tests on it, including a taste test.

<table>
<thead>
<tr>
<th>What are the risks in doing this experiment?</th>
<th>How can you manage these risks to stay safe?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science laboratories contain chemicals, which can be harmful.</td>
<td>This recipe must be made in a food preparation area using appropriate food-handling techniques. You should not prepare or eat food in a science laboratory.</td>
</tr>
</tbody>
</table>

**Materials**

- 1 cup of icing sugar
- 1 teaspoon of citric acid
- 1 teaspoon of bicarbonate of soda
- 2–3 drops of food colouring
- mixing bowl
- tablespoon
- clean, dry sieve
- cup and plastic spoon per group member
- large spatula
- universal indicator paper or small dropper bottle of universal indicator solution
- three test tubes
- test-tube rack

**Method**

1. Sieve the dry ingredients into the mixing bowl and mix thoroughly with the tablespoon.
2. Add the food colouring drop by drop while stirring. You have made sherbet!
3. Take out about a teaspoon of your sherbet for testing. Keep the rest for enjoying later. (Note: Only taste the sherbet if it has been prepared in a food preparation area, see risk assessment above.)
4 Take a spatula full of your sherbet and place it into a test tube. Add a little water to dissolve the sherbet, and then immediately dip in a strip of universal indicator paper or add 3 drops of universal indicator solution. Record your observations in a table.

5 Repeat step 4 with a small sample of citric acid and a sample of bicarbonate of soda in two clean test tubes.

6 Taste a small amount of the sherbet. Record its taste and any other observations.

7 Repeat step 6 for the citric acid and bicarbonate of soda. Be careful – you only need a very small amount.

**Results**

Record your observations in the table like the one shown here.

<table>
<thead>
<tr>
<th>Sherbet</th>
<th>Citric acid</th>
<th>Bicarbonate of soda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour of universal indicator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taste test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion**

1 Predict what causes the tingle on your tongue.

2 What can you conclude from your indicator results?

3 Explain why chemists rarely perform taste tests.

4 The sugar does not take part in the reaction. Why do you think it is added to the mixture?

5 Why do you think the sherbet does not react until you put it in your mouth or in water?

6 What observations can you use to show that there is a chemical reaction occurring?

**Acids reacting with metals**

Some metals react with an acid to produce a salt and hydrogen gas. We can represent this reaction with the general equation:

\[
\text{metal} + \text{acid} \rightarrow \text{salt} + \text{hydrogen gas}
\]

The salt is the compound produced from the metal and what is left of the acid after it has lost its hydrogen(s). In most cases, the salt will dissolve, forming a solution. During this reaction, you can observe the metal dissolving, bubbles of gas being produced and the solution warming up.

To confirm that the gas produced is hydrogen gas, a lit splint or taper is placed near the gas. If the gas is hydrogen, a ‘pop’ sound can be heard. This is called the **pop test**.

In the science laboratory, you may have added magnesium metal to an acid. When the magnesium is added to hydrochloric acid, a

**Figure 7.14** Magnesium reacts with hydrochloric acid. The white colour is due to the many bubbles of hydrogen gas.
salt (magnesium chloride) and hydrogen gas are produced. This can be represented by the equations below.

**Word equation:**

magnesium + hydrochloric acid → magnesium chloride + hydrogen gas

**Chemical equation:**

\[ \text{Mg(s)} + 2\text{HCl(aq)} \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \]

**An example in a non-living system**

Artists utilise the reaction between a metal and acid in etching. Here a metal plate is covered with a layer that will not react with the acid. The artist then makes a design, removing the protective layer and exposing the metal underneath. The plate is then submerged in the acid. Where the metal is exposed, it will react with the acid and leave an indentation in the metal surface (Figure 7.15).

**Figure 7.15** A plaque made by etching steel, a process in which a metal and an acid react

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**Activity 7.2.1**

**Which antacid should you choose?**

**Your challenge**

Antacids are available at pharmacies and supermarkets. The manufacturers claim that these substances can be taken to settle an upset stomach. Your task is to plan, conduct and analyse an investigation in order to make a recommendation regarding which antacid is the best one to buy.

**This might help**

Most antacids use metal hydroxides, metal carbonates or metal hydrogen carbonates to react with the excess acid. Look at the ingredients for the antacid tablets that you are investigating.

**Things to think about**

While you are planning your investigation, consider the following.

- What acid is in the stomach, and therefore what acid will you test the antacid tablets with?
- How will you measure how much acid is neutralised by the antacid tablet?
- How will you know when the acid is neutralised?
- How will you make this a fair test?
- What safety risks are associated with your investigation? Prepare a risk assessment and show this and your method to your teacher before proceeding.
Remembering
1 Define the following glossary terms: carbonate, hydrogen carbonate, limewater test, metal hydroxide, metal oxide, neutralise, pop test, salt, splint and taper.

Understanding
2 Complete each of the following general equations.
   a acid + base → __________ + water
   b acid + __________ → salt + carbon dioxide + __________
   c __________ + metal → salt + hydrogen gas
3 Describe why it is safer to use sodium hydrogen carbonate to neutralise an acid spill than sodium hydroxide.

Applying
4 State what type of chemical each of the following is (acid, base, carbonate, salt or metal).
   a Lead
   b Sodium chloride
   c Potassium hydroxide
   d Sodium carbonate
   e Sulfuric acid
5 List the products formed from each pair of reactants.
   a Zinc + hydrochloric acid
   b Sodium carbonate + sulfuric acid
   c Barium oxide + hydrochloric acid
   d Nitric acid and magnesium hydroxide
6 What might you observe during a reaction between a piece of zinc metal and sulfuric acid?
7 Write a word equation for the reaction between iron and hydrochloric acid.
8 When acid rain containing sulfuric acid falls on limestone buildings, which contain calcium carbonate (CaCO₃), the buildings gradually erode. Explain this observation using your knowledge of chemical reactions.

Analysing
9 Compare and contrast the reaction of an acid and a metal hydroxide with the reaction between an acid and a metal carbonate.

Evaluating
10 A student mixed up the labels for three colourless solutions. She knows that they are sodium carbonate, sodium hydroxide and sodium chloride. Explain what tests you could do to determine which solution is which.
7.3 Combustion

In Chapter 6 you were introduced to combustion reactions. Combustion reactions play an important role in our lives. Obtaining energy from food, burning fossil fuels to produce electricity, burning wood for warmth in winter and using petrol to run our cars all utilise combustion reactions.

Exothermic and endothermic reactions

During a chemical reaction, the total amount of energy is conserved. However, different chemicals contain different amounts of energy. If the products have less energy than the reactants, then the excess energy is released to the surroundings, usually in the form of heat. This type of reaction is an exothermic reaction. When wood is burned, energy is released, warming the air around it. This is why we use a wood fire for warmth.

Alternatively, if the products have more energy than the reactants, the extra energy needed is taken from the surrounding. This means that the surroundings now have less energy and cool down. This is an endothermic reaction. Chemical icepacks utilise this type of chemical reaction. When the chemicals are mixed, an endothermic reaction occurs, making the icepack cold.

What is a combustion reaction?

Combustion is an exothermic reaction that occurs when a substance reacts with oxygen. The elements in the original substance combine with the oxygen, forming oxides. Many combustion reactions involve hydrocarbons, compounds of hydrogen and carbon, reacting with oxygen. In these reactions, carbon dioxide, water and heat are produced.

When you light a Bunsen burner with the air hole open, the methane gas (CH₄) reacts with oxygen to form carbon dioxide (CO₂) and water (H₂O) (Figure 7.16). Carbon dioxide is one of the oxides of carbon and water is the oxide of hydrogen.

![Figure 7.16 A Bunsen burner uses the combustion of methane gas.](Shutterstock.com/ggw1962)
Chapter 7

Chemical reactions in living and non-living systems

Cellular respiration is a chemical process that occurs within every living cell, such as in these cheek cells. 

Word equation:

\[
\text{methane} + \text{oxygen} \rightarrow \text{carbon dioxoide} + \text{water} + \text{energy}
\]

Chemical equation:

\[
\text{CH}_4(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g}) + \text{energy}
\]

This same reaction occurs when you use a hotplate on a gas stove at home.

When there is not enough oxygen to produce carbon dioxide in the combustion reaction of hydrocarbons, carbon monoxide is produced instead. This often happens in cars, heaters and stoves running in enclosed spaces. Carbon monoxide is highly poisonous. It prevents the transport of oxygen in the blood, and can result in death. Carbon monoxide is a colourless, odourless, tasteless gas and so may not be detected until it is too late. Cars are now fitted with catalytic converters that convert much of the harmful emissions into less harmful substances.

Examples of combustion reactions in non-living systems

Combustion reactions are used to provide energy for many of our daily activities. Coal is burned to produce energy to drive the turbines of power stations. Petrol, diesel and natural gas are burned in the combustion chambers of car engines to produce the energy for our cars to operate. Petrol is made up of a range of hydrocarbons, including pentane (C₅H₁₂). The combustion of pentane produces carbon dioxide and water as well as energy.

Word equation:

\[
\text{pentane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}
\]

Chemical equation:

\[
\text{C}_5\text{H}_{12}(\text{l}) + 8\text{O}_2(\text{g}) \rightarrow 5\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g}) + \text{energy}
\]

Examples of combustion reactions in living systems

Cellular respiration is a chemical reaction that occurs within cells. During cellular respiration, reactants such as glucose are broken down in combustion reactions to release the energy stored within them. This energy is transformed into kinetic energy and heat energy. This allows you to perform all of your daily activities, such as thinking, talking and running. Some of the energy is used to keep your body at a constant temperature. Therefore, cellular respiration is an essential reaction for organisms.

Word equation:

\[
\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}
\]

Chemical equation:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}
\]
# Experiment 7.3.1

## How much energy is in food?

### Aim

To determine the amount of energy release by the combustion of a breakfast cereal.

### What are the risks in doing this experiment? How can you manage these risks to stay safe?

<table>
<thead>
<tr>
<th>What are the risks in doing this experiment?</th>
<th>How can you manage these risks to stay safe?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A blue Bunsen burner flame is hard to see and very hot, so you may burn yourself.</td>
<td>Ensure that the air hole is closed before lighting the Bunsen burner. Leave it on the safety flame when not in use, so the flame is easily visible.</td>
</tr>
<tr>
<td>Some students may have allergies.</td>
<td>If you have any food allergies, let your teacher know before you start the experiment.</td>
</tr>
</tbody>
</table>

### Materials

- one piece of a breakfast cereal such as Kellogg’s® Nutri-Grain
- pin
- cork
- 10 mL measuring cylinder
- retort stand, bosshead and clamp
- test tube (5–7 mL)
- thermometer or temperature probe
- matches

### Method

1. Stick the pin through the piece of Nutri-Grain and attach it to the cork. (The cork and pin form the stand for the Nutri-Grain.)
2. Measure 5 mL of water and transfer it to the test tube.
3. Measure the initial temperature of the water and record this in a results table.
4. Place the test tube in the clamp.
5. Place the Nutri-Grain under the test tube of water.
6. Use the matches to light the piece of Nutri-Grain.
7. Measure the final temperature of the water after the Nutri-Grain has finished burning.

### Results

Devise a table to record your observations.

### Discussion

1. What was the difference in the temperature of the water from the start to the end of the experiment?
2. Explain why the temperature of the water increased.
3. Did you need to hold the match under the cereal continuously? Suggest why.
4. It takes 4.2 kJ of energy to increase the temperature of 1 mL of water by 1°C. Therefore, it takes 21 kJ \((4.2 \times 5)\) to increase the temperature of your 5 mL of water by 1°C. Calculate the amount of energy absorbed by the water.
5. Comment on whether all the energy from the Nutri-Grain was absorbed by the water. Include any observations that you made to support your comment.
6. Describe some improvements that you could make to this experiment to gain more accurate results.
7. Justify or refute the statement: ‘All cereals will produce the same results as the Nutri-Grain.’

### Extension

Design an investigation to test your response to question 7. Your teacher may allow you to carry out your investigation with different foods.
Photosynthesis – the opposite of cellular respiration

Photosynthesis is an endothermic reaction that is the opposite of cellular respiration. During cellular respiration, glucose and oxygen react to produce carbon dioxide, water and energy. However, in photosynthesis carbon dioxide, water and energy form glucose and oxygen.

Word equation:

\[
\text{carbon dioxide} + \text{water} + \text{energy} \rightarrow \text{glucose} + \text{oxygen}
\]

Chemical equation:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

Plants are organisms that undergo both photosynthesis and cellular respiration. Plants do not eat food, as animals do. Instead they make their own food. They take in carbon dioxide and energy from sunlight through their leaves and absorb water through their roots. Through the process of photosynthesis, plants break down carbon dioxide and water and use this to produce glucose and oxygen. This glucose is a store of chemical energy and can then be used by the plant for respiration.

Comparing photosynthesis and cellular respiration

Photosynthesis and cellular respiration work together in living systems to provide energy. Photosynthesis captures the Sun’s energy and converts it into a form that cells can use. Cellular respiration then releases this energy for the organism.

Photosynthesis and cellular respiration have many similarities and differences. Table 7.2 compares these two processes.
<table>
<thead>
<tr>
<th><strong>Characteristic</strong></th>
<th><strong>Photosynthesis</strong></th>
<th><strong>Cellular respiration</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisms it occurs in</td>
<td>Plants</td>
<td>Most</td>
</tr>
<tr>
<td>Location within the cell</td>
<td>Chloroplasts</td>
<td>Mitochondria</td>
</tr>
<tr>
<td>When it occurs</td>
<td>In the presence of light</td>
<td>All the time</td>
</tr>
<tr>
<td>Endothermic or exothermic reaction</td>
<td>Endothermic</td>
<td>Exothermic</td>
</tr>
<tr>
<td>Reactants</td>
<td>Carbon dioxide, water, energy</td>
<td>Glucose, oxygen</td>
</tr>
<tr>
<td>Products</td>
<td>Glucose, oxygen</td>
<td>Carbon dioxide, water, energy</td>
</tr>
<tr>
<td>Energy source</td>
<td>Sunlight</td>
<td>Chemical stored energy (glucose)</td>
</tr>
<tr>
<td>Energy produced</td>
<td>Chemical stored energy (glucose)</td>
<td>Heat, kinetic energy</td>
</tr>
</tbody>
</table>

**Disadvantages of combustion reactions**

One of the main products of the combustion of hydrocarbons is carbon dioxide. Our increasing reliance on the burning of fossil fuels, including coal, petrol, diesel and natural gas, has increased the amount of carbon dioxide in the atmosphere. Carbon dioxide is one example of a greenhouse gas – a gas that will trap heat in the atmosphere.

The increase in carbon dioxide in the air has also led to a change in the pH of the oceans. When carbon dioxide dissolves in water, it forms carbonic acid. This lowers the pH of the water. Currently, the pH of the oceans is approximately 8.2. It is predicted that this could fall to 7.8 by 2100. While this may not seem like a significant change, it can have a huge impact on the marine environment. One of these impacts is the reduction of carbonate ions available. This affects the ability of coral to build their limestone skeletons and therefore can affect whole habitats such as the Great Barrier Reef. It can also dissolve shells of organisms as well as make it harder for shells to form initially.

![Figure 7.20 Ocean acidification can affect the shells of marine animals.](Shutterstock.com/Andreas Alexander)
Non-metallic oxides (teacher demonstration)

Aim
To observe the acidity of the non-metallic oxide, carbon dioxide.

<table>
<thead>
<tr>
<th>What are the risks in doing this experiment?</th>
<th>How can you manage these risks to stay safe?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal indicator may be harmful if ingested.</td>
<td>This experiment is to be done as a teacher demonstration. Do not ingest any universal indicator by sucking it up through the straw. Only blow through the straw.</td>
</tr>
<tr>
<td>Universal indicator is harmful to eyes.</td>
<td>This experiment is to be done as a teacher demonstration. Wear safety glasses while performing this experiment. Don’t blow too hard through the straw or the solution will splash up into your face.</td>
</tr>
</tbody>
</table>

Materials
- universal indicator in a dropper bottle, with colour chart
- plastic water bottle with a lid that has a hole in it to fit a straw
- 50 mL water
- straw

Method
1. Pour approximately 50 mL of water into the plastic bottle.
2. Add 5 drops of universal indicator to the water.
3. Screw the lid onto the bottle and place a straw through the hole into the water.
4. Gently blow through the straw for 2 minutes and record your observations.

Discussion
1. What gas were you blowing into the solution that caused the colour change?
2. What colour was the universal indicator at the beginning?
3. What colour was the universal indicator at the end?
4. State the pH of the solution formed by the gas dissolving in the water.
5. Identify whether the solution formed by the gas dissolving in the water is acidic, basic or neutral.

Conclusion
Write a conclusion regarding the acidity of the non-metallic oxide carbon dioxide.

Extension
Plan a method to test the effect of varying the amount of carbon dioxide dissolved in the water. Your teacher may carry out your method to see the results.

Remembering
1. Define the following glossary terms: cellular respiration, coal, hydrocarbon and photosynthesis.

Understanding
2. Name the products formed when a hydrocarbon undergoes combustion.
3. Identify two combustion reactions.
4. Write a word equation for the combustion of butane (C₄H₁₀).
5. Identify the reactants and the products for:
   a. photosynthesis
   b. respiration.
6. When magnesium burns in air, it reacts with oxygen to form magnesium oxide, producing a bright light. Explain why this reaction is an example of combustion.
Applying
7 Classify each of the following reactions as either exothermic or endothermic.
   a A fireworks display
   b Ice melting
   c Burning butane in a cigarette lighter
   d Cooking a cake
8 In commercial cold packs, two liquids are mixed and a chemical reaction occurs. This is an endothermic reaction that dramatically reduces the temperature of the pack. This can then be applied to sore muscles. What are two other household uses of either endothermic or exothermic reactions?

Analysing
9 If a lolly, made of sugar, is burned, it will produce carbon dioxide and water. This reaction usually happens so fast that the energy is released very quickly as heat, light and sound. Describe the similarities and differences between this reaction and cellular respiration.
10 The respiratory system supplies oxygen gas and the digestive system supplies glucose. The circulatory system transports the oxygen and glucose to the cells.
   a Explain why it is important for the cells to receive oxygen and glucose.
   b Predict what substances the circulatory system would take away from the cells. Explain your answer.
   c People suffering from pneumonia have difficulty breathing. Suggest a reason for why fatigue or tiredness is one symptom of pneumonia.
REMEMBERING
1. Complete the generalised word equations.
   a. Acid + metal hydroxide →
   b. Acid + metal carbonate →
   c. Acid + metal →
2. State the gas that must be present for combustion to occur.
3. Write the word and chemical equations for cellular respiration.
4. State the physical properties of:
   a. acids
   b. bases.

UNDERSTANDING
5. A piece of magnesium was placed in a test tube of hydrochloric acid. Bubbles were produced.
   a. Identify the gas that produced the bubbles.
   b. Name the test you could perform to support your answer to part a.
   c. Write a word equation for this reaction.
6. Classify the chemical reactions of photosynthesis and cellular respiration as endothermic or exothermic.
7. Many emergency spill kits contain sodium bicarbonate, also known as bicarb soda or sodium hydrogen carbonate. Explain why this would be included in the kits.

APPLYING
8. Justify whether the following statement is true or false. ‘A substance with a pH of 9 is an acid.’
9. One substance has a pH of 8 and another has a pH of 10. Justify which substance is more acidic.
10. Justify whether you would use universal indicator or a pH meter to prepare a solution of pH 8.3.
11. Bicarbonate of soda is often added to cake mixtures. It reacts with other ingredients to produce bubbles of carbon dioxide. What effect does this have on the cooked cake?
12. Many camping stoves use the combustion reaction of butane (C₄H₁₀). Explain why the instructions say to use the stove in a well-ventilated area.
13. Write a word equation for the reaction between magnesium hydroxide and nitric acid.
14. Sulfuric acid is found in car batteries. While changing the battery of the family car, your father spilt sulfuric acid onto the floor of the garage.
   a. What should you put on the acid to neutralise it before it is cleaned up?
   b. Write a word equation for this reaction.
   c. Outline the observations you would be able to make when the acid is reacting.
   d. List two ways that you would know when it was safe to clean up the spill.

ANALYSING
15. Compare the roles of cellular respiration and photosynthesis in living systems.
16. Many modern diets are high in fizzy drinks and fruit juices. These drinks are very acidic. The pH of the mouth is around 7.4, yet many of these drinks have a pH of around 3.4. Predict the effect of overconsumption of these drinks on the teeth and stomach.
17 Students will often use the reaction between vinegar and bicarbonate of soda to make a ‘volcano’.

Word equation: ethanoic acid + sodium hydrogen carbonate → sodium ethanoate + carbon dioxide + water

Chemical equation: CH₃COOH(aq) + NaHCO₃(s) → NaCH₃COO(aq) + CO₂(g) + H₂O(l)

a Outline why this reaction would be suitable to make a ‘volcano’.
b Name the salt produced in this reaction.
c Name the test that could be performed to correctly identify the gas produced.
d This is an endothermic reaction. Describe the temperature change that you would expect to observe.

EVALUATING

18 To maintain a marine aquarium, you must spend a lot of time ensuring that the pH is within the optimal range of 7.8–8.5.

a Is the optimal pH acidic, basic or neutral?
b If the aquarium water was tested with universal indicator, what colour would you expect to see in a healthy aquarium?
c In houses with the windows shut, there is an increase in carbon dioxide in the air. This can lead to a decrease in pH. Explain this observation.
d One method used to increase the pH is to add lime (calcium hydroxide, Ca(OH)₂). Explain how this would result in an increase in pH.

CREATING

19 Design a method to determine the amount of energy released or absorbed from the reaction between sulfuric acid and zinc metal.

REFLECTING

20 Discuss one thing that you have learned in this chapter that you can use in your everyday life.

21 Today’s society would not be possible without combustion reactions. Discuss this statement using specific examples.