Chapter 5

Compounds are classified in different ways.

A pigment is a chemical that absorbs some frequencies of light and reflects others, changing the colour of light an object reflects. The blue pigment in blue jeans is made from a chemical called phthalocyanine, a covalent compound that contains many carbon atoms. As well as dyeing cloth, pigments are also used to colour paint, food, cosmetics, and plastic. Pure pigments reflect light in a very specific way. Some pigments change colour depending on the mixture to which they are added.

What You Will Learn

In this chapter, you will

- **distinguish** among acids, bases, and salts by examining their chemical formulas and properties
- **explain** the significance and uses of the pH scale, with reference to common substances
- **write** names and formulas of acids, bases, and simple organic compounds
- **examine** chemical reactions that involve acids, bases, and organic compounds
- **describe** organic compounds

Why It Is Important

You encounter acids, bases, and salts in your everyday life. You also encounter organic compounds, which make up more than half of all known chemical compounds. Understanding organic chemistry helps us to understand the world around us and the processes that occur within us as well.

Skills You Will Use

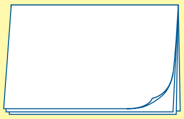
In this chapter, you will

- **predict** whether materials are acidic, basic, or neutral
- **measure** the pH of solutions
- **model** the bonding in organic molecules
- **classify** a compound as organic or inorganic from its name, formula, a diagram, or a model

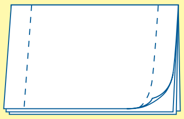
FOLDABLES™
Reading & Study Skills

Make the following Foldable. Use it to record notes about what you learn in Chapter 5.

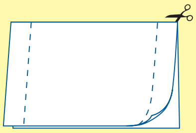
STEP 1 Take two sheets of notebook or 22 cm by 28 cm paper and **fold** them in half.



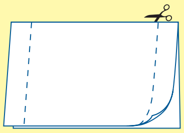
STEP 2 Use a pencil to **mark** each fold 2.5 cm in from the left and right edges.



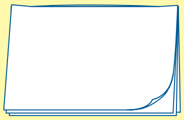
STEP 3 On one of the folded sheets, **cut** the top edge of the fold in to the marks or margins.



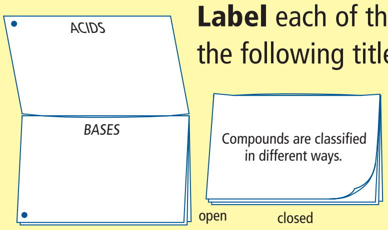
STEP 4 On the other folded sheet, start at one of the marked spots and **cut** the fold in between the two marks or margins, creating a slit in the centre of the fold.



STEP 5 Take the cut sheet from Step 3, **roll** it into a tube, and **insert** it through the other sheet and then open. **Fold** the bound pages in half to form a six-page book.



STEP 6 **Label** the exterior with the chapter title. **Label** each of the six pages with the following titles: Acids, Bases, Salts, Organic, Inorganic, and Vocabulary.



As you progress through the chapter, **record** information, write formulas, and define key terms on the appropriate pages.

5.1 Acids and Bases

Many common pure substances can be classified according to whether they are acids or bases. Some acids and bases are corrosive and poisonous, whereas others add flavour to food or are vitamins. Acid-base indicators are chemicals that change colour in response to acidic or basic conditions. The pH scale is a number scale for measuring how acidic or basic a solution is. A pH value below pH 7 is acidic, pH 7 is neutral, and a pH value above pH 7 is basic. Generally, the chemical formula for an acid starts with H (hydrogen) on the left of the formula. Bases generally have OH on the right of their chemical formulas.

Words to Know

acids
bases
bromothymol blue
concentration
indigo carmine
litmus paper
methyl orange
pH indicators
phenolphthalein

You have learned that one way to classify compounds is to determine whether they have ionic bonds or covalent bonds. There are other ways you can use to classify compounds. For example, you can classify some compounds as acids or bases.

You are very familiar with acids and bases because you see them, use them, and even eat them every day. The sour taste of grapefruit, the tart taste of carbonated drinks, and the tangy taste of salad dressings all come from acids. We add acidic juices to our foods to improve taste as well as to help absorb nutrients. For example, lemon juice contains ascorbic acid, which is another name for vitamin C, which may help our bodies absorb iron. Very strong acid in your stomach (Figure 5.1) helps digest what you eat. Acids dissolved in rainwater can form enormous caverns and destroy valuable buildings and statues over time. Because of their corrosive properties, we use some acids to remove rust and to purify and process metals.

Did You Know?

The whip scorpion is also known as the vinegaroon because it smells like vinegar. In self-defence, the whip scorpion sprays a combination of concentrated acetic acid and caprylic acid from glands near the rear of its abdomen.

Figure 5.1 The pits in the lining of your stomach secrete hydrochloric acid (HCl) to break down the food you eat. The surface cells on your stomach lining secrete mucus to protect your stomach from the acid.

Bases are bitter-tasting compounds with a slippery feel. Many cleaning products, such as soap and oven cleaner, are bases. Some medical drugs, such as lidocaine, a local anesthetic used by dentists, are bases. Eggs and baking soda are two examples of bases that are found in foods we eat.

Acids and bases have useful properties, but they should be handled with care. Some acids and bases are **corrosive**, which means they can burn your throat or stomach if swallowed and will burn your skin or eyes on contact. You should never attempt to identify an acid or a base, or any substance in the laboratory by its taste or feel.

The **pH scale** is a number scale for measuring how acidic or basic a solution is. One simple definition of **acids** is that they are chemical compounds that produce a solution with a pH of less than 7 when they dissolve in water. **Bases** are compounds that produce a solution of pH of more than 7 when they dissolve in water. If a solution has a pH of 7, it is said to be **neutral** (neither acidic nor basic). Notice that the "p" in pH is always lower case, and the "H" is always upper case. pH values do not have a unit of measurement written after the number.

5-1A Acidic, Basic, or Neutral?

Find Out ACTIVITY

In this activity, you will use pH paper or universal indicator to determine whether common liquids are acidic, basic, or neutral.

Safety

- Follow your teacher's recommendations for which fluids to bring to class and how to transport them safely.
- Never taste or eat anything in the science room.
- Wash your hands and equipment thoroughly after completing this activity.

Materials

- a variety of common liquids that you bring in from home or that are provided by your teacher, such as shampoo, detergent, juice, tonic water, bottled water
- spot plate
- pH paper or universal indicator
- indicator colour chart provided by your teacher

What to Do

1. Read this entire activity. Then, create a data table with several columns to record your results. Give your table a title.
2. Predict whether each of the test liquids is acidic, basic, or neutral.
3. Place a small amount of each liquid in a well of the spot plate, keeping track of where each is placed. Take care not to mix any of the substances.
4. Place a few drops of acid-base indicator or a piece of pH paper in each spot plate well that contains a test liquid.
5. Use the indicator colour chart to determine the pH of each liquid.
6. Create a pH number scale to display your results. Draw a horizontal line across a piece of paper. On the middle of the line, write 7 (neutral). On the left end, write a 0. On the right end, write a 14. Enter the name and pH of each liquid in the appropriate position on your number scale.
7. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

What Did You Find Out?

1. (a) Which liquids were acidic?
   (b) How do you know?
2. (a) Which liquids were basic?
   (b) How do you know?
3. (a) Which liquids were neutral?
   (b) How do you know?

internet connect

The Richter scale of earthquake intensity and the decibel scale of sound intensity are other number scales in which a one unit change represents a much larger change. You can find out more about number scales. Start your search at **www.bcscience10.ca**.

pH Values of Common Substances

You can see the pH values of some common substances in Figure 5.2. Notice that the more acidic a substance is, the lower the pH is. For example, a solution of lemon juice, with a pH of about 2, has a greater acidity than a solution of tomato juice, which has a pH of about 4.

Substances that have a pH greater than 7 are said to be basic, or alkaline. You may recognize the term alkaline from the family of metals called the alkaline earth metals (group 2 on the periodic table), which includes calcium and magnesium. These metals are not basic by themselves, but they react with water to produce basic solutions. For solutions containing bases, the greater the pH, the more basic or alkaline the solution is. For example, an oven cleaner with a pH of 13 is more basic than a soap that has a pH of 10.

Substances that are neither basic nor acidic are neutral. Pure water is neutral and has a pH of 7. Human saliva is close to neutral, ranging from a pH of 6.5 to a pH of 7.4. Human blood is slightly basic with a pH of 7.3 to 7.5.

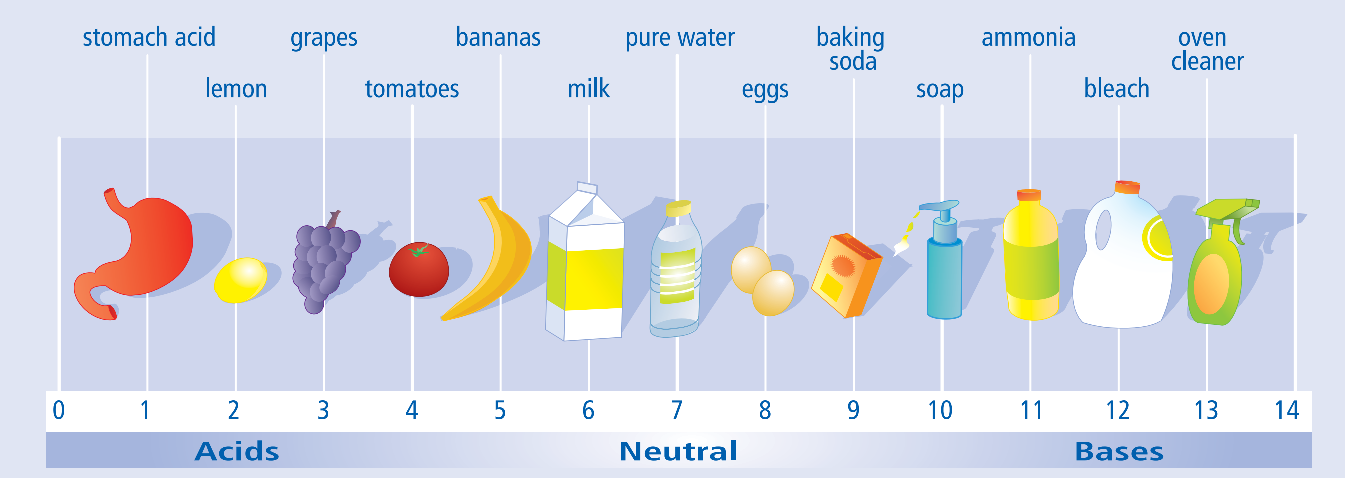


Figure 5.2 pH values of common substances

Using the pH Scale

The pH scale allows chemists to express a wide range of measurements using a small and easily understood range of numbers. On the pH scale, one unit of change represents a 10 times change in the degree of acidity or basicity.

What is the increase in acidity if the pH drops from pH 6 to pH 4? A two unit drop in pH is a 10^2 or 100 times increase in acidity. For example, normal precipitation has a pH of about 6 and acid precipitation has a pH of about 4. This means the acidity levels are increased by 100 times or more in acid precipitation as compared with normal precipitation. A delicate balance between acids and bases is vital for organisms to survive. Even a small increase in acidity harms coral reefs and organisms that require a specific pH level to use calcium to make their shells.

pH Indicators

Many common acids and bases form colourless solutions. These solutions look just like water but may be hazardous. One safe way to tell whether a solution is acidic or basic is to use a pH indicator. **pH indicators** are chemicals that change colour depending on the pH of the solution they are placed in.

One common pigment used as an indicator is litmus, a compound that is extracted from various lichens. Litmus is especially useful when dried onto thin paper strips called **litmus paper**. You can use litmus paper to determine whether a solution is acidic or basic (Figure 5.3). Litmus paper comes in two forms, red and blue. When blue litmus is placed in a solution that is acidic (below pH 7), the blue litmus paper turns red. When red litmus paper is placed into a solution that is basic (above pH 7), the red litmus paper changes to blue. You can use both red litmus paper and blue litmus paper to tell if a solution is neutral (pH 7). In a neutral solution, blue litmus stays blue and red litmus stays red.

Universal indicator (Figure 5.4A and B) contains a number of indicators that turn different colours depending on the pH of the solution. A digital pH meter or pH computer probe (Figure 5.4C) measures an electrical property of the solution and uses this to determine the pH.

Figure 5.3 Litmus is red in acids and blue in bases.

Word Connect

You can remember the colour changes of litmus with the following memory device.

BAR = **Blue** + **Acid** → **Red**

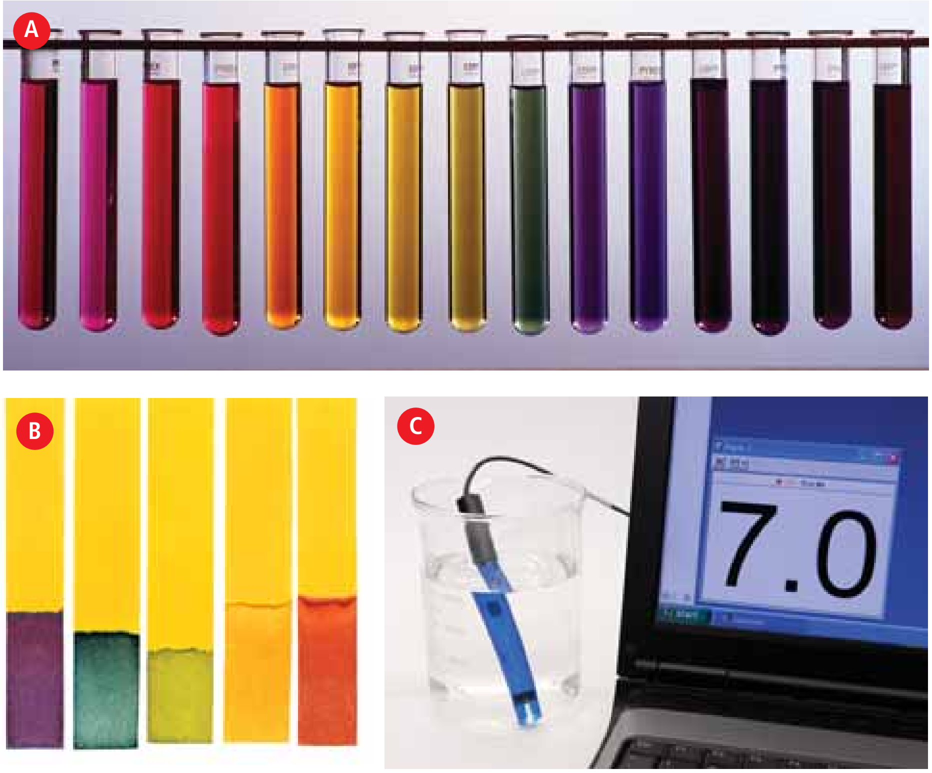


Figure 5.4 Universal indicator can be prepared as a liquid and then dropped into a test sample (A), or it can be dried onto paper called pH paper (B). The sensor is measuring the pH of a solution (C).

Figure 5.5 Phenolphthalein indicator in an acidic solution (left) and in a highly basic solution (right).

Other pH indicators

Not all pH or acid-base indicators change colour at pH 7 like litmus does. For example, **phenolphthalein** is a colourless chemical compound in acidic or slightly basic solutions but turns pink in moderately basic to highly basic solutions (Figure 5.5).

There are many other acid-base indicators that you can use. Some acid-base indicators, such as **bromothymol blue, indigo carmine**, **methyl orange**, and **methyl red** are named after their colour changes. For example, the pH at which methyl orange changes from red to yellow occurs over the pH range of 3.2 to 4.4. In this range, the methyl orange is mixture of both red and yellow, which makes this colour change orange. Table 5.1 and Figure 5.6 show the colour change of several acid-base indicators.

Table 5.1 Acid-Base Indicators

Acid-base indicator	pH Range in Which Colour Change Occurs	Colour Change as pH Increases
Methyl orange	3.2–4.4	red to yellow
Methyl red	4.8–6.0	red to yellow
Bromothymol blue	6.0–7.6	yellow to blue
Litmus	7.0	red to blue
Phenolphthalein	8.2–10.0	colourless to pink
Indigo carmine	11.2–13.0	blue to yellow

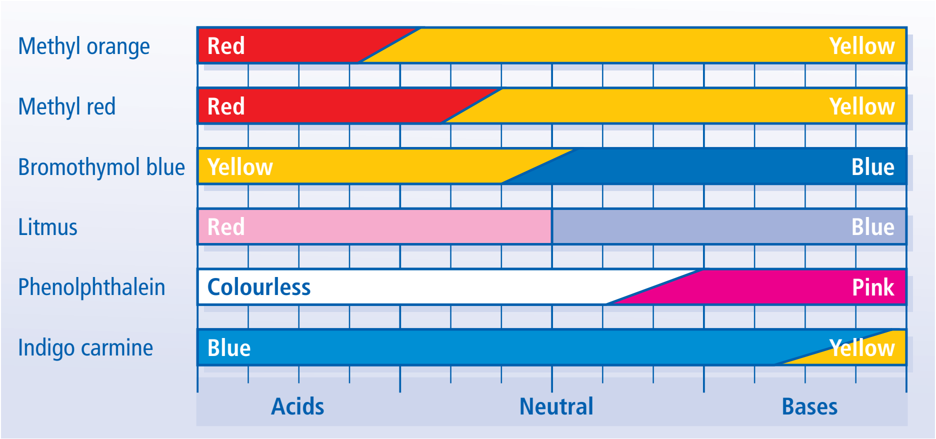


Figure 5.6 Common acid-base indicators and their pH colour change

Did You Know?

Natural sources for acid-base indicators include the following.

- beets
- blueberries
- cherries
- curry powder
- grapes
- pansy petals
- poppy petals
- red cabbage
- rose petals
- strawberries
- tulip petals
- violet petals

Reading Check

1. What is the pH scale?
2. Above what pH level is a solution said to be basic or alkaline?
3. When the pH rises from 10 to 12, how many times more basic has the solution become?
4. What colour is litmus paper in an acidic solution?
5. What colour is bromothymol blue at the following pH levels?
   (a) pH 5
   (b) pH 7
   (c) pH 9

Acids

You can sometimes identify acids by their chemical formulas. Many compounds, such as HCl, take on acid properties only when mixed with water. For this reason, acids are often indicated as being dissolved in water when the formula is written. For example, HCl dissolved in water is written as HCl(aq) where the (aq) refers to aqueous, or "dissolved in water to make a solution."

The chemical formulas for acids are usually written with an H on the left side of the formula, such as HCl(aq). For acids containing the element carbon, the H may be written on the right side, such as with acetic acid or vinegar, $CH_3COOH(aq)$.

Acids can be named in several ways. If no state of matter is given, the name may be given beginning with hydrogen, as in hydrogen chloride (HCl). If the acid is shown as being aqueous, as in HCl(aq), a different name may be used that ends in "**-ic acid**" as in hydrochlor**ic acid**.

Table 5.2 shows the formulas, names, and uses of some common, important acids. All four of these acids are extremely corrosive. Highly corrosive acids can eat into or wear away a variety of materials, such as metals and human tissue. Figure 5.7 shows an application for a hightly corrusive acid.

Figure 5.7 The sulfuric acid in this battery has a pH of 1.2, which means it is extremely corrosive.

Table 5.2 Some Common Acids

Formula	Chemical Name	Common Name	Examples of Uses
HCl(aq)	hydrochloric acid	muriatic acid	• Produced in the stomach to help digest food
$H_2SO_4(aq)$	sulfuric acid	battery acid	• Used in automobile batteries • Used to clean metals
$HNO_3(aq)$	nitric acid	nitric acid	• Used to make fertilizers
$CH_3COOH(aq)$	ethanoic acid	acetic acid	• Present in vinegar

Names of acids

There are many, many different types of acids. Some acids, such as those in Table 5.3, do not contain oxygen. Other acids, such as those shown in Table 5.4, do contain oxygen. There is a basic pattern when oxygen is present in the formula. Names that begin with hydrogen and end with the suffix -**ate** can be changed by dropping "hydrogen" from the name and changing the suffix to -**ic acid**. For example:

H_2CO_3—hydrogen carbonate
$H_2CO_3(aq)$—carbon**ic acid**

When the name begins with hydrogen and ends with the suffix -**ite**, then the name can be changed to end with the suffix -**ous acid**. For example:

H_2SO_3—hydrogen sulf**ite**
$H_2SO_3(aq)$—sulfur**ous acid**

Table 5.3 Some Non-Oxygen Acids

Formula	Chemical Name	Formula in Solution	Formula Name Can Be Changed to	Examples of Uses
HF	hydrogen fluoride	HF(aq)	hydrofluoric acid	• Manufacturing aluminum and uranium
HCl	hydrogen chloride	HCl(aq)	hydrochloric acid	• Producing plastic
HBr	hydrogen bromide	HBr(aq)	hydrobromic acid	• Extracting metal ore
HI	hydrogen iodide	HI(aq)	hydriodic acid	• Taking part in chemical reactions to make other compounds

Table 5.4 Some Acids Containing Oxygen

Formula	Chemical Name	Formula in Solution	Formula Name Can Be Changed to	Examples of Uses
$HClO_4$	hydrogen perchlorate	$HClO_4(aq)$	perchloric acid	• Manufacturing explosives and speeding up chemical reactions
$HClO_3$	hydrogen chlorate	$HClO_3(aq)$	chloric acid	• Air pollution control
$HClO_2$	hydrogen chlorite	$HClO_2(aq)$	chlorous acid	• Disinfectant
HClO	hydrogen hypochlorite	HClO(aq)	hypochlorous acid	• Treating water in swimming pools

Did You Know?

Vitamin C is the common name for ascorbic acid, which is essential for healthy gums, skin, and muscles. Most animals can produce ascorbic acid in their bodies, but humans cannot. We must obtain vitamin C in our diet.

Reading Check

1. How can you recognize an acid by its chemical formula?
2. State which acid is present in:
   (a) your stomach; (b) vinegar; (c) automobile batteries
3. State another name for aqueous hydrogen fluoride, HF(aq).
4. State another name for aqueous hydrogen perchlorate, $HClO_4(aq)$.
5. What does corrosive mean?

Bases

You can identify bases by their chemical formulas since they are usually written with an OH on the right side of the formula. Common bases are shown in Figure 5.8 and listed in Table 5.5. Some of these bases are much stronger than other bases. For example, the magnesium hydroxide found in an antacid is gentle enough to be taken internally in the correct dose. However, the sodium hydroxide found in a drain cleaner is extremely reactive with human skin and tissues. Solutions made from highly reactive bases, such as drain cleaner and oven cleaner, are called **caustic**. You should be familiar with the safety hazard symbols shown in Figure 5.9.

Figure 5.8 All of these common household bases have warnings on their labels for their handling and use. Never mix household chemicals without first checking the warning labels on the containers. Some combinations can be hazardous.

Figure 5.9 Symbols used on Canadian products to indicate corrosive material

Table 5.5 Some Common Bases

Formula	Chemical Name	Common Name	Examples of Uses
NaOH	sodium hydroxide	caustic soda, lye	• Drain and oven cleaner • Used to manufacture paper, glass, and soap
$Mg(OH)_2$	magnesium hydroxide	milk of magnesia	• Active ingredient in some antacids
$Ca(OH)_2$	calcium hydroxide	hydrated lime	• Soil and water treatment
NH_4OH	ammonium hydroxide	household ammonia	• Kitchen cleaner • Used to make fertilizer

Reading Check

1. How can you recognize a base by its formula?
2. State which base is present in:
   (a) milk of magnesia
   (b) drain cleaner
   (c) household ammonia
3. Give an example of a highly reactive base.
4. What is another term used to describe highly reactive bases?

Production of Ions

A solution that is either acidic or basic can conduct electricity because it contains freely moving ions. Acids produce **hydrogen ions** (H^+) when dissolved in solution. Bases produce **hydroxide ions** (OH^-) when dissolved in solution. Testing the pH of a solution is a way of measuring its concentration of hydrogen ions, $H^+(aq)$. **Concentration** of hydrogen ions refers to the number of hydrogen ions in a specific volume of solution. Solutions with a high concentration of hydrogen ions are highly acidic (low pH). Similarly, solutions with a high concentration of hydroxide ions are highly basic (high pH). Because H^+ ions and OH^- ions readily react with each other, a solution cannot have a high H^+ concentration and a high OH^- concentration at the same time (Figure 5.10). For this reason, acids and bases are considered to be chemical opposites.

Word Connect

You could think of "pH" as standing for the "power of the hydrogen ion." Power refers to the number of ions dissolved in a solution. For example, 1 L of a solution with a pH of 1 will contain 1 000 000 or 10^6 times more $H^+(aq)$ than 1 L of a solution with a pH of 7.

When separate solutions containing H^+ ions and OH^- ions are combined, they react by forming water.

$$H^+ + OH^- \rightarrow H_2O$$

When an acidic solution is mixed with a basic solution, the solutions can *neutralize* each other, which means that the acidic and basic properties are in balance. In many cases (but with some important exceptions), this reaction produces a neutral solution.

Did You Know?

The sting you feel from an ant bite or a bee sting comes from formic acid, which dissolves the ends of the nerves in your skin. When you use a cream containing ammonia, which is a base, to neutralize the acid, you change the acid's properties so it cannot do more damage to the nerve.

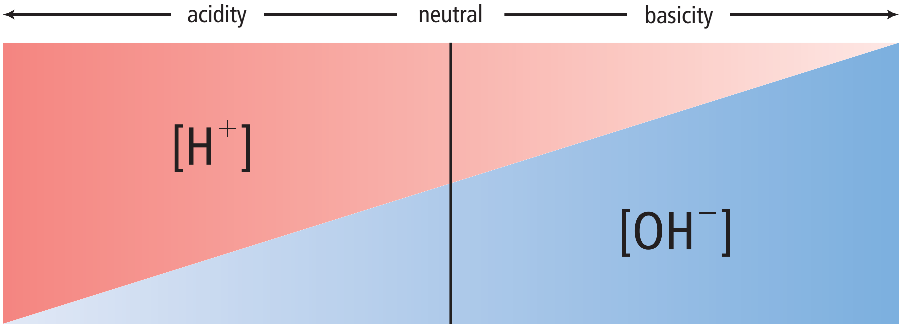


Figure 5.10 Notice how H^+ and OH^- change simultaneously. As H^+ decreases to the right, OH^- increases.

Mining operations in British Columbia result in large volumes of rock being ground up and processed. After the valuable minerals have been removed, the remaining ground rock, called tailings, is usually deposited in a tailings pond (Figure 5.11). Sometimes the tailings release acids, which lower the pH of the water in the pond and affect the surrounding environment. One way to combat this problem is to add a base to the pond to raise the pH to normal levels.

Figure 5.11 A tailings pond

Properties of Acids and Bases

Acids and bases have a number of properties in common and several very important differences, which are summarized in Table 5.6.

Table 5.6 Properties of Acids and Bases

Property	Acid	Base
Taste CAUTION: Never taste chemicals in the laboratory.	• Acids taste sour. Lemons, limes, and vinegar are common examples.	• Bases taste bitter. The quinine in tonic water is one example.
Touch CAUTION: Never touch chemicals in the laboratory with your bare skin.	• Many acids will burn your skin. Sulfuric acid (battery acid) is one example.	• Bases feel slippery. • Many bases will burn your skin. Sodium hydroxide (lye) is one example.
Indicator tests	• Acids turn blue litmus paper red. • Phenolphthalein is colourless in an acidic solution.	• Bases turn red litmus blue. • Phenolphthalein is colourless in slightly basic solutions and pink in moderate to strongly basic solutions.
Reaction with some metals, such as magnesium or zinc	• Acids corrode metals.	• No reaction
Electrical conductivity	• Conductive	• Conductive
pH	• Less than 7	• More than 7
Production of ions	• Acids form hydrogen (H^+) ions when dissolved in solution.	• Bases form hydroxide (OH^-) ions when dissolved in solution.

Suggested Activity

Conduct an Investigation 5-1B on page 230

Explore More

Your muscles may feel sore after a heavy workout due to the build-up of lactic acid. Find out why your body produces lactic acid and why cooling down after exercise helps prevent a build-up of lactic acid. Begin your research at **www.bcscience10.ca**.

5-1B Properties of Acids and Bases

Skill Check

- Observing
- Predicting
- Classifying
- Communicating

Safety

- Wear safety goggles and protective clothing.
- Handle chemicals safely.
- Some of the indicators are also stains. Keep them off clothing.
- Do not remove any materials from the science room.
- Wash your hands and equipment thoroughly after completing this activity.

Materials

- 4 × 6 spot plate
- masking tape
- Solutions A, B, C, and D (CAUTION: Some of the solutions are corrosive.)
- 4 pieces of Mg ribbon
- 4 pieces of red litmus paper
- 4 pieces of blue litmus paper
- bromothymol blue solution
- indigo carmine solution
- methyl orange solution

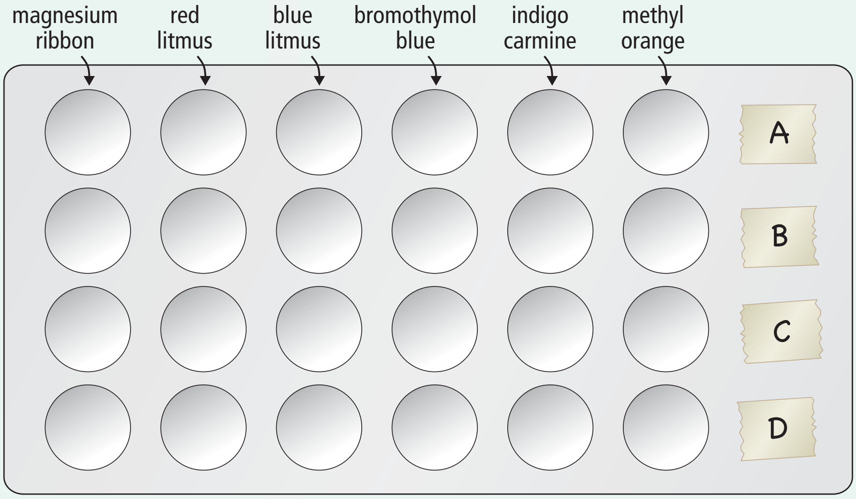
In this activity, you will investigate the acid-base properties of four solutions. Take care in handling the solutions as they may be corrosive. You will test each of the solutions with Mg ribbon and with several pH indicators and look for patterns.

Question

How can the properties of acids and bases be used to classify solutions?

Procedure

1. First, read this entire procedure. Then, design a data table to record your results. Include a title for each column and row in your data table. Make sure your data table clearly indicates each solution you will be using and the indicator it will be mixed with. Give your data table a title.
2. Use masking tape to label the rows on your spot plate A, B, C, and D.
3. Add a few mL of Solution A to each of the six wells of row A of the spot plate. Place Solution B in the next six wells in row B. Repeat for Solution C and Solution D.
4. Place a piece of magnesium ribbon in the first well of each of the four rows.
5. Place red litmus in the second well of each row. Place blue litmus in the third wells of each row.
6. Add five drops of bromothymol blue solution to the fourth well of each row. Add five drops of indigo carmine solution to the fifth well. Add five drops of methyl orange solution to the sixth well.
7. Record your results in your data table. State the colour or other observations.
8. Your teacher may wish to see your spot plate once it is completed. Be sure to check before you begin clean-up.
9. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.



Set-up of spot plates

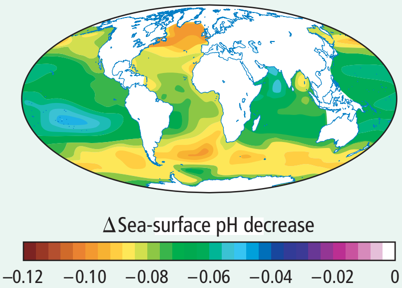
Analyze

1. List the solutions in order from most acidic to least acidic (most basic).
2. Which solution do you think was neutral? Explain how you know.
3. You used two bases. Explain how you know which solution was more alkaline (more basic).
4. How can magnesium metal be used to distinguish between an acid and a base?

Conclude and Apply

1. (a) What colour would each of the five indicators be in a solution that is pH 3?
   (b) What colour would each of the five indicators be in a solution that is pH 10?
2. Suppose you are asked to put together a test kit to determine whether water taken from a factory waste drain is acidic, basic, or neutral. Your kit can contain only three tests. Which tests would your kit contain? Explain.
3. Refer to the photo of the lichen *Roccella tinctoria* on this page, from which litmus is extracted. If this lichen were ground up and then soaked in vinegar, what colour would the solution likely be?
4. What is the colour of seawater that has had bromothymol blue added to it?
5. Consider the colour-coded map of the world's oceans shown to the right.
   (a) Which regions of the world's oceans appear to be most affected by the drop in pH level?
   (b) Which regions are the least affected?

Litmus is a mixture of dyes extracted from lichens such as the *Roccella tinctoria* shown here.



Between 1750 and 2000, the pH of the oceans fell from 8.109 to 8.104, likely as a result of human activity that put more carbon dioxide into the air.

Science Watch

Acid Oceans

What do corals, barnacles, clams, and oysters all have in common, besides living in the ocean? They all make protective shells out of calcium carbonate. Ocean water contains dissolved calcium ions and carbonate ions, and many ocean organisms use these ions to build their shells. This remarkable bit of biochemistry is under threat from the activity of humans, not because of what we are doing directly to the oceans but because of what we are doing to the air.

The energy we use for industry, transportation, power, and heating and cooling buildings mostly comes from burning coal, gasoline, and other carbon sources as fuels. The burning of fuels adds large amounts of carbon dioxide to the atmosphere. Natural absorption of this extra carbon dioxide by the oceans helps to slow down the effects of carbon dioxide build-up and its effects on global warming as a greenhouse gas. This might seem like a good thing.

Coral can dissolve in acidic water.

A marine biologist collects samples from a coral reef to study how human activity is affecting the reef and how best to protect it.

However, like most ecological damage, this absorption has far-reaching effects. When carbon dioxide gas enters the ocean, it can react with water to form carbonic acid (H_2CO_3).

Some of the dissolved carbonate ions, which are basic, work to neutralize the excess carbonic acid. As a result, carbonate levels drop in the ocean. With lower carbonate concentrations, the ability of sea creatures to make shells also decreases. Even the tiny plankton that form the basis of the marine food chain are affected because many of them produce a skeleton made from calcium carbonate.

If the pH of the oceans drops too far, coral reefs may begin to dissolve. Coral reefs are treasure troves of biodiversity. They are the underwater equivalent of tropical rainforests in that they are homes for countless forms of sea life. If we do not bring the problem of carbon dioxide emissions to the atmosphere under control, we may cause irreparable damage to our oceans.

Questions

1. What are two planet-wide environmental problems associated with burning carbon as a fuel source?
2. How does adding excess carbon dioxide gas to the atmosphere result in a decreased ability of shellfish to make shells?
3. How can we halt the acidification of our oceans?

Check Your Understanding

Checking Concepts

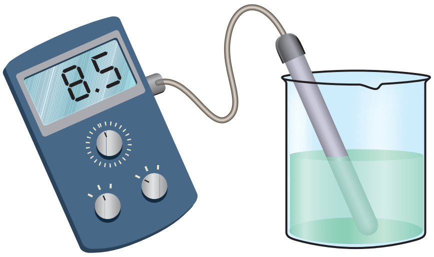
1. (a) List three solutions commonly found in a kitchen or in a home that are acids.
   (b) List three solutions that are bases.
2. Use the pH scale to help you define the following terms.
   (a) acid
   (b) base
   (c) neutral
3. Why should you never taste a solution to determine whether it is an acid or a base?
4. Solution A has a pH of 3. Solution B has a pH of 6.
   (a) Which solution is more acidic?
   (b) How many times more acidic is it?
5. Copy and then complete the following chart in your notebook.

Indicator	Colour at pH 1	Colour at pH 7	Colour at pH 10
Red litmus paper			
Blue litmus paper			

6. Refer to Figure 5.6 to find the colour of the following indicators.
   (a) phenolphthalein indicator when placed in a solution that is pH 8
   (b) bromothymol blue when placed in a solution that is pH 7
   (c) indigo carmine when placed in a solution that is pH 13
7. Describe the following properties of acids.
   (a) taste
   (b) reaction to metals
   (c) electrical conductivity
8. Describe the following properties of bases.
   (a) taste
   (b) reaction to metals
   (c) electrical conductivity
9. (a) What is the chemical name of the acid present in vinegar?
   (b) What is its chemical formula?
10. (a) What is the chemical name of the acid present in automobile batteries?
    (b) What is its chemical formula?
11. (a) What is the chemical name of the base used as an antacid?
    (b) What is its chemical formula?
12. (a) What is the chemical name of the base used to clean drains?
    (b) What is its chemical formula?

Understanding Key Ideas

13. For each of the following compounds, give what its formula name can be changed to when it is present in an aqueous solution.
    (a) $HClO_4$
    (b) H_2SO_4
    (c) HF
14. For each of the following compounds, give what its formula name can be changed to when it is present in an aqueous solution.
    (a) hydrogen chloride
    (b) hydrogen nitrate
    (c) hydrogen acetate
    (d) hydrogen sulfate
15. The illustration below shows the pH of a solution. Describe each of its following properties.
    (a) taste
    (b) touch
    (c) colour of red litmus
    (d) reaction to magnesium metal



Pause and Reflect

You have learned that acids can be corrosive to metals and human tissue and must be handled with care. What gentle acids have you used? How did you use them? In what situations might it be beneficial to apply a gentle acid directly to skin or hair?

5.2 Salts

Salts are a class of compounds including the ionic compounds that can be produced when an acid and a base react. Oxides and carbonates can chemically react with acids and produce salts. Salts can also be produced by the chemical reaction of a metal and an acid. Metal oxides combine with water to form bases. Non-metal oxides combine with water to form acids.

Words to Know

metal oxide
neutralization (acid-base)
non-metal oxide
oxide
salts

When did you last use table salt? Was it to flavour a meal? Was it as part of a sports drink after an intense workout? What about using salt to help your country gain independence?

On April 6, 1930, in British-occupied India, Mahatma Gandhi stepped onto the beach in Dandi, on the west coast of India. He had led thousands of Indians on a 400 km march to the ocean to gather salt from the beach, in protest of the tax on salt required by the ruling British. By picking up a piece of salt crusted on the sand, he violated a British law (Figure 5.12). This public display of peaceful disobedience was part of a chain of events that helped India achieve independence.

Civilizations around the world have placed great value on table salt because it is so necessary to life. At various times throughout human history, table salt was worth its weight in gold, wages were paid in salt, and wars were fought for control over the salt trade. Common table salt is chemically sodium chloride and is normally obtained from seawater, salt lakes, or rock deposits (Figure 5.13). Both sodium and chlorine are chemical elements that are necessary for our survival.

Figure 5.12 Mahatma Gandhi and his followers gathering salt

Figure 5.13 Western Canada has a huge deposit of rock salt that averages 122 m in thickness, covers approximately 390 000 km^2, and contains more than a million billion tonnes of salt. The salt is mined for use as road salt.

Sodium chloride is only one of many types of salt, all of which can trace their origin to acids and bases. A salt is made up of a positive ion from a base and a negative ion from an acid. In chemistry, **salts** are a class of ionic compounds that can be formed during the reaction of an acid and a base. Different kinds of salts are used in a variety of ways, such as in the making of batteries, explosives, and fertilizers. Many multivitamin and mineral tablets contain minerals such as calcium, iron, and magnesium, which are present in the tablet as salts. Salts are an important part of cytoplasm in cells, sap in plants, and blood and urine in animals.

Did You Know?

Iodized table salt has very small amounts of sodium iodide (NaI) or potassium iodide (KI) added to help prevent iodine deficiency in the human body. Iodine deficiency can cause goitre, a disease of the thyroid gland.

5-2A Three Salts

Find Out ACTIVITY

You can observe salts being formed in several different types of chemical reactions. In this activity, you will observe and compare the results of several chemical reactions.

Safety

- Handle chemicals carefully. Avoid touching all reactants and products.
- Follow your teacher's directions regarding using open flames.
- Do not taste anything in the science room.
- Do not remove any materials from the science room.
- Wash your hands and equipment thoroughly after completing this activity.

Materials

- 3 medium-sized test tubes
- test tube rack
- labelling pen
- hydrochloric acid, HCl(aq)
- universal indicator
- zinc metal
- wooden splints
- matches
- plastic spoon
- sodium carbonate powder, Na_2CO_3
- magnesium hydroxide slurry (milk of magnesia)

What to Do

1. Place three medium-sized test tubes in a test tube rack, and label them 1, 2, and 3.
2. Place hydrochloric acid solution, HCl(aq), into each of the test tubes to a depth of about 2 cm.
3. Add a few drops of universal indicator into each test tube. Note the colour.
4. To test tube 1, add one or two pieces of zinc metal. Observe. Your teacher may ask you to test the gas that is produced with a burning splint or glowing splint. Record your results.
5. To test tube 2, add a small scoop (about 3 g or 5 mL) of sodium carbonate powder. Observe. Your teacher may ask you to test the gas that is produced with a burning splint or glowing splint. Record your results.
6. To test tube 3, add a small scoop (about 3 g or 5 mL) of magnesium hydroxide slurry. Observe for several minutes as changes may continue to occur. Record your results.
7. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

What Did You Find Out?

1. A salt was formed in each reaction. Predict the name and formula of the salt that was formed in:

   (a) test tube 1; (b) test tube 2; (c) test tube 3
2. Predict the identity of any gases you may have tested.
3. Which chemical was most effective at raising the pH of the HCl solution? Explain how you are able to determine this.

Suggested Activities

Find Out Activity 5-2B on page 240
Conduct an Investigation 5-2C on page 241

Acid-Base Neutralization

Many products that you use are produced through acid-base neutralizations. **Neutralization (acid-base)** is the name for the type of chemical reaction that occurs when an acid and a base react to form a salt and water. For example:

$$\begin{array}{lllllll} HCl & + & NaOH & \rightarrow & NaCl & + & H_2O \\ \text{acid} & + & \text{base} & \rightarrow & \text{salt} & + & \text{water} \end{array}$$

In this reaction, the salt that is produced is sodium chloride, or table salt.

Aluminum sulfate is used to reduce the pH of garden soil and is also used in water purification because it helps impurities coagulate (stick together) and settle out. Aluminum sulfate is prepared by dissolving aluminum hydroxide in sulfuric acid. The reaction is:

$$\begin{array}{lllllll} 3H_2SO_4 & + & 2Al(OH)_3 & \rightarrow & Al_2(SO_4)_3 & + & 6H_2O \\ \text{acid} & + & \text{base} & \rightarrow & \text{salt} & + & \text{water} \end{array}$$

Another example of acid-base neutralization occurs when vinegar is mixed with a base such as $Mg(OH)_2$. The acetic acid (CH_3COOH) in the vinegar reacts with the base as follows.

$$\begin{array}{lllllll} 2CH_3COOH & + & Mg(OH)_2 & \rightarrow & Mg(CH_3COO)_2 & + & 2H_2O \\ \text{acid} & + & \text{base} & \rightarrow & \text{salt} & + & \text{water} \end{array}$$

The product of this reaction is magnesium acetate. Mixtures of magnesium acetate and calcium acetate are used as road salt to remove ice from roadways (Figure 5.14). These mixtures do not cause as much rust on automobiles as other de-icing salts such as calcium chloride, and they cause less damage to the environment.

Figure 5.14 We use road salt in many parts of our country to improve winter driving conditions. Canada is the largest user of road salt in the world on a per capita basis. We average about 360 kg of salt per person per year.

Practice Problems

Complete and balance the following neutralization reactions. Then, write the names of all the reactants and all the products in each chemical reaction. Consider the formulas of your products carefully before you begin to balance.

1. $HCl + KOH \rightarrow$
2. $H_2CO_3 + Mg(OH)_2 \rightarrow$
3. $CH_3COOH + CsOH \rightarrow$
4. $H_3PO_4 + NaOH \rightarrow$
5. $HNO_3 + Ca(OH)_2 \rightarrow$

Answers provided on page 592

Metal Oxides and Non-Metal Oxides

Metals react with oxygen to form oxides. An **oxide** is a chemical compound that includes at least one oxygen atom or ion along with one or more other elements (Figure 5.15). A **metal oxide** is a chemical compound that contains a metal chemically combined with oxygen. When a metal oxide dissolves in water, the solution becomes basic.

$Na_2O(s) + H_2O(\ell) \rightarrow 2NaOH(aq)$ (a base)
sodium hydroxide

$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$ (a base)
calcium hydroxide

Non-metals also react with oxygen to form oxides, such as carbon dioxide and sulfur dioxide. A **non-metal oxide** is a chemical compound that contains a non-metal chemically combined with oxygen. When non-metal oxides dissolve in water, the solution becomes acidic.

$SO_2(g) + H_2O(\ell) \rightarrow H_2SO_3(aq)$
sulfurous acid

$SO_3(g) + H_2O(\ell) \rightarrow H_2SO_4(aq)$
sulfuric acid

$2NO_2(g) + H_2O(\ell) \rightarrow HNO_2(aq) + HNO_3(g)$
nitrous acid + nitric acid

$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$
carbonic acid

Figure 5.15 Silicon reacts with oxygen to form silicon dioxide, SiO_2, which is used in the manufacture of glass. The mineral quartz, which is the main component of sand, is silicon dioxide. Silicon and oxygen are the two most abundant elements in Earth's crust.

Connection

Section 2.2 has more information about acid precipitation.

When fuels such as coal and gasoline are burned, they combine with oxygen. The products are non-metal oxides, which are released into the atmosphere. The non-metal oxides dissolve in rainwater to produce acid precipitation. You may be familiar with the environmental problems that result when acid precipitation gets into freshwater ecosystems and the harm that acid precipitation can do to all plants, including farm crops. Acid precipitation also reacts chemically to damage the limestone in buildings and in monuments.

You may recall from previous studies that the periodic table organizes the elements based on similar chemical properties. For example, metals appear on the left and in the centre of the table and non-metals appear on the upper right hand corner. Oxides from elements on the left and centre of the periodic table form bases in water. Oxides of elements from the upper right-hand corner of the periodic table form acids in water.

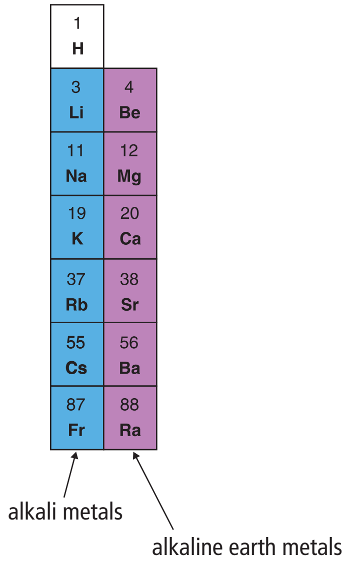


Figure 5.16 Metals increase in reactivity as you go down columns 1 and 2.

Reading Check

1. What two types of pure substances are produced from the neutralization of an acid and a base?
2. What environmental problem is associated with the burning of coal and gasoline?
3. When a non-metal oxide is mixed with water, does the water become acidic or basic?
4. When a metal oxide is mixed with water, does the water become acidic or basic?

Acids and Metals

The most reactive metals appear on the extreme left of the periodic table (Figure 5.16). Alkali metals and alkaline earth metals react vigorously with water and also with acids. Within these groups, the elements at the bottom of the columns react the most vigorously. For example, cesium is more reactive than sodium.

Other metals, such as copper, silver, gold, and platinum, are much less reactive. For example, gold will react only in a mixture of concentrated nitric acid and hydrochloric acid. Neither acid can dissolve gold on its own. When metals react with acids, they usually release hydrogen gas, such as shown in the following two examples.

$$2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$$

$$3H_2SO_4(aq) + 2Al(s) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

Practice Problems

Complete and balance the following chemical reactions between an acid and a metal. Remember that each reaction will produce a salt and hydrogen gas (H_2). Consider the formulas of your products carefully before you begin to balance.

1. $HCl + Zn \rightarrow$
2. $H_2SO_4 + Mg \rightarrow$
3. $HBr + Al \rightarrow$
4. $HCl + Ca \rightarrow$
5. $H_2SO_3 + Al \rightarrow$

Answers provided on page 592

Did You Know?

The mixture of nitric acid and hydrochloric acid is known as "aqua regia," which is Latin for royal water. This mixture is extremely corrosive and has been used to etch designs in royal crowns.

Acids and Carbonates

Much of the carbon dioxide on the surface of Earth is trapped in rocks such as limestone, dolomite, and calcite that contain carbonate ions. When carbonate rocks react with acids, the carbonates help to neutralize the acid. Many lakes in western Canada are located in rocky areas that have limestone deposits and so can neutralize much of the acid precipitation that falls on them. However, many lakes in eastern Canada do not have carbonates in them and are more easily damaged by acid precipitation. Liming is a process of adding calcium carbonate to lakes to help neutralize acid (Figure 5.17). Liming is very expensive and is only a temporary measure. A better solution is to not make the acid precipitation in the first place.

Did You Know?

Geologists identify rocks that contain limestone (mostly $CaCO_3$) by using HCl(aq). If a few drops of the acid produce bubbles of carbon dioxide, the rock contains limestone.

Figure 5.17 Adding lime to a lake

Sulfuric acid is one component of acid precipitation. The chemical reaction between acid precipitation and carbonate rocks releases carbon dioxide gas. The equation for the reaction of sulfuric acid and carbonates is:

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

Another component of acid precipitation is nitric acid. The equation for its reaction with carbonates is:

$$2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$$

Explore More

The Great Sphinx of Giza in Egypt is one of the oldest and largest statues ever built. The sphinx is made of limestone. The limestone reacts with the acid precipitation caused by the emission of non-metal oxides from industry in nearby Cairo, a city of 15 million people. Find out what is being done to preserve this statue and other famous statues around the world. Begin your search at **www.bcscience10.ca**.

5-2B Purifying Table Salt

Find Out ACTIVITY

Unrefined salt is a mixture of sodium, potassium, and other positive ions combined with chloride and other negative ions. In this activity, you will attempt to purify a sample of unrefined table salt by dissolving it in water, then decanting the solution to leave the impurities behind as solids.

Safety

- Follow your teacher's directions regarding using open flames.
- Do not taste anything in the science room.
- Do not remove any materials from the science room.
- Wash your hands and equipment thoroughly after completing this activity.

Materials

- unrefined table salt
- 100 mL beaker
- balance
- water
- glass stirring rod
- boiling chips
- large test tube
- Bunsen burner
- matches or flame striker
- test tube tongs or clamp

What to Do

1. Obtain a sample of unrefined table salt. Examine it visually.
2. Place an empty 100 mL beaker on a balance, and press the tare button so that the scale reads zero. Place the sample of unrefined salt into the beaker. Record the mass of the unrefined salt sample.
3. Remove the beaker from the balance. Add water to the 10 mL mark on the beaker. Stir, using a glass stirring rod. If not all the salt has dissolved, stir in a bit more water. Any impurities in the solution will not dissolve. Add at most 10 mL of water in addition to the original 10 mL of water.
4. Place three boiling chips into a large dry test tube. Find the mass of the chips and test tube. Record the mass.
5. Decant (pour) the salt solution into the test tube, leaving the impurities behind in the beaker.
6. Light a Bunsen burner. Hold the test tube in tongs or in a clamp. Heat the salt solution to boiling. The boiling chips will help the solution boil as smoothly as possible. Boil the solution to dryness.
7. Let the test tube cool. Then find the mass of the test tube and pure salt. Record this value.
8. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Science Skills

Go to Science Skill 10 for information on how to boil a solution to dryness.

What Did You Find Out?

1. Find the mass of purified salt by subtracting the mass of the empty test tube and boiling chips from the mass of the test tube, boiling chips, and purified salt.
2. Find the percent purity of the unrefined salt by dividing the mass of purified salt by the mass of the unrefined salt and converting it to a percentage. State the percent purity of your unrefined salt.
3. Pure salt is completely white. How does the colour of your refined salt compare with pure salt?

5-2C Which Solution Is More Acidic?

Conduct an INVESTIGATION

SkillCheck

- Observing
- Predicting
- Measuring
- Work co-operatively

Safety

- Handle chemicals carefully. Avoid touching all reactants and products.
- If burettes and/or pipettes are used, be very careful not to drop or break them. Your teacher will instruct you on their use.
- Sodium hydroxide (NaOH) is caustic. Rinse any spills immediately with plenty of water and inform your teacher.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- 3 Erlenmeyer flasks
- masking tape
- 10 mL each of three different HCl(aq) solutions numbered 1, 2, and 3
- 10 mL graduated cylinder (or 10 mL pipette and bulb)
- phenolphthalein indicator solution
- medicine dropper (or burette and stand)
- dilute NaOH(aq)

Inquiry Focus

In this activity, you will be given three different solutions of HCl(aq). The solutions represent acid run-off from the tailings of three different mining operations in British Columbia. By neutralizing each with a sample of NaOH (a base), you will measure the acidity of each solution.

Question

How can you measure the acidity of different solutions?

Procedure

1. Read through the entire procedure. Then, make a data table to record the number of drops of NaOH(aq) needed to neutralize each of the HCl(aq) solutions. Give your data table a title.
2. Use the masking tape to label the Erlenmeyer flasks 1, 2, and 3.
3. Measure 10 mL of one of the three HCl solutions of unknown concentration into one of the flasks. Measure the 10 mL as precisely as possible. Repeat for the two remaining flasks and HCl solutions.
4. Add 3 to 5 drops of phenolphthalein indicator to each flask. You may see some brief white cloudiness, but the solution should remain colourless.
5. Carefully use a medicine dropper to add NaOH(aq) to one of the Erlenmeyer flasks. Count the number of drops as you add. Swirl the Erlenmeyer flask while you add the drops to help mix the NaOH(aq) into the solution.
6. As soon as the solution turns light pink, stop adding NaOH(aq). Record the total number of drops added. The pink colour may fade. When the pink colour lasts for about 15 s, the test is finished. If the colour fades before 15 s, repeat steps 5 and 6.
7. Repeat the process for the other two samples of HCl(aq).
8. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. (a) Which of the three solutions had the lowest pH?
   (b) Which of the three solutions had the highest pH?
2. How many times more acidic was the sample with the highest acidity compared to the sample with the lowest acidity?

Conclude and Apply

1. Rank the mine tailing samples from most acidic to least acidic.
2. How might the techniques in this activity be used to analyze the run-off from mine tailings?

Cueva de los Cristales

You may have seen tiny crystals, such as those used in watches or credit cards or electronic equipment. You may have seen larger crystals, such as gems used in jewellery. But have you ever seen crystals that are taller than a diving platform (10 m) and more than a metre wide?

In order to see the largest crystals so far discovered on Earth, you would have to travel to an underground mine near the town of Naica, in northern Mexico. There are hundreds or possibly thousands of these enormous crystals in Cueva de los Cristales, which is Spanish for Cave of the Crystals. The cave is 290 m deep and was discovered in 2000 when water was pumped out of the mine.

A crystal is a solid whose atoms, molecules, or ions occur in an orderly, geometric, three-dimensional structure. The crystals in Cueva de los Cristales are made of the mineral gypsum and were formed over millions of years. Because gypsum was quarried near Paris, France, it is sometimes called "plaster of Paris." For many years, gypsum was used as a casting material to set broken bones. Today, the walls of many houses in British Columbia are made of drywall, the main component of which is gypsum.

Gypsum's chemical name is calcium sulfate. Calcium sulfate can form when calcium oxide and sulfur trioxide gas meet in hot, wet conditions like those found deep underground. The starting materials are calcium oxide (a metal oxide), which forms a base in water, and sulfur trioxide (a non-metal oxide), which forms an acid in water. The base and the acid neutralize each other to form gypsum, which is a salt. In Cueva de los Cristales, the neutralization reaction has startlingly beautiful results.

The crystals grow under very extreme conditions of over 58°C and 100 percent humidity. The heat in the cave comes from water heated by magma, underground molten rock, from nearby volcanic activity. If you put your hand in water that temperature, you could hold it there for only a second or two without becoming burned. The cave is so hot that anyone exploring these caves without some sort of cooling system could not stay inside for more than a few minutes. The exploration team is working to develop suits capable of permitting deeper exploration of this remarkable cave. It is not yet known how deep the cave is or how many crystals it contains.

Inside Cueva de los Cristales

Check Your Understanding

Checking Concepts

1. What is the definition of a salt?
2. What is neutralization?
3. When metal oxides react with water, do they produce an acid or a base?
4. When non-metal oxides react with water, do they produce an acid or a base?
5. Which alkali metal will react more vigorously with an acid, cesium or lithium?
6. List the following metals in order from most reactive with acids to least reactive with acids: sodium, gold, zinc, copper.
7. Why is calcium carbonate added to some lakes in eastern Canada?
8. State what gas is produced in the reaction of:
   (a) acids with metals
   (b) acids with carbonates

Understanding Key Ideas

9. State whether each of the following is an acid, a base, a salt, or none of these.
   (a) HCl
   (b) NaOH
   (c) $Al(OH)_3$
   (d) H_2O
   (e) $MgCl_2$
   (f) H_3PO_4
   (g) Na_2SO_4
10. Complete and balance the following reactions.
   (a) $HF + NaOH \rightarrow$
   (b) $H_3PO_4 + KOH \rightarrow$
   (c) $H_2SO_4 + Ca(OH)_2 \rightarrow$
   (d) $CH_3COOH + NaOH \rightarrow$
   (e) $H_2CO_3 + Al(OH)_3 \rightarrow$
11. If magnesium metal is burned in air and the white powder produced is dissolved in a solution containing litmus, what colour will the litmus turn?
12. A sample of powdered yellow sulfur burns in air. The gas that is produced is dissolved in a solution of bromothymol blue. What colour will the bromothymol blue turn?

Pause and Reflect

Suppose you are helping to design a refinery that would refine mineral deposits into lead metal and zinc metal. The mineral deposits contain sulfur, and the refining (smelting) process will produce sulfur oxides. What environmental concerns would you need to consider? How could you deal with the concerns in an environmentally friendly way?

5.3 Organic Compounds

Organic compounds always contain carbon and almost always contain hydrogen as well. Other elements, including metals and non-metals, may also be present. Inorganic compounds are all other compounds. To recognize a compound as organic, look for an indication of the presence of carbon in its name, chemical formula, or diagram. Organic chemistry is the study of compounds that contain carbon.

Words to Know

alcohol
hydrocarbon
inorganic
organic
organic chemistry
solvent

Did You Know?

Organic chemistry is the basis of the study of biochemistry, which is a large branch of modern biology. Pharmacists, nurses, and physicians all study organic chemistry.

Chemists in the early 19th century knew that organisms produce a huge number of compounds containing carbon. The chemists called these organic compounds because the compounds were made by organisms. Today, we use the term **organic** compound to refer to almost all carbon-containing compounds, whether they are produced naturally by organisms or are synthesized in a laboratory. **Inorganic** compounds include compounds that generally do not contain carbon and also a few exceptions to the organic classification, such as carbon dioxide, carbon monoxide, and ionic carbonates.

Organic chemistry is the study of compounds that contain carbon. Well over half of all known compounds are classified as organic. Carbon is an element in group 14 of the periodic table. Carbon has four electrons in its valence shell and forms four covalent bonds. In almost all organic compounds, carbon atoms are bonded to hydrogen atoms or other elements that are near carbon in the periodic table, especially nitrogen, oxygen, sulfur, phosphorus, and the halogens. Carbon can also bond with itself to form long chains of atoms, such as found in plastics. Because carbon forms four bonds, it forms complex, branched-chain structures, ring structures, and even cage-like structures (Figure 5.18). Carbon can even make double or triple connections between two carbon atoms.

No other element can match carbon's ability to make stable compounds with such a variety of shapes and arrangements. Chemists have identified millions of different organic compounds and are synthesizing more every day. Many of these new compounds are used in medicines and foods and to create new materials for buildings and clothing.

Figure 5.18 Several forms of the organic compound chlorophyll are present in the leaves of green plants. One molecule of chlorophyll *b* contains 55 carbon atoms (shown as brown in this model) and 70 hydrogen atoms (green). Chlorophyll also contains nitrogen (blue), oxygen (red), and magnesium (white).

5-3A Sketching Organic Compounds

Think About It

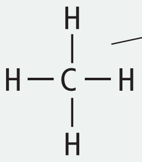
The simplest organic compounds contain only the elements carbon and hydrogen. How many different combinations do you think the two elements can form? In this activity, you will investigate simple organic compounds by analyzing models and drawing structural formulas.

What to Do

1. The following diagram shows four ways of representing the compound methane, the main component of natural gas. Examine the models of methane, and then copy the molecular formula and the structural formula for methane, just as they appear in the diagram below.

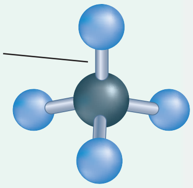
CH_4

molecular formula



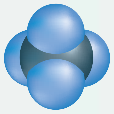
$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Shows a single covalent bond



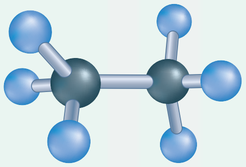
structural formula

ball-and-stick model

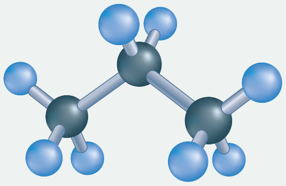


space-filling model

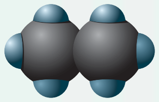
2. The following diagram shows ball-and-stick models and space-filling models for the compounds ethane and propane.
   (a) Give the molecular formula of each compound.
   (b) Draw the structural formula of each compound.



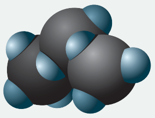
ethane



propane



ethane



propane

3. There are two different organic compounds that have the formula C_4H_{10}. Draw two different structural formulas for C_4H_{10}.
4. How many different ways can the atoms in C_5H_{12} be put together? Write as many structural formulas for C_5H_{12} as you can.

What Did You Find Out?

1. How many different ways are there to build each of the following compounds?
   (a) CH_4
   (b) C_2H_6
   (c) C_3H_8
   (d) C_4H_{10}
   (e) C_5H_{12}
2. Examine each formula in question 1. What is the pattern in the ratio of the number of carbon atoms to the number of hydrogen atoms?

Recognizing Organic Compounds

You can often tell whether a compound is organic or inorganic by examining its chemical formula. The formula for an organic compound must contain carbon. Inorganic carbon compounds contain carbonates, carbides, and oxides. Examples of organic compounds and inorganic compounds are shown in Table 5.7.

Table 5.7 Comparing Formulas of Organic Compounds and Inorganic Compounds

Organic: Must Contain Carbon		**Inorganic Containing Carbon**
CH_4	methane (a hydrocarbon)	$CaCO_3$, Na_2CO_3 (carbonates)
CH_3CH_2OH	ethanol (an alcohol)	Al_4C_3, SiC (carbides)
C_6H_5COOH	benzoic acid (an organic acid)	CO, CO_2 (oxides)
$K_2HC_6H_5O_7$	potassium citrate (an organic salt)	**Inorganic Not Containing Carbon**
		$FeCl_2$
$C_8H_{10}N_4O_2$	caffeine (a stimulant)	$(NH_4)_2SO_3$
$CH_3(CH_2)_nCH_3$	polyethylene (a plastic) where $n = 5000$ approximately and the CH_2 unit repeats about 5000 times	PBr_3

You may have noticed that hydrogen does not come first in the formulas in Table 5.7. For example, methane is CH_4, not H_4C. There is an important reason for this, which is that most organic compounds are not acids. Acids such as HCl have the hydrogen written on the left. Methane, however, is not an acid. Writing the formula with H coming after carbon, as in CH_4, helps to show the compound is not an acid.

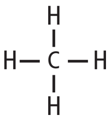
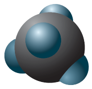
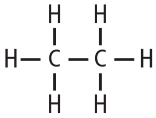
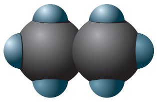
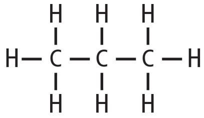
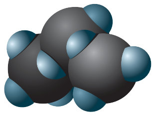
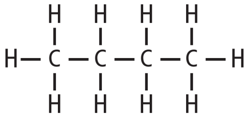
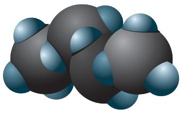
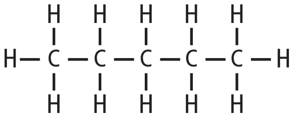
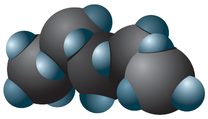
Hydrocarbons

A **hydrocarbon** is an organic compound that contains only the elements carbon and hydrogen. Thousands of hydrocarbons are known. The simplest of all organic compounds is the hydrocarbon molecule called methane, CH_4, which consists of a carbon atom bonded to four hydrogen atoms. Other hydrocarbons are formed by linking two or more carbons together to make a chain. Table 5.8 shows the first five hydrocarbons as well as their common uses. These are presented as examples only. It is not necessary to memorize the names or formulas of specific hydrocarbons.

All of these hydrocarbons are flammable. Some hydrocarbons are regularly used as fuels. Methane and ethane are gases at room temperature. Propane and butane are gases but are easily turned into liquids under pressure. This is why they are useful as fuels for camp stoves, Bunsen burners, and hand-held lighters (Figure 5.19). The larger the molecule of a hydrocarbon, the more easily it becomes a liquid. Pentane is a liquid at room temperature.

Figure 5.19 Some Bunsen burners use propane as a fuel.

Table 5.8 The First Five Hydrocarbons

Name	Molecular Formula	Structural Formula	Shortened Structural Formula	Space-Filling Model	Common Uses
methane	CH_4		CH_4		• Natural gas heaters
ethane	C_2H_6		CH_3CH_3		• Manufacturing plastic
propane	C_3H_8		$CH_3CH_2CH_3$		• Camp fuel
butane	C_4H_{10}		$CH_3CH_2CH_2CH_3$		• Hand-held lighters
pentane	C_5H_{12}		$CH_3CH_2CH_2CH_2CH_3$		• Component of gasoline

Reading Check

1. What element must be present for a compound to be considered organic?
2. What other element is almost always present in an organic molecule?
3. List three carbon-containing compounds that are considered inorganic.
4. List three inorganic compounds that do not contain carbon.
5. What two elements are present in a hydrocarbon?

Suggested Activity

Find Out Activity 5-3C on page 249

Alcohols

An **alcohol** is one kind of organic compound that contains C, H, and O. There are many kinds of alcohols, such as methanol, ethanol, and isopropyl alcohol. Methanol, also called wood alcohol, is a poison that is very useful as a solvent. A **solvent** is a liquid that can dissolve other substances. Methanol will dissolve many substances that water cannot. For example, permanent black marker ink can often be removed using methanol, even though soapy water cannot do so.

Ethanol is used in some beverages as well as in some disinfectants. When consumed in large amounts, ethanol is a poison. Ethanol is used as a fuel or a fuel additive in gasoline mixtures and in medicines and plastics.

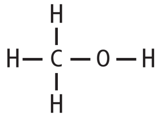
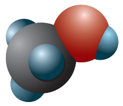
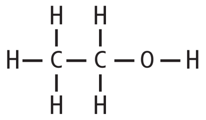
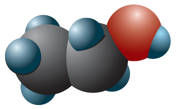
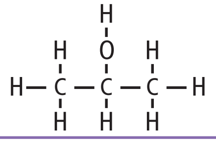
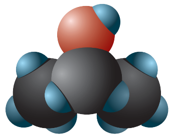
Explore More

If you extended a hydrocarbon chain to about 5000 carbon atoms linked end to end, you would have the compound used in plastic sandwich wrap. Explore the organic chemistry of plastics at **www.bcscience10.ca**.

Isopropyl alcohol, commonly known as rubbing alcohol, is used in sterilizing pads and as a cleaner on contact pins in electronic devices. Rubbing alcohol is poisonous to drink but can be applied to the skin in small quantities as a disinfectant. Isopropyl alcohol can be used as a solvent and to keep automobile fuel lines free from ice in cold weather.

Methanol, ethanol, and isopropyl alcohol are highly flammable compounds. Table 5.9 shows several ways to represent alcohols. It is not necessary to memorize the names or formulas of specific alcohols.

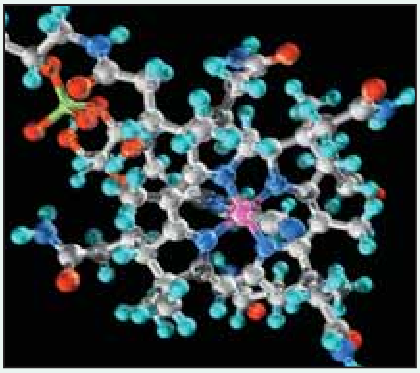
Table 5.9 Some Common Alcohols

Name	Molecular Formula	Structural Formula	Shortened Structural Formula	Space-Filling Model	Common Use
methanol	CH_4O	 $\begin{array}{ccccc} & & \text{H} & & \\ & & \vert & & \\ \text{H}- & & \text{C} & -\text{O}- & \text{H} \\ & & \vert & & \\ & & \text{H} & & \end{array}$	CH_3OH		• Solvent
ethanol	C_2H_6O	 $\begin{array}{cccc} & \text{H} & \text{H} & \\ & \vert & \vert & \\ \text{H}- & \text{C}- & \text{C} & -\text{O}-\text{H} \\ & \vert & \vert & \\ & \text{H} & \text{H} & \end{array}$	CH_3CH_2OH		• Fuel
isopropyl alcohol	C_3H_8O	 $\begin{array}{ccccc} & & \text{H} & & \\ & & \vert & & \\ & \text{H} & \text{O} & \text{H} & \\ & \vert & \vert & \vert & \\ \text{H}- & \text{C}- & \text{C}- & \text{C} & -\text{H} \\ & \vert & \vert & \vert & \\ & \text{H} & \text{H} & \text{H} & \end{array}$	$(CH_3)CH_2OH$		• Sterilizer • Cleaner

5-3B Researching a Group of Organic Compounds

Think About It

There are many groups of organic compounds, including antibiotics, herbicides, pesticides, explosives, and the plastic fibres used in fabrics. In this activity, you will research either a group of organic compounds or one specific compound.



Vitamin B_{12} is a specific compound in a class of compounds called vitamins.

What to Do

1. Select a group of organic compounds or a particular organic compound to research.
2. Consult with your teacher about your topic to make sure that it is appropriate.
3. Research your topic.
4. Prepare a presentation on the discovery, development, uses, benefits, and disadvantages of using the compound or compounds. Your teacher may give you an assessment guide for your presentation. Make sure to provide a complete bibliography including Internet references. The presentation should be appropriate to your audience, and your ideas should be presented logically. Try to make sure each part of the presentation captures the attention of your audience. Where possible, use examples and analogies that help make the topic memorable.

5-3C Using Models to Represent Organic Compounds

In this activity, you will use models to represent organic molecules containing carbon, hydrogen, oxygen, and chlorine. Most model kits have standard colour coding for the elements. Usually, carbon atoms are black with four holes, hydrogen atoms are white with one hole, oxygen is red with two holes, and chlorine is green with one hole. Filling the holes in the models represents completing a valence shell of an atom.

All the bonds in this activity are covalent. Single bonds are represented with a short connector. Long flexible connectors are used for double bonds and triple bonds in which more than one connection exists between the same two atoms.

Materials

- organic model kit

What to Do

1. Work in a group as directed by your teacher. Carefully build the molecules, and then examine their shapes.
2. Build models to represent the following formulas. The models can be put together in only one way, regardless of the order in which you assemble the atoms. Your teacher may ask you to draw a structural diagram to represent them.
   (a) CH_4 (methane)
   (b) C_2H_6 (ethane)
   (c) C_2H_4 (ethene)
   (d) C_2H_2 (ethyne, commonly called acetylene)
   (e) C_3H_8 (propane)
   (f) CH_4O (methanol)
   (g) C_2H_5Cl (chloroethane)
3. Build models to represent the following formulas. These have more than one way of being put together. This means that more than one arrangement of the atoms in that compound with the same number of atoms is possible. You may wish to leave off hydrogen atoms and the bonds that connect to them. You may be asked to draw structural diagrams to represent them.
   (a) C_3H_6 (two ways)
   (b) C_4H_{10} (two ways)
   (c) C_3H_7Cl (two ways)
   (d) C_2H_6O (two ways)
   (e) $C_2H_4Cl_2$ (two ways)

Science Skills

Go to Science Skill 8 for information on using models in science.

What Did You Find Out?

1. How many covalent bonds do atoms of each of the following elements make?
   (a) carbon
   (b) oxygen
   (c) hydrogen
   (d) chlorine
2. State which of the following elements are capable of forming a double bond: hydrogen, carbon, oxygen, chlorine.
3. Explain how the positions of the holes in the models representing carbon and oxygen produce a 3D shape.

Career Connect

Research and Development Chemist

Moulding resin, gloss pomade, structurizing paste, root volumizer, styling lotion. These are just a few of the products that Zdravka Stoyeff, from Vancouver, British Columbia, helps to develop and test as a research and development chemist for a hair cosmetics company.

Zdravka Stoyeff

Q. What do you do as a research and development chemist?

A. I create products that meet the manufacturer's standards for performance, effectiveness, and safety. We are continually conducting research on existing products as well as creating new and innovative products.

Q. What is a typical day like for you?

A. Every day is different. Sometimes I have meetings with the marketing, production, and sales teams to see where the needs are in the consumer market. Then, I go back to the lab to develop and test products. I create and prepare samples of these products for our stylist teams and then refine them with the feedback from the stylist.

Q. What training do you need to become a product developer with a hair cosmetics company?

A. You need a university degree in chemistry, biology, or natural sciences. Then, you train to familiarize yourself with the materials generally used in the industry. Over time, you gain experience in formulating products and learn what works and what does not.

Q. How is chemistry connected to hair care products?

A. Chemistry is involved in almost everything we do. When you cleanse, condition, or thicken your hair, there are chemical and physical changes that occur. When you colour, perm, or straighten your hair, chemical reactions are occurring. I am always using chemistry when I take the raw materials, mix them according to the formulas we create, and then observe the chemical reactions and the products that are created.

Q. How are acids and bases used in your work?

A. We use organic acids like citric acid ($C_6H_8O_7$) to adjust the pH of products. We use stearic acid ($C_{18}H_{36}O_2$) as an emulsifier in making creams. We also use inorganic bases like sodium hydroxide ($NaOH$) and organic bases like triethanolamine ($C_6H_{15}NO_3$) to neutralize some of the hair-set polymers.

Q. What safety issues do you need to be aware of in your work?

A. We usually wear protective clothing, safety glasses, and protective footwear. There are many laboratory safety regulations we follow, including ones from Heath Canada. We also have to comply with the GMP (Good Manufacturing Practice) for the plant and have SOPs (Standard Operation Procedures) in place for the lab. We have to ensure the Material Safety Data Sheet (MSDS) is readily available for every chemical we use.

Questions

1. How are acids used in hair care products?
2. How are bases used in hair care products?
3. Why is knowledge of chemistry important for developing new hair care products?

Check Your Understanding

Checking Concepts

1. What is organic chemistry the study of?

2. (a) What element do all organic compounds contain?
  (b) What other element do most organic compounds contain?

3. Explain why carbon forms so many compounds.

4. Classify each of the following compounds as organic or inorganic by examining their formulas.
  (a) CH_3CH_2OH
  (b) $K_2HC_6H_5O_7$
  (c) Al_4C_3
  (d) $C_8H_{10}CH_2OH$
  (e) $CaCO_3$
  (f) $FeCl_2$
  (g) CH_4
  (h) PBr_3
  (i) CO_2
  (j) C_6H_5COOH

5. What is the definition of a hydrocarbon?

6. (a) What is the chemical name of the simplest hydrocarbon?
  (b) What is its common name?
  (c) What is it used for?

7. What three elements are present in alcohols?

8. What is the definition of a solvent?

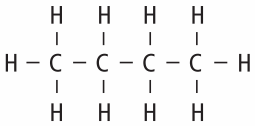
9. What is one use for each of the following?
  (a) methanol
  (b) ethanol
  (c) isopropyl alcohol

10. What is the difference in molecular formula between each of the following pairs?
  (a) methane and methanol
  (b) ethane and ethanol
  (c) propane and isopropyl alcohol

Understanding Key Ideas

11. Classify each of the compounds illustrated as organic or inorganic.

(a)

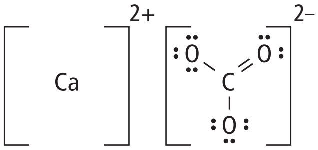


$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & \end{array}$$

(b)

Methane

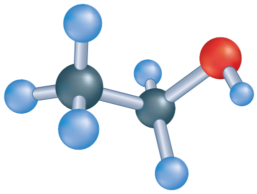
(c)



(d) C_5H_{12}

(e) CO_2

(f)



Ethanol

Pause and Reflect

Organic compounds are modelled using molecular formulas, structural formulas, ball-and-stick models, and space-filling models. Which model do you find easier to use? Why? List some advantages and disadvantages of each type of model.

Chapter 5

Chapter Review

Prepare Your Own Summary

In this chapter, you learned about the properties of acids, bases, and salts, and also how to distinguish between organic and inorganic compounds. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Using pH and Acid-Base Indicators to Measure Acidity Levels
2. Names, Formulas, and Properties of Common Acids and Bases
3. Common Reactions Involving Acids
4. Distinguishing between Organic Compounds and Inorganic Compounds
5. Hydrocarbons and Alcohols

Checking Concepts

1. State the pH value or pH range of the following.
(a) a neutral solution
(b) a basic solution
(c) an acidic solution

2. Copy and complete the following chart in your notebook.

Term	Definition	Used to Describe Acids, Bases, or Both?
Alkaline		
Corrosive		
Caustic		
Low pH		

3. What is a pH typical of each of the following?
(a) pure water
(b) normal rainwater
(c) acid precipitation
(d) human blood
(e) human saliva

4. What is the increase in acidity associated with a decrease of one unit on the pH scale?

5. Describe how you would use litmus paper to determine whether a solution is acidic, basic, or neutral.

6. (a) How can you identify an acid by looking at its chemical formula?
(b) How can you identify a base by looking at its chemical formula?

7. State the formula of each of the following.
(a) an acid used to make fertilizers
(b) a base that has the common name of caustic soda
(c) a household base used as a kitchen cleaner
(d) the active ingredient in milk of magnesia
(e) an acid in your stomach that helps digest food
(f) the battery acid used in automobiles
(g) hydrated lime, used in soil and water treatment
(h) the acid present in vinegar

8. Give the chemical name for each compound in question 7.

9. State whether each of the following describes acids, bases, or both.
(a) taste sour
(b) taste bitter
(c) feel slippery
(d) conduct electricity
(e) have a pH greater than 7
(f) produce hydrogen (H^+) ions in solution
(g) react with metals, causing them to corrode

10. What is meant by the term acid-base neutralization?

11. (a) When metal oxides are dissolved in water, are the resulting solutions acidic or basic?
(b) When non-metal oxides are dissolved in water, are the resulting solutions acidic or basic?

12. How does adding lime (calcium carbonate) help reduce the effects of acid precipitation in lake water?

13. Define:
(a) organic compound
(b) inorganic compound

14. (a) What two elements are present in all hydrocarbon compounds?
(b) What are three uses for hydrocarbons?

15. (a) What three elements are present in all alcohols?
(b) What are three uses for alcohols?

Understanding Key Ideas

16. How many times more basic is a solution of pH 11 compared to a solution of pH 9?

17. What is the colour of the indicator after it is added to each of the following solutions? (Assume the colour of the solution being tested does not mask the colour of the indicator.) Refer to the indicator chart in Figure 5.6 on page 224.
(a) lemon juice in the presence of indigo carmine indicator
(b) milk in methyl red indicator
(c) bleach in phenolphthalein
(d) tap water in phenolphthalein
(e) egg white in litmus

18. Change the following names to the names used when the acid is aqueous.
(a) hydrogen fluoride
(b) hydrogen perchlorate
(c) hydrogen sulfate
(d) hydrogen chloride

19. Complete and balance the following neutralization reactions. Then, write the names of all the reactants and all the products in each chemical reaction.
(a) $HNO_3 + Al(OH)_3 \rightarrow$
(b) $HF + KOH \rightarrow$
(c) $H_3PO_3 + Ca(OH)_2 \rightarrow$
(d) $CH_3COOH + NaOH \rightarrow$
(e) $H_2SO_4 + NaOH \rightarrow$

20. Complete and balance the following chemical reactions between an acid and a metal.
(a) $HBr + Mg \rightarrow$
(b) $H_2SO_3 + Al \rightarrow$
(c) $HI + Ca \rightarrow$
(d) $HClO + Zn \rightarrow$
(e) $H_3PO_3 + Na \rightarrow$

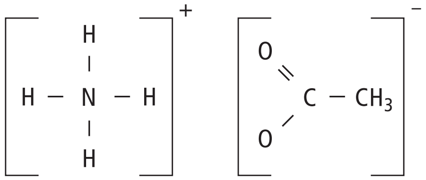
21. State whether each of the following is an acid, a base, a salt, or none of these.
(a) $HCl(aq)$
(b) KOH
(c) $Sr(OH)_2$
(d) $MgCl_2$
(e) K_3PO_4
(f) $H_2SO_4(aq)$

22. Classify each of the following compounds as organic or inorganic by examining their formulas.
(a) CH_3OH
(b) $Mg(HC_2O_4)_2$
(c) SiC
(d) Na_2CO_3
(e) $FeBr_3$
(f) CH_4
(g) NH_3
(h) CO

23. Draw structural diagrams for these organic compounds.
(a) CH_4
(b) $CH_3CH_2CH_3$

Applying Your Understanding

24. Some compounds, such as ammonium acetate, can fall into more than one category at a time.



Ammonium acetate is made of positive ammonium ions and negative acetate ions, consistent with the formula of a salt. The acetate ion contains carbon atoms, making it organic. The ammonium ion can react with water to release hydrogen ions, so it is an acid. The acetate ion can react with water to make hydroxide ions, so it is a base.
(a) Do you think it is possible for this salt to make a solution both acidic and basic at the same time?
(b) How would you test your prediction?

Pause and Reflect

In this chapter, you used your knowledge of chemical formulas to classify compounds. How might you use this knowledge in your daily life? Why might it be important for you to recognize the type of compound by reading its chemical formula?