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:

$$HCl + NaOH \rightarrow NaCl + H_2O$$
acid + base → salt + water

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:

$$3H_2SO_4 + 2Al(OH)_3 \rightarrow Al_2(SO_4)_3 + 6H_2O$$
acid + base → salt + water

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.

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.

$$2CH_3COOH + Mg(OH)_2 \rightarrow Mg(CH_3COO)_2 + 2H_2O$$
acid + base → salt + water

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.

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.

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

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

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

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 5.15 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.

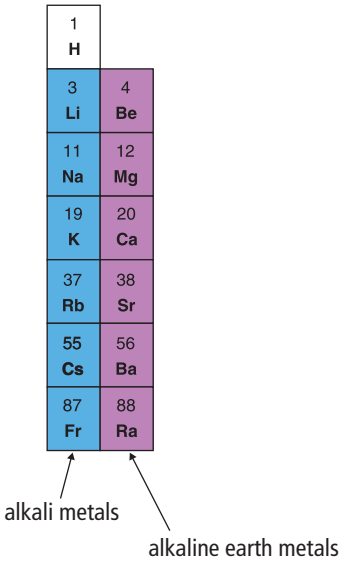

Figure 5.16 Metals increase in reactivity as you go down columns 1 and 2.

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.

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:

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

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.

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

Inquiry Focus

SkillCheck

- Observing
- Predicting
- Measuring
- Work co-operatively

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.

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)

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?

Wild, Weird, Wonderful

www Science

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

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?