Home Quit

5.1 Acids and Bases

Here is a summary of what you will learn in this section:

- The pH scale is used to classify aqueous solutions as acidic, basic, or neutral.
- Acids and bases react with pH indicators.
- Acids have a pH less than 7.
- Bases have a pH greater than 7.
- A neutral solution has a pH of 7.

Figure 5.1 During exercise and in its day-to-day functioning, your body gets much of the energy it needs from the breakdown of glucose. The process by which glucose is broken down produces carbon dioxide gas, which dissolves in your blood and forms an acid.

Acids, Bases, and Your Body

Acids and bases are compounds with particular properties. Members of these two classes of compounds play many different roles in the functioning of your body.

Some acids are harmful to your body. For example, the cells in your body are fuelled by the breakdown of molecules of glucose (Figure 5.1). The products of this process usually include carbon dioxide gas ($CO_2(g)$). This carbon dioxide gas dissolves in the water in your blood and forms carbonic acid ($H_2CO_3(aq)$). A build-up of this acid in the blood would be harmful, so your body converts the carbonic acid to a hydrogen ion (H^+) and a hydrogen carbonate ion (HCO_3^-). These ions are then transported in the blood without harming the body.

Other acids are essential to your body functions. One such essential acid is deoxyribonucleic acid (DNA). DNA is a complex molecule that is responsible for passing on inherited characteristics, such as hair colour, from one generation to the next.

Similarly, some bases produced by your body are harmful and some are helpful. An example of a harmful base is ammonia (NH_3). Your body produces ammonia as a waste product of the breakdown of some types of food. Ammonia is toxic to humans, so your body converts it to urea ($(NH_2)_2CO$). Urea is not toxic and is removed from your body in your urine.

Digestion is a process that breaks down your food into components that your body can use for energy. The digestive process begins with the saliva in your mouth (Figure 5.2). The saliva of a healthy person is usually basic. Your stomach contains hydrochloric acid (HCl), which helps your stomach to break down your food into smaller particles. However, hydrochloric acid can also damage the cells of your body. The lining of your stomach is protected from acid by a thick layer of mucus, but the rest of your digestive system lacks a protective layer. An organ called the pancreas produces a base called sodium hydrogen carbonate ($NaHCO_3$). This base counteracts the hydrochloric acid, which protects the rest of your digestive system. The digestion of fats depends on the production of another base, called bile. Bile is produced by the liver.

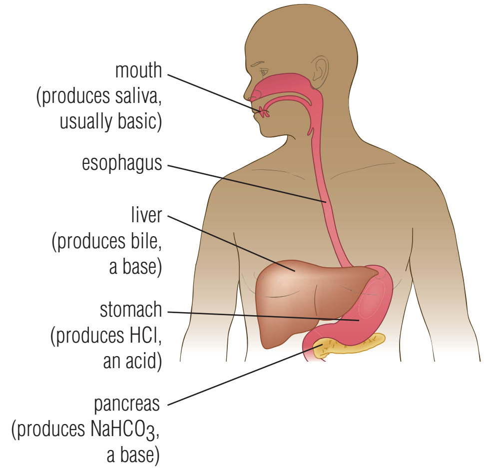

Figure 5.2 A simplified drawing of some of the organs involved in human digestion

B13 *Quick Lab*

What Do You Know about Acids and Bases?

Acids and bases are found in many of the foods we eat and the products we use. For example, grapes contain an acid and some soaps are made using a base (Figure 5.3 and Figure 5.4). In this activity, you will identify foods and products that are acids or bases or that contain an acid or a base.

Purpose

To brainstorm a list of foods and household products that are acids and bases or that contain an acid or a base

Procedure

1. Working with a partner or in a group, brainstorm foods and products that you think are acids or bases or that contain an acid or a base.

Figure 5.3 Grapes contain tartaric acid.

2. Record your list in a T-chart with two columns.
3. Share your T-chart with your classmates. Add any new ideas from their T-charts to yours.

Questions

4. What criteria did you use to predict if a food or product was an acid or a base?
5. Compare and contrast the criteria you used with those used by your classmates.

Figure 5.4 The base potassium hydroxide (KOH) is used in producing soft and liquid soaps.

Many acids have common names. Table 5.4 shows you the formulas, chemical names, and common names of some acids and some ways in which these acids are used.

Table 5.4 Formulas, Chemical and Common Names, and Uses of Some Acids

Chemical Formula	Chemical Name	Common Name(s)	Uses
$HCl(aq)$	hydrochloric acid	muriatic acid, stomach acid	cleaning concrete, making other chemicals
$H_2SO_4(aq)$	sulphuric acid	battery acid	car batteries, making fertilizer, manufacturing
$HCOOH(aq)$	methanoic acid	formic acid	dyeing wool, tanning leather
$CH_3COOH(aq)$	ethanoic acid	acetic acid	diluted to make vinegar, making plastic, added to foods for flavour

Learning Checkpoint

1. State the common names of the following acids.
   (a) $HCl(aq)$
   (b) $HNO_3(aq)$
   (c) $CH_3COOH(aq)$
2. Name the polyatomic ion in each of the following acids.
   (a) sulphuric acid
   (b) nitric acid

Identifying and Naming Bases

A base can also be identified from its name or its chemical formula. A substance is a base if its name begins with the name of a metallic ion and ends with the word "hydroxide." A substance is also a base if:

- the chemical formula starts with a metallic ion or with the ammonium ion NH_4^+ AND
- the chemical formula ends with OH (called a hydroxyl group)

For example, $NaOH(s)$ starts with the metallic ion sodium (Na^+) and ends with OH^-. Similarly, $KOH(s)$ starts with the metallic ion potassium (K^+) and ends with OH^-. $NH_4OH(aq)$ starts with the ammonium ion and ends with OH^-. All these compounds are bases.

Sodium hydroxide (NaOH) is a base you may know about. The base is commonly found in drain cleaners and oven cleaners (Figure 5.11). Sodium hydroxide is a white solid that easily dissolves in water. The resulting solution is very basic and corrosive.

Figure 5.11 This oven cleaner contains sodium hydroxide and is very basic. This warning label shows the symbol for corrosive chemicals. You should always wear gloves when working with corrosive substances.

Naming Bases

The name of a base can be determined from its chemical formula by following the steps shown in Table 5.5. Notice that all bases are followed by the word "hydroxide."

Table 5.5 Naming Bases

Step	Examples	
	$KOH(aq)$	$NH_4OH(aq)$
1. Write the name of the positively charged metallic ion that is at the beginning of the chemical formula. This step remains the same if the positively charged ion is a polyatomic ion.	potassium	ammonium
2. Add the word "hydroxide."	potassium hydroxide	ammonium hydroxide

Like acids, many bases also have common names. A substance that is a base may be called an alkali or said to be alkaline. Table 5.6 shows the formulas, chemical names, and common names of some bases and some ways in which they are used.

Table 5.6 Formulas, Chemical Names, Common Names, and Uses of Several Important Bases

Chemical Formula	Chemical Name	Common Name	Uses
$NaOH(s)$	sodium hydroxide	caustic soda	cleaning drains; making soap, plastic, and textiles; controlling pollution
$NH_4OH(aq)$	ammonium hydroxide	ammonia solution	cleaning windows; making dyes, plastic, and glass; controlling pollution
$Ca(OH)_2(s)$	calcium hydroxide	slaked or hydrated lime	making glass, cement, and steel; correcting acidic soil; removing hair; making baby formula
$Mg(OH)_2(s)$	magnesium hydroxide	milk of magnesia	treating indigestion, bleaching clothes, treating wastewater, making articles fire resistant

Learning Checkpoint

1. Name the following bases.

(a) $KOH(s)$

(b) $Ca(OH)_2(s)$

(c) $Mg(OH)_2(s)$

(d) $NH_4OH(aq)$

2. Which polyatomic group is found at the end of the chemical formula for most bases?

Take It Further

Deoxyribonucleic acid (DNA) is found in every cell of your body. The three-dimensional structure of this acid remained a mystery for many years. You can solve the mystery for yourself. Begin your research at ***ScienceSource***.

Adjusting Soil pH

Soil pH can also change the variety and numbers of micro-organisms that live in the soil. Some micro-organisms help plant growth, but others cause disease.

Even areas that are close to each other can have different soil conditions, including soil pH. Therefore, farmers and other large growers, such as flower producers, need to know the soil pH in many areas of their land. On commercial operations such as farms, soil pH is usually determined by specially trained technologists. On a smaller scale, home gardeners can test their soil using a test kit.

Once soil pH is known, growers can use this information in one of two ways. First, they could plant crops that are most suited to the soil pH. For example, legumes (beans and peas) grow best at a pH of 6.2 or higher, but corn can do well in soils with a pH as low as 6.0. Second, a grower can adjust the pH of soil to support particular plants (Figure 5.15). If the soil pH is too acidic, adding a basic substance can increase the pH. If the soil pH is too basic, then adding acidic substances can lower the pH.

Figure 5.15 Calcium carbonate, commonly called lime, is added to soil to raise the pH.

B15 *Quick Lab*

Testing Soil pH

Purpose

To compare the pH of soil samples from different sources

Materials & Equipment

- paper towels
- potting soil
- 2 or more samples of soil from outdoors
- teaspoon or scoopula
- soil pH test kit
- water

Procedure

1. Working on paper towels, remove any larger objects, such as stones or twigs, from the potting soil. Break up any clumps with a teaspoon or scoopula.
2. Add soil to fill the testing container supplied with the soil pH test kit, according to the instructions that came with the kit.
3. Add the testing powder to the soil in the testing container. Add the amount of water indicated by the manufacturer's instructions.
4. Mix the contents. Allow any particles to settle, then compare the colour with the colour chart supplied in the test kit.
5. Repeat steps 1 to 4 for the remaining soil samples.
6. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Questions

7. Potting soil is intended for use with a wide variety of plants. Based on your analysis, do you think most plants prefer acidic soil or basic soil?
8. Plants in the mint family grow best in basic soil (from pH 7.0 to 8.0). Which outdoor soil would be best for mint?
9. Roses grow well in a pH range from 5.5 to 7.0. Which outdoor soil would be best for roses?

Applications of Neutralization Reactions

Neutralization reactions have commercial uses, such as in pharmaceutical manufacturing, waste treatment, and agriculture. In making pharmaceuticals, the pH of a solution may be changed from acidic to basic (or vice versa) so that the desired product forms a precipitate. The precipitate can then be collected by filtering the products of the reaction. In agriculture, calcium carbonate may be added to acidic soil. The calcium carbonate enters into a neutralization reaction with some of the acid in the soil water, and the soil pH becomes more basic.

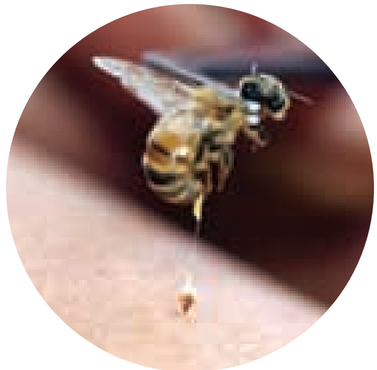

Figure 5.17 The methanoic acid in a bee sting, also known as formic acid ($HCOOH$), can be neutralized with an ammonia-based cream.

Neutralization reactions are also used in medicine. For example, acid reflux is a condition in which stomach acid (HCl) causes discomfort. The symptoms of acid reflux can be treated with antacids, which are composed of bases. They can produce a neutralization reaction with some of the hydrochloric acid in the stomach. Bee stings can also be treated using a neutralization reaction (Figure 5.17). When it stings, a bee releases methanoic acid, which attacks nerves in the skin. Bee stings can be treated with a cream that contains ammonia, which is a base. The ammonia enters into a neutralization reaction with the methanoic acid, which prevents further irritation of the nerve endings.

Suggested Activity •
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The food industry uses neutralization reactions to adjust the pH of products. Packaged and processed foods often have an acidic pH, since harmful bacteria are less likely to grow under these conditions. For example, vinegar (dilute acetic acid) or citric acid may be added to foods to lower the pH. You will find vinegar in the ingredient list of many prepared foods, such as ketchup (Figure 5.18).

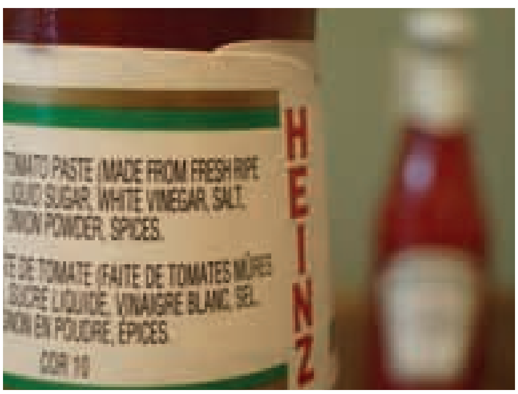


Figure 5.18 Vinegar is added to packaged foods, such as ketchup, for taste and to prevent harmful bacteria growing and causing them to spoil.

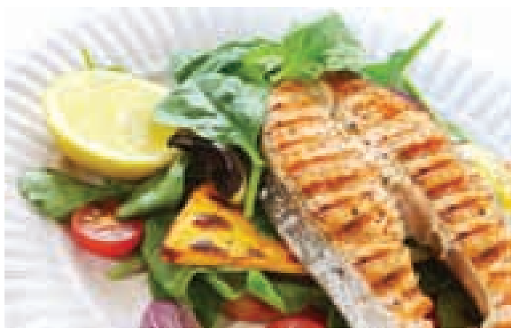


Figure 5.19 A neutralization reaction occurs when lemon juice is added to fish.

You may be using acids and bases without realizing it. For example, we often serve fish with a wedge of lemon (Figure 5.19). Fish is a weak base. Lemon juice (an acid) lowers the pH, which eliminates the fishy odour. Lemon juice is also often added to spinach salads. Spinach contains iron, which is an important nutrient for your body. Lemon juice contains vitamin C (ascorbic acid). Nutritionists believe that adding lemon juice will help your body to absorb iron.

Figure 5.20 The damage to the limestone on this building is the result of acid precipitation.

Using Neutralization Reactions to Solve Environmental Challenges

Every day, you use products that use acids and bases in some way. Your clothes may be dyed bright colours that are produced using acids and bases. Your home is made of materials such as lumber, steel, and copper, which are manufactured or processed using acids and bases. Although industries that use acids and bases are beneficial to us, they can also affect the environment negatively. Sometimes, neutralization reactions can help to reduce negative effects and even repair environmental damage.

Acid Precipitation

Acid precipitation is rain, snow, fog, or dew that has a pH less than 5.6. (Rain usually has a pH of around 5.6.) Two main causes of acid precipitation are sulphur dioxide (SO_2) and nitrogen oxides in the atmosphere. Nitrogen oxides come in many forms, such as N_2O, NO_2, and N_2O_4. The gases then undergo chemical reactions in the atmosphere that result in the formation of acids, which eventually fall as acid precipitation.

Sulphur dioxide is converted to sulphuric acid by the following two chemical reactions:

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$
$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

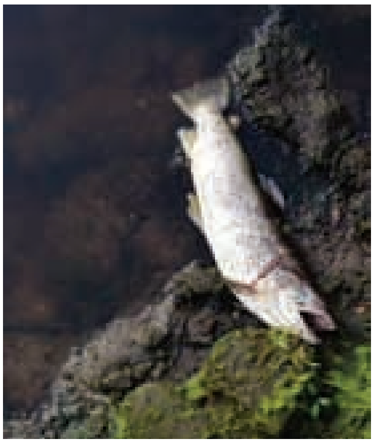
Nitrogen dioxide gas dissolves in water droplets in the atmosphere to form nitric acid.

A significant source of gases that cause acid precipitation is electricity production in coal-fired power plants. Iron and steel production, smelting of metals (such as zinc, nickel, and copper), fertilizer production, pulp and paper production, and automobile engines also emit gases that contribute to acid precipitation.

When acid precipitation falls on cities and towns, it can corrode the stone surfaces of buildings and statues and the concrete of roads and bridges. The acids in the precipitation enter into neutralization reactions with bases in the stone. For example, limestone contains calcium carbonate, which can be dissolved by acid precipitation (Figure 5.20). Acids react with metals, so acid precipitation can cause corrosion of iron reinforcing rods in structures.

Acid precipitation changes the pH of the soil in forests, which can cause trees and other plant species to die (Figure 5.21(a)). This reduces habitat for the species that depend on forests. Loss of forests means losses in the forestry industry and in recreational use. The water in lakes, streams, and other freshwater bodies can also become more acidic as a result of acid precipitation. The change in pH can cause fish and other water organisms to die (Figure 5.21(b)).

(a)



(b)

Figure 5.21 (a) This photograph shows the effect of acid precipitation on forests. (b) When lakes and streams become too acidic, fish and other organisms may die.

Learning Checkpoint

1. What gases are the main causes of acid precipitaion?
2. What are nitrogen oxides?
3. Write two chemical equations for reactions that cause acid precipitation.
4. What is the source of water in the reactions you wrote in question 3?
5. Name two industries or human activities that contribute to acid precipitation.

Neutralizing Acidic Lakes

In some provinces, such as Alberta and Saskatchewan, most lakes are naturally protected from the effects of acid precipitation because they are surrounded by limestone. This type of rock reacts with excess acid and neutralizes it, which restores the pH of the lake water. However, this is not true of lakes in Ontario. The surroundings of Ontario lakes do not contain much limestone, and a significant amount of acid precipitation enters the lakes in Ontario. This means that Ontario lakes are at greater risk of acidification.

One way to raise the pH of heavily acidified lakes is by adding a substance called lime. When lime mixes with water, the base calcium hydroxide ($Ca(OH)_2$) is formed. Calcium hydroxide can neutralize both the sulphuric acid and the nitric acid that are found in acid precipitation. The neutralization reaction involving nitric acid is:

$$2HNO_3(aq) + Ca(OH)_2(s) \rightarrow Ca(NO_3)_2(aq) + 2H_2O(l)$$

However, this process is very expensive and, therefore, only practical in protecting lake ecosystems in the short term.

Reducing Acid Precipitation

Once the relationship between sulphur dioxide and nitrogen oxides and acid precipitation was understood, work began to develop technology that could help reduce the emission of these gases. Two of those technologies are smokestack scrubbers and automobile emissions controls.

Scrubbers are devices that are found in tall industrial smokestacks of industries that release sulphur dioxide gas and nitrogen oxide gases, such as coal-fuelled power plants and ore smelting facilities (Figure 5.22). Scrubbers remove these gases using a specially formulated chemical mixture.

Figure 5.22 Scrubbers in these smokestacks trap pollutants that could otherwise cause acid precipitation.

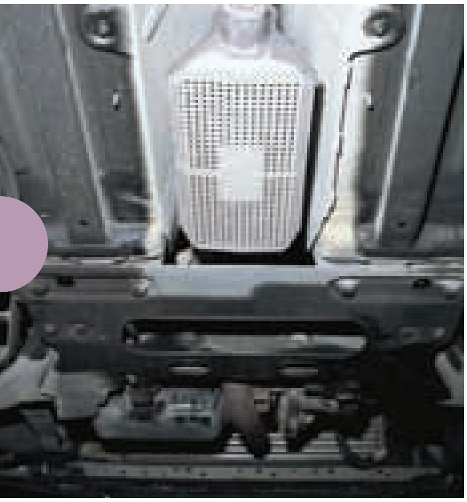


Figure 5.23 A catalytic converter converts various emissions into less harmful chemicals, often using a combination of metals and chemical reactions.

The gases in a smokestack contact the chemical mixture in the scrubber and enter into chemical reactions. The products of the chemical reactions are a wet slurry or a solid. Scrubbers also have a filter that collects and traps small particles that would otherwise be released into the atmosphere. The substances collected can then be separated and removed for recycling.

Internal combustion engines found in automobiles emit a number of harmful gases, including nitrogen oxides. One approach to reducing harmful emissions is to use technologies that convert the harmful gases to other, harmless substances. The most common of these technologies is the catalytic converter, which is located in the exhaust system of a vehicle (Figure 5.23). A catalytic converter uses nitrogen oxides in a chemical reaction that decomposes them into nitrogen gas and oxygen gas. For example, when dinitrogen trioxide is the reactant, the following chemical reaction occurs:

$$2N_2O_3(g) \rightarrow 2N_2(g) + 3O_2(g)$$

More Work Needed

Researchers continue to closely study the acid content of lakes. One study looked at changes in the pH of 152 lakes in southeastern Canada. From 1988 to 2008, only 41 percent of the lakes studied were less acidic, 50 percent had not changed, and 9 percent were more acidic.

Central Ontario is the only region where there has been a significant decline of acidity in most lakes. Scientists believe this change is due mostly to the considerable reduction in sulphur dioxide emissions from smelters in the nearby Sudbury area. Computer models have predicted that up to one-quarter of the lakes in eastern Canada will remain chemically damaged for years to come.

Learning Checkpoint

1. Describe two effects that acid precipitation has on the environment.
2. How can the pH of an acidic lake be increased?
3. Why are lakes on limestone rock less affected by acid rain?
4. What are scrubbers, and what do they do?
5. Catalytic converters use chemical reactions to reduce the emission of a number of harmful gases. Write the chemical equation for the reaction with dinitrogen trioxide that occurs in a catalytic converter.

Heavy Metals

Heavy metals are metal elements that have a high atomic mass. Examples of heavy metals include arsenic (As), copper (Cu), mercury (Hg), and zinc (Zn). Heavy metal accumulation can cause kidney disease, diseases of the lungs, bone defects, and damage to nervous system development.

The soil in areas with a lot of heavy industry is often contaminated with heavy metals and other contaminants. However, roadways and automobiles can also be contaminated with high levels of heavy metals (Figure 5.24). Copper may be released from bearings, engine parts, and brakes, and nickel is found in diesel fuel and gasoline. Nickel and cadmium in rechargeable batteries can also cause heavy metal contamination, if they are not properly disposed of.

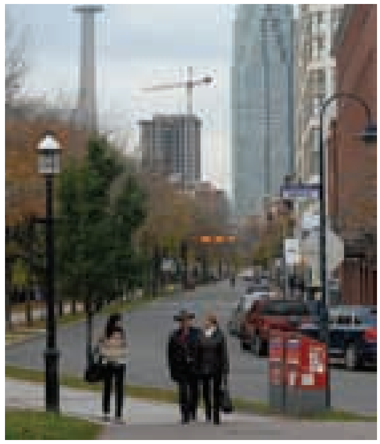


Figure 5.24 Soils may be contaminated with heavy metals anywhere that automobiles are used.

Contamination at Mine Sites

In Ontario, many abandoned mine sites are significantly contaminated with heavy metals. Old mines often were operated in ways that would no longer be allowed. There were no rules that required mine owners to clean up the sites after the mines were closed.

In times past, waste from mines was stored in tailings ponds or in slag heaps. The rock waste (tailings) in these sites contained metals that generate acids when they are exposed to air. For example, many mine tailings in Ontario contain iron sulphide (pyrite or fool's gold). In the presence of oxygen and water, the iron sulphide enters into a series of chemical reactions. The end products of these reactions are iron hydroxide, sodium sulphate, and sulphuric acid.

As this process continues, the soil and water in the area become more and more acidic. **Acid leaching** is a process in which acids dissolve metals found in soil. As the pH falls, the heavy metals begin to dissolve. At least 250 abandoned mine sites in Ontario continue to add to soil and water contamination through acid leaching of the wastes left behind (Figure 5.25). For example, the Kam Kotia mine site, located near Timmins, Ontario, caused acidification of soil and water and release of heavy metals into the surrounding areas.

Figure 5.25 Tailings ponds and slag heaps at many abandoned mine sites in Ontario are contaminating the surrounding soil and water with heavy metals, through acid leaching.

Restoring Soils

Soils contaminated by heavy metals can be restored to a healthy state by acid leaching. When soil is heavily contaminated, such as in an abandoned mine, it is first removed and taken to a treatment facility. The contaminated soil is treated with acid to decrease the pH. This dissolves the metals in the soil, which are then collected in an acidic solution. The metals are recovered by raising the pH of the solution with a base, which causes the metals to form a precipitate.

Neutralization reactions are used to prevent further acid leaching from mine sites. For example, at the closed Deloro Mine site near Peterborough, Ontario, which was leaching heavy metals and the poison

Take It **Further**

The rehabilitation of the abandoned sites of the Kam Kotia mine, near Timmins, and of the Deloro mine, near Peterborough, continues. Find out what progress has been made and whether these sites continue to negatively affect the environment. Begin your research at ***ScienceSource***.

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arsenic into the environment, an eight-hectare tailings pond was capped with half a metre of crushed limestone (calcium carbonate) to raise the pH and reduce the amount of acid leaching. Acid leaching at this old gold mine had contaminated the water in the area with heavy metals and the poison arsenic.

B16 STSE Science, Technology, Society, and the Environment

Transporting Acids

On March 30, 2007, two dozen cars of an Ontario Northland train jumped the tracks about 16 km north of Englehart, a community of about 1500 people north of North Bay, Ontario. Nine of the cars were carrying sulphuric acid. Over 100 tonnes (100 000 kg) of acid spilled into the Blanche River (Figure 5.26). This massive acid spill quickly killed fish and other organisms in or by the shores of the river. Health officials from Ontario's Ministry of the Environment were also concerned that the drinking water for the people and livestock in the area would be contaminated.

To monitor the damage caused by the acid spill, health officers immediately began to take water and soil samples at the spill site. To reduce the environmental impact, emergency response crews added kilogram amounts of lime (calcium hydroxide, $Ca(OH)_2$) to the river several kilometres upstream.

Figure 5.26 Sulphuric acid was released into the Blanche River when tank cars overturned, spilling their contents.

1. Why was calcium hydroxide added to the river? Use a word equation and a skeleton equation in your answer.
2. Should acids be transported large distances? Why or why not?

B17 Skill Builder Activity

Making an Inference

In Activity B18, you will be making inferences. An inference is a conclusion made by analyzing facts. When you draw conclusions about the observations you make in a scientific investigation, you are making inferences. An inference is a logical analysis of facts, so it can always be justified by those facts.

For example, an advertisement states that 20 out of 25 people prefer Brand A cola over Brand B. Can you infer that 80 percent of all people prefer Brand A cola? No, because you do not know how many people were interviewed or how these people were chosen. Were they chosen at random, or were they all regular buyers of Brand A cola? Without this information, there is not enough data to make an inference.

For each of the following situations, write an inference based on the given data. If there isn't enough data to justify an inference, write a sentence to explain why.

1. The juice stored in the back of the bottom shelf of the refrigerator is frozen. What can you infer about the temperature in the refrigerator?
2. Your cake comes out of the oven looking more like a pancake than a light, fluffy cake. What can you infer about the length of the baking time?
3. Eight in 10 dentists recommend Brand X toothpaste for reducing cavities. What can you infer about this toothpaste?