TOPIC 3 How Do You Spell Relief?

Ahh! After a hard day mowing the lawn or raking leaves, there isn't anything better than the clean, refreshing taste of your favourite soft drink, accompanied by a big plate of sliced vegetables with a tangy blue cheese or sour cream dip, maybe even a peanut butter and jelly sandwich. As your aching muscles relax and you take another sip of that tart, cold drink, let your thoughts wander to the importance of acids and bases in your world.

You are already familiar with acids and bases in your environment — you experience them on a daily basis, as shown in Figure 3.7. The tart taste of carbonated beverages, the tang of a salad dressing, even the burning sensation in your muscles during exertion — all are due to **acidic** substances. The bitter taste of celery or radishes, the soothing action of a sunburn lotion, the slippery feel of soap — these are due to **basic** substances.

Figure 3.7 Some of the objects in this picture contain acids, while others contain bases.

Acids and Bases

Acids and **bases**, the chemicals that produce acidic and basic substances, have many uses in our lives. For example, phosphoric acid is a key component in the manufacture of fertilizers, detergents, and many pharmaceuticals. It is a flavouring agent in carbonated beverages, cheeses, jams, jellies — virtually any food with a tangy flavour.

Another important acid, sulfuric acid, is most familiar as the ingredient of the battery for your family's vehicle. But it is also used in the manufacture of paints and dyes, the refining of oil and gas, and the production of synthetic textiles. In fact, it is possible to get an approximate measure of any country's industrial activity by looking at the volume of sulfuric acid used by that country.

Of the basic substances, sodium hydroxide is a component of household and industrial cleaners, bleaching agents for the production of paper, fixatives in textile dying, solvents in the making of electronic circuit boards, and as a reagent in film processing. The base, aluminum hydroxide, is a key ingredient in antacid tablets. You may need this if you are going to mix peanut butter and jelly with blue cheese dressing!

The Observable Properties of Acids and Bases

As you can see, acids and bases are used for very different roles, so it is important to be able to identify acids and bases. You probably noticed that one of the first clues to whether a substance is acidic or basic is its taste. Acids taste sour (e.g., lemons) and bases taste bitter (e.g., horse-radish). Unfortunately, tasting is not usually an acceptable option for laboratory work, so you can omit this method as a means of determining the basic or acidic nature of an unknown substance. Fortunately, acids and bases react differently with other substances, so we can devise tests to determine the acidic or basic nature of an unknown substance.

Likely you have experienced the slippery feel of soap (a basic substance). Although that property identifies basic substances, touching an unknown liquid with your bare hands is not a good idea in any lab setting.

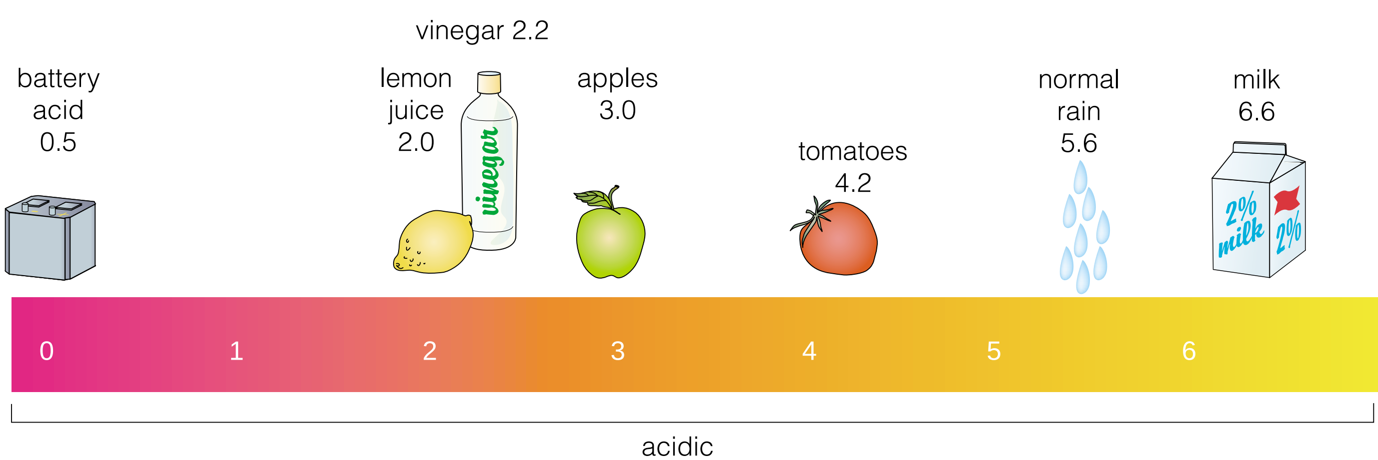
To safely tell whether a substance is an acid or a base, look for a noticeable colour change that occurs when an acid or base reacts with a chemical **indicator**. One of the best known indicators is **litmus**, a mixture of plant compounds extracted from certain lichens. This pinkish mixture turns red when in contact with an acid and blue when it contacts a base. Small strips of paper soaked in litmus are a standard diagnostic tool for chemistry.

Off the Wall

Some people like a wedge of lemon with their fish. Others prefer to sprinkle vinegar. Did you know that both of these are examples of neutralizing reactions? Fish contain a compound that is basic, so the acid in lemon juice or vinegar neutralizes the base. It may sound fishy, but it's true!

Stretch Your Mind

The "power" reported as pH is actually a power of ten in scientific notation. Take a strong acid, with pH 0.0, as a starting point. An acid with pH 1.0 has one tenth, or 10^{-1} times, the concentration. Vinegar, with pH 3.0, has only one thousandth, or 10^{-3} times, the concentration. How many times lower is the concentration of rainwater?



pH: A Powerful Scale

While litmus turns red in acid solutions and blue in basic solutions, it gives only an approximate idea of how acidic or basic a substance is. A more exact reading requires some technology.

The strength or concentration of an acid or base determines the extent to which it reacts with water. This reaction changes the electrical conductivity of the water, which can be measured with a sensitive meter, as shown in Figure 3.8. The **pH scale** is a way of comparing the relative acidity or alkalinity of a substance. In later courses, you will learn more about the criteria for measuring acidity and alkalinity and the exact chemical changes that occur when an acid or base reacts with water.

Figure 3.8 There are several ways to determine the pH of a substance. A pH meter and pH paper are two ways shown here.

As shown in Figure 3.9, a pH of 7 indicates a solution that is neither acidic nor basic. It is neutral. If the pH of a substance registers below 7, the solution is acidic. Above 7, it is basic. There are a number of indicator substances that turn different colours depending on the pH of the solution. Universal indicator (containing many such indicators) or **pH paper** will change to a colour that is characteristic of a specific pH. These colours are then matched against a chart that shows the range of colours for known pH values.

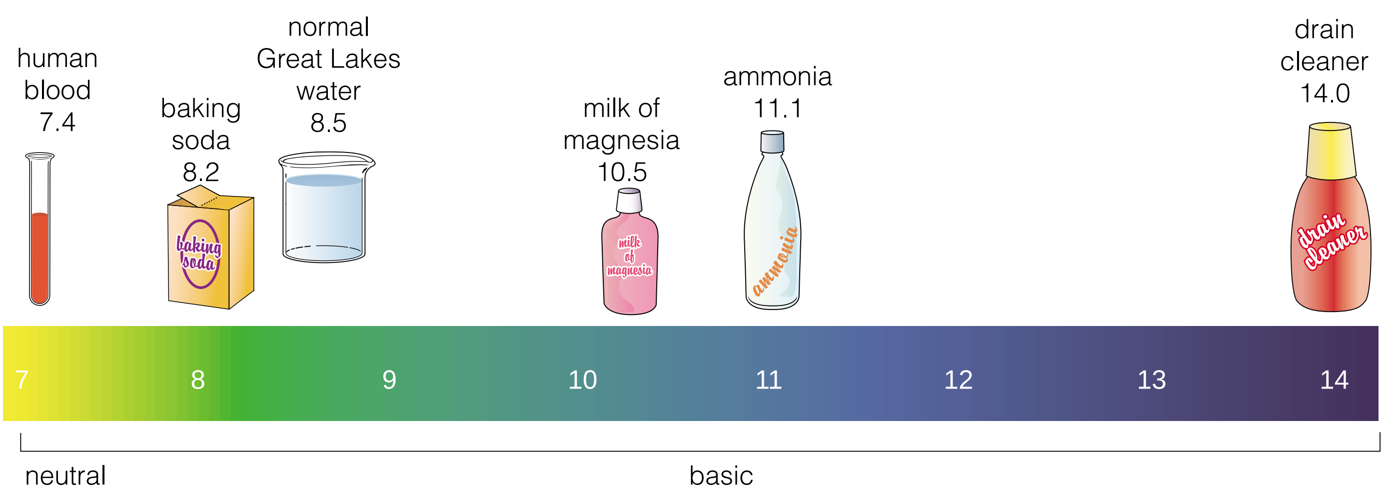


Figure 3.9 This diagram shows the pH of some common substances. Approximately how much more acidic is lemon juice than drain cleaner?

Find Out **ACTIVITY**

What Is the pH of Your Rain?

In this activity you will investigate the pH of some common acids and bases.

Materials

plastic container
rainwater (or melted snow)
pH paper, indicators, or pH meter

Procedure ✷ Performing and Recording

1. Decide which method you can use to test the pH of rain or snow.
2. During the next rainfall or snowfall, use the plastic container to collect a sample of the rainwater or snow. If you collect snow, let it melt.
3. Use an appropriate method to determine the pH of your sample.
4. Compare your results with your classmates' results.

What Did You Find Out? ✷ Analyzing and Interpreting

1. How did the pH value you obtained compare with your classmates' pH values? Account for any large discrepancies.
2. Calculate the average pH of the samples obtained by your class. Is this value what you might expect for your area? Why or why not?

DidYouKnow?

The word "pH" means the "power of hydrogen" and refers to the formation of hydrogen atoms that have lost an electron. Each pH unit on the pH scale stands for a tenfold increase in acidity or alkalinity. For example, a pH of 5.3 is ten times more acidic than a pH of 6.3, and a pH of 4.7 is 100 times more acidic than a pH of 6.7.

Word CONNECT

In Danish, the "p" of pH stands for *portenz* meaning "strength." In German, the word for "power" is *potenz*. Both of these words come from the Latin *potens*. Which words in English are related to the Latin word *potens*?

Some common acids and bases

INQUIRY

INVESTIGATION 3-D

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

The pH of Common Acids and Bases

Many common substances are either acidic or basic. In this investigation, you will make your own indicator and use it to find the pH of some common substances.

Question

What is the pH of a carbonated drink, and other common solutions?

Part 1

The Cabbage Test

Safety Precautions

- Ammonia is corrosive and toxic. Inform your teacher if you accidentally spill ammonia.
- If you spill any of the solution on your skin, immediately wash the area with cool water.

Apparatus

plastic container with a tight lid
potato masher, spoon, or fork
universal pH paper
test tubes and a test tube rack
100 mL beaker
glass stirring rod
medicine dropper
pH meter (for teacher use)
kettle (for teacher use)

Materials

2 red cabbage leaves

Solutions to Test (10 mL each)

lemon juice
vinegar
rainwater
distilled water
black coffee
liquid soap or shampoo
milk of magnesia
household ammonia
club soda (leave to last)

Procedure

1. Take two leaves from a red cabbage. Tear them into pieces about the size of a postage stamp. Put the pieces into a plastic container.
2. Ask your teacher to pour about 40 mL of hot water from a kettle into the container. Carefully seal the container, and leave it on your table to cool until it can be handled safely. While the water is cooling, complete step 3.
3. Copy the table below into your notebook. You will need enough space to **record** your observations for nine solutions. Also make a pH diagram similar to Figure 3.9. You will fill in substances as you determine their pH.
4. When the water in the container has cooled enough for you to handle the container safely, use the potato masher to mash its contents. Keep doing this until the liquid is deep blue or purple.

Solution	Colour of cabbage indicator	Approximate pH range
lemon juice		

CONTINUED ▶

5. Open the container, and carefully pour the liquid into a 100 mL beaker. Discard the cabbage leaves as directed by your teacher.

6. Pour about 10 mL of lemon juice into a test tube. Use a clean glass stirring rod to transfer a drop of the juice to a piece of universal indicator paper. Compare the colour with the colours in the chart. Estimate the pH of lemon juice, and **record** it in your table. Write "lemon juice" above the corresponding pH on your diagram. Rinse the stirring rod with water, and dry it with a paper towel.

7. Use the medicine dropper to add a few drops of cabbage juice indicator to the lemon juice. **Record** the colour of the indicator beneath the pH you estimated for the lemon juice.

8. Repeat steps 6 and 7 for each of the other solutions, except the club soda. About 20 mL of cabbage juice indicator should be left for step 9 and Part 2.

9. Pour about 10 mL of club soda into a test tube. Using only your observations of the colours of the cabbage juice indicator, estimate the pH of the club soda. Enter your observations for club soda in your table.

10. Set aside the cabbage juice indicator for Part 2. All other solutions can be rinsed down the sink with plenty of water. Discard indicator paper as directed. Wash your hands.

Teacher Demonstration

11. Although pH meters are more accurate than indicator paper, they are relatively expensive and require larger volumes of liquid. For these reasons, your teacher may demonstrate how a pH meter is used to measure the pH of the solutions you tested.

Part 2

Breath Check

You will use your indicator to analyze your breath. Does breath produce an acidic, basic, or neutral solution in water?

Safety Precautions

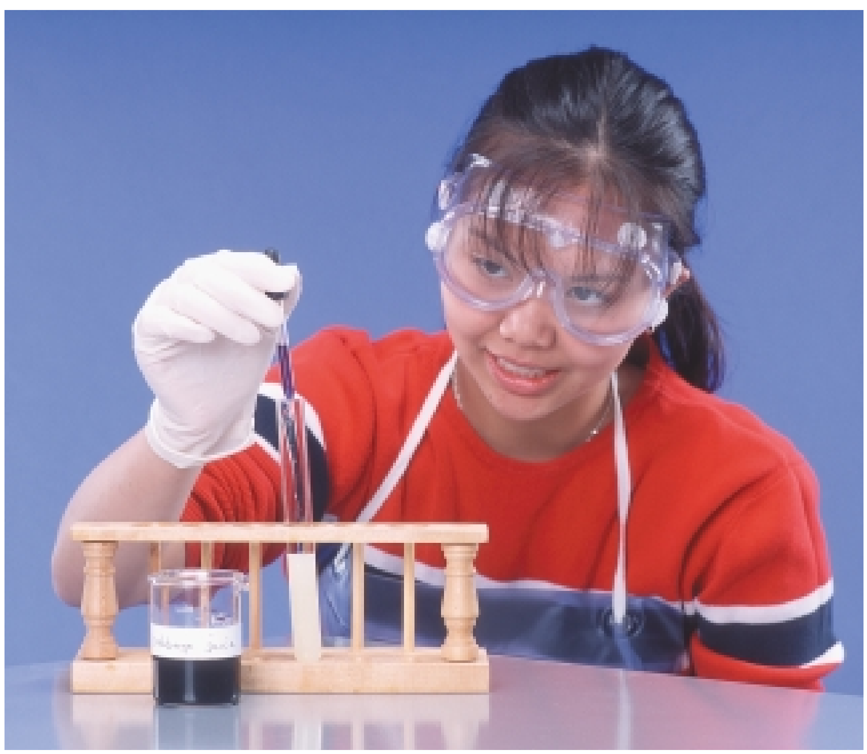
- If you spill any of the solution on your skin, wash the area immediately with cool water.

Apparatus

clean plastic straw
250 mL beaker
medicine dropper
stirring rod

Materials

cabbage juice indicator from Part 1
100 mL distilled water
5 mL household ammonia
20 mL vinegar



You can make your own indicator to test for acids and bases.

Procedure

1. Pour about 100 mL of distilled water into the 250 mL beaker. Use the medicine dropper to add two drops of household ammonia to the water. Stir the solution. Rinse the medicine dropper with distilled water.

2. Drop by drop, add just enough of the dilute ammonia solution from step 1 to the cabbage juice indicator to change the colour from deep blue or purple to pale green.

3. Using a clean plastic straw, carefully and gently blow a steady stream of bubbles through the indicator solution. Continue blowing until you **observe** a change. Remove, rinse, and discard the straw. Describe the change in your notebook.

4. Pour a little vinegar into the solution from step 2, until the colour changes. **Record** the new colour. Pour your solutions down the sink, and rinse with plenty of water. Wash your hands.

The straw is used to gently blow bubbles through the indicator. When finished, the student will rinse and discard the straw.

Analyze

1. List the solutions you tested from most acidic to most basic. Compare your list with the lists of other classmates.

Conclude and Apply

2. Which is more acidic, club soda, or a cola drink with a pH of about 3.0? Check the labels on containers for both drinks, and find an ingredient that might account for the difference.

3. Did the gas in exhaled breath dissolve in water to produce a solution that is acidic, basic, or neutral? Summarize the evidence that supports your conclusion. Which gas in exhaled breath caused the change?

Stretch Your Mind

Since soils in different environments have different natural pH values, the plants that grow there have evolved to suit the pH ranges they must grow and live in. For example, rhododendrons flourish in moist, acidic environments and grow best at a pH of about 5. Many grasses, including wheat and maize, grow in drier environments, where they must tolerate a pH of 7 or 8. (What can you determine about the "natural" pH of rainwater from this?)

Gardeners and farmers can adjust the pH balance to suit the plants and crops they want to grow. Clay soils are harder to "fix" than sandy soils, for example. Lime (calcium carbonate) or dolomitic lime (which also contains magnesium carbonate) can be added to acidic soils, while ferrous sulfate or aluminum sulfate can help correct soil that is too alkaline.

Why do you think these substances can change the pH of a soil? Work out balanced chemical equations for reactions when (a) calcium carbonate is added to soil with excess nitric acid and (b) aluminum sulfate reacts with the water in an alkaline soil. Why are sodium hydroxide and sulfuric acid never used to adjust the pH of soil?

DidYouKnow?

Acid precipitation in one country can be caused by emissions from another country. In fact, more than 50 percent of the acid precipitation affecting eastern Canada is due to oxides originating in the United States. This has been an issue in political discussions between Canada and the United States since the 1970s.

DidYouKnow?

In 2001, David Schindler, an internationally recognized ecologist at the Univeristy of Alberta won one of the largest science prizes on the continent. His research on acid precipitation and the impact of phosphorus-based detergents on the world's freshwater supplies netted him the $1-million Gerhard Herzberg Canada Gold Medal for Science and Engineering.

Acid Precipitation—a Global Concern

Over the past 30 years, there have been few issues that have created more studies, debate, or controversy than acid precipitation. The chemistry behind acid precipitation is clear. Oxides of carbon, nitrogen, and sulfur produced by burning organic materials react with moisture in the air to form acids. The process is illustrated below.

$$SO_{2(g)} + H_2O_{(\ell)} \rightarrow H_2SO_{3(aq)}$$ ◀ sulfurous acid

$$SO_{3(g)} + H_2O_{(\ell)} \rightarrow H_2SO_{4(aq)}$$ ◀ sulfuric acid

$$2NO_{2(g)} + H_2O_{(\ell)} \rightarrow HNO_{2(aq)} + HNO_{3(aq)}$$ ◀ nitrous acid and nitric acid

$$CO_{2(g)} + H_2O_{(\ell)} \rightarrow H_2CO_{3(aq)}$$ ◀ carbonic acid

In a process called **acid precipitation**, these acid compounds are washed out of the air by rain and snow and may be deposited a long way from the source of the oxides. Acid rain or snow looks, feels, and even tastes normal, but this rain or snow causes an estimated $1 billion in damage each year.

Acid damages and, in some cases, destroys aquatic ecosystems of lakes and streams, reduces productivity of crops, harms other vegetation, and accelerates the decay of our buildings, structures, and monuments. Acid corrosion is such a problem in Italy that some famous marble statues have had transparent cases filled with inert gases erected around them to prevent further damage. In Canada, the loss in productivity for agriculture, forestry, and fisheries means fewer jobs and lower profits. Corrosion and erosion of structural materials requires expensive maintenance and repairs to our buildings, bridges, and machinery.

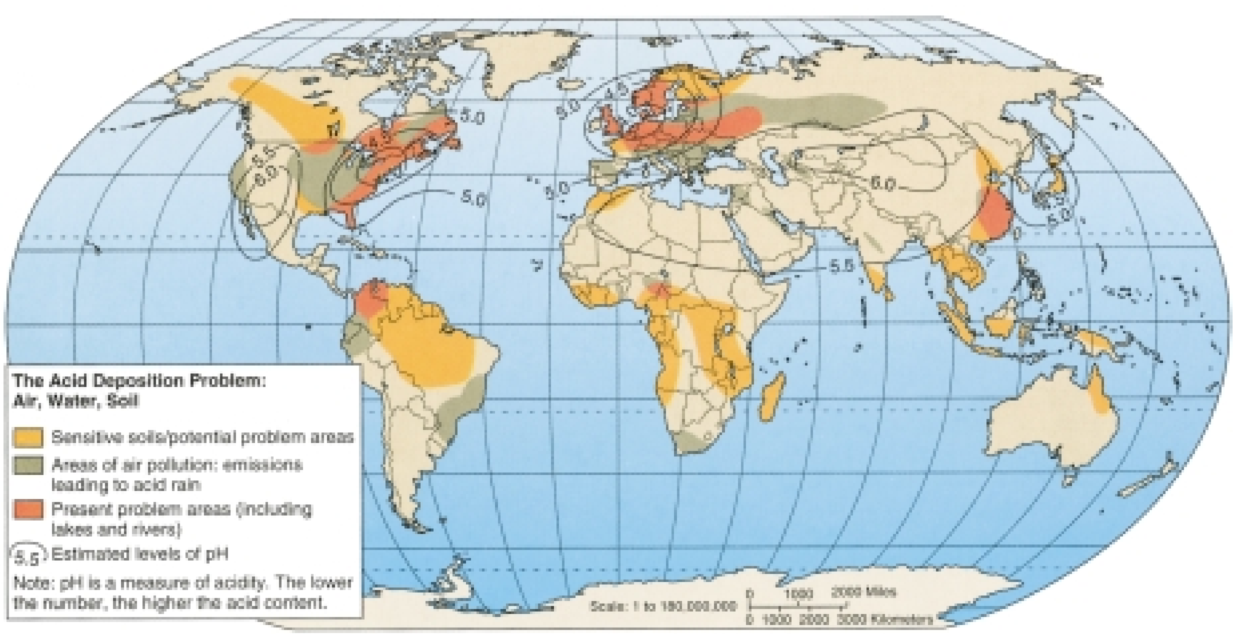


Figure 3.10 Sulfuric and nitric acids formed in the air by burning fossil fuels and other industrial activities threaten crops, water quality, building materials, and living organisms.

International Agreements

In 1996, in response to the public's concern about increasing damage to the environment, Canada and the United States agreed to reduce industrial exhaust emissions by 10 percent by the year 2000. In addition, exhaust emissions from cars built before 1998 were to be reduced by 60 percent. As a result of these pollution control measures, levels of sulfur and nitrogen oxides in the environment are diminishing.

There has been much disagreement over exactly how acid precipitation affects living organisms. After all, it looks, feels, and tastes normal. What is it about acid precipitation that causes damage? For terrestrial ecosystems, one major effect is that acid added to the soil dissolves mineral nutrients and allows them to be leached or washed away, resulting in nutrient-poor soil and poorer growing conditions for plants. In certain areas leaching may also free heavy metals to wash into streams and water supplies, where they may then be consumed by plants and animals. Heavy metals are those with a density of over 4.0 g/mL such as lead, mercury, cadmium, and nickel. These metals are deadly to most organisms. You will learn more about their effects in later Topics.

Figure 3.11 These maple leaves show damage by acid precipitation.

Career **CONNECT**

Toxic Substances Officer

Lori Forster-Clegg loved animals while growing up. She also loved biology. Lori brought those passions together with a diploma in biological sciences and pollution technology and then a Bachelor of Science in biology. During the summers she banded ducks, gathered information about spills, created pamphlets, and researched toxic substances. Now Lori is a toxic substances officer with Environment Canada's prairie and northern region — Alberta, Saskatchewan, Manitoba, Northwest Territories, and Nunavut — from her Edmonton office.

Lori's job involves being on the lookout for banned substances entering Canada, focussing mostly on ozone-depleting substances and substances new to Canada. Industries contact her to see if materials they want to import are regulated or illegal. New substances that aren't on the approved list need to be tested. The industry that is trying to import a substance conducts environmental and toxicity tests on the substance. They then submit these results to Environment Canada's headquarters in Ottawa. Lori helps industries put together their submission package and helps them understand the rules so they can more easily follow them.

Inspectors, ensuring that the environmental laws are being followed, also contact Lori about whether certain substances are banned. They look to her for answers and training. "I'm in a position to know the science behind the regulations — why they're in place — and how they benefit the environment," she says. Lori explains the environmental regulations so inspectors know what to look for when they are on-site. While she spends most of her time at her desk on her computer, inspectors often ask Lori to come along on calls because they are not familiar with the hundreds of different chemicals.

Does Lori's job sound interesting to you?

- Conduct some research over the Internet or at the library to find out more about what it takes to become a toxic substances officer.
- What level of education does it require?
- Which volunteer opportunities will give you experience in the field while you're still in school?

INQUIRY

INVESTIGATION 3-E

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

The Effect of pH on a Population

In this investigation, you will examine the effects of acid precipitation by observing the effects of pH on the growth of a yeast culture.

Question

How do variations in pH affect the growth of yeast?

Safety Precautions

- Handle the hot plate with care to avoid burns.
- Handle the microscope slides with care.
- If you spill any of the solutions on your skin, wash the area with plenty of cool water.

Apparatus

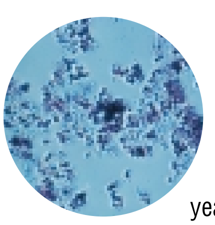
microscope	7 test tubes
microscope slides	thermometer
cover slips	100 mL beaker
100 mL graduated cylinder	hot plate
	marker

Materials

yeast culture
water
dilute acid solution
dilute base solution
sugar
labels

Procedure

1. Work in a small group. Measure 100 mL of water into the beaker. Place the beaker on the hot place, and bring the water temperature to 30°C. **CAUTION:** Handle the hot plate with care.



yeast cells

2. Add 3 g of sugar and 0.5 g of yeast. Stir well.
3. Prepare seven test tubes with a pH range of 2 to 8. Label each test tube.
4. Add 10 mL of yeast culture to each test tube. Allow the test tubes to sit for 24 h.
5. Devise a sampling technique to estimate the relative population density of yeast in each test tube. Examine each sample under the microscope. **Record** your results.
6. Make a graph that shows the relationship between population density and pH.
7. Wash your hands after completing this investigation.

Analyze

1. At what pH did the yeast population show the most growth? At what pH did it show the least growth?

Conclude and Apply

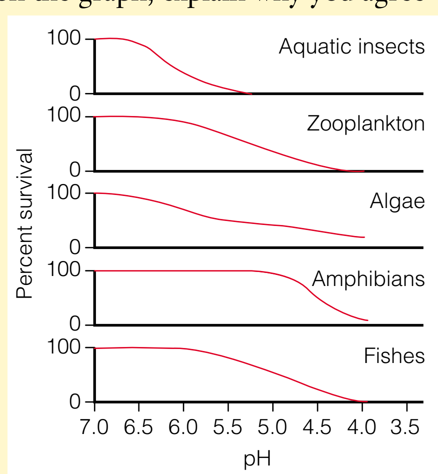
2. The graph shows changes in the populations of various aquatic organisms in Canadian lakes and rivers in relation to pH levels. Study the graph, and answer the questions.

   (a) Which organisms appear to be most sensitive to acid conditions? Which are least sensitive?

   (b) Why might the population of a species of fish that is tolerant of high acid levels still decline in an acidified lake?

   (c) "When fish start dying, the damage has already been done." From the information on the graph, explain why you agree or disagree with this statement. Which species might be better used as an early warning of acid damage in lakes?

3. From your results, and the data presented, make a general statement about the effects of acid precipitation on organisms.



Using Chemistry to Control Acid Effects

Acid precipitation falls all across Canada, but some areas are affected more than others. Believe it or not, the same chemical reaction that is destroying the marble tablet in Figure 3.12 is exactly the same reaction that protects areas of western Canada from acid precipitation. Study the chemical equation that accompanies Figure 3.12. Did you notice that the products of the reaction of calcium carbonate and sulfuric acid are not acidic?

During the last ice age (about 20 000 years ago), glaciers covered much of North America. As the glaciers advanced, they eroded the rocks over which they passed, carrying the debris with them. When the glaciers melted at the end of the ice age, the crushed rocks were left behind. In western Canada, the rock debris contained a substantial amount of alkaline minerals such as calcium carbonate or calcite. This calcium carbonate lying at the bottoms of lakes in the Canadian west neutralizes the acids entering these lakes.

This presents us with a chemical solution to the problem of acidified lakes. Add a quantity of powdered calcium carbonate to the lake in question and voilà — instant neutral water. One major source of calcium carbonate is limestone; the process of adding calcium carbonate to the environment is referred to as **liming**, as shown in Figure 3.13. The correct term for such a chemical reaction is an **acid-base neutralization**.

You might be wondering why we aren't neutralizing the effects of acid precipitation in all the acidified lakes if it is so easy. You will find out why after the next investigation.

Figure 3.12 Many monuments and statues — some thousands of years old — are made of marble and limestone. These substances contain calcium carbonate ($CaCO_3$), which is easily decomposed by sulfuric acid:

$$CaCO_{3(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(s)} + H_2O_{(\ell)} + CO_{2(g)}$$

Calcium sulfate dissolves in water more readily than calcium carbonate. Thus the monuments and statues corrode as the calcium sulfate is washed away.

Figure 3.13 Liming is done by releasing powdered calcium carbonate from aircraft.

Off the Wall

Normal rainwater has a pH as low as 5.6 due to the carbonic acid formed as carbon dioxide gas dissolves into the water. The presence of sulfur oxides and nitrogen oxides from industry and transportation in the atmosphere results in rain that is even more acidic. Central Europe, Japan, and eastern North America are severely affected by acid precipitation. In these areas, rainwater can have an acidity approaching that of vinegar (pH 3.0), which is about 1000 times more acidic than normal rainwater. Amazingly, there are even more extreme acid conditions. In 1974 a storm dropped rain with a pH of 2.4 over Scotland, and fog over Los Angeles has been measured with a pH as low as 1.7! This is 10 000 times more acidic than normal.

INQUIRY

INVESTIGATION 3-F

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Drop-by-Drop Neutralization

As you know from Unit 2, when acids and bases neutralize each other, the products are water and a "salt" compound. Regardless of the strength of the acid or base, neutralization will occur, even though the amounts of acid and base may not be equal. A relatively weak acid or base can be used to neutralize spills of much stronger acid or base. An antacid is a good example. Acid in your stomach that helps digest your food has a pH of about 2. "Heartburn" occurs when acid from your stomach enters your esophagus. It is relieved by swallowing an antacid, which is just a weak base.

Question

How does an antacid compare with baking soda and a strong base in neutralizing an acid?

Prediction

Make a prediction about whether an antacid, baking soda, or a strong base will be most effective in neutralizing acid.

Safety Precautions

- This investigation uses caustic, corrosive substances. Clean up any spills carefully and inform your teacher.
- Bromothymol blue is flammable. Keep it well away from flames.

Apparatus

3 100 mL beakers or 3 petri dishes
2 medicine droppers or 1 mL micro-pipettes
stirring rod
balance

Materials

dropper bottle of bromothymol blue indicator
dilute sodium hydroxide, NaOH (aq)
dilute hydrochloric acid, HCl (aq)
(**Note:** These two solutions should have the same concentration)
water
antacid tablet
baking soda

Procedure

1. Place a few drops of bromothymol blue indicator in a small, clean beaker or petri dish. Then add 2 mL of sodium hydroxide solution.
2. While stirring the solution with the stirring rod, add hydrochloric acid slowly, counting the drops until the colour of the indicator just changes, and the colour change lasts at least 20 s. **Record** the number of drops and appearance of the solution.
3. Dissolve 2 g of baking soda into 2 mL of water. Repeat steps 1 and 2, using the baking soda solution in place of the sodium hydroxide solution.
4. Plan the steps you will take to compare the antacid tablet to the sodium hydroxide and baking soda solutions. (Hint: Break the tablet into pieces.)
5. Remove your gloves and wash your hands.

Analyze

1. Compare your results (the number of drops added in the three neutralization reactions) with your classmates' results. Discuss any differences.
2. Using the number of drops of hydrochloric acid needed to neutralize the antacid tablet and baking soda, calculate the mass of baking soda equal to one antacid tablet.

Conclude and Apply

3. What would happen if more baking soda were added after neutralization occurred? What colour would the indicator turn? Why?
4. What would be the danger in swallowing many antacid tablets?
5. Which base was most effective in neutralizing acid? How does the "alkalinity" of antacid compare to sodium hydroxide solution?

Using Chemistry to Control Harmful Emissions

You have observed how alkaline substances react with acids in a neutralizing reaction. So why not use this process to eliminate the problem of acidified lakes?

Liming has been used, but with limited success. Rivers and streams constantly feed acidified water into lakes, so the lakes would have to be limed continually to keep up with the new influx of acid. Imagine the cost of treating between 14 000 and 150 000 affected lakes! Do you think the cost would outweigh the benefits, or vice versa?

Since it is impractical and expensive to neutralize all of the acid precipitation we humans are causing, the only other option is to reduce or eliminate the oxides. How can this be done? Chemistry to the rescue!

Chemical engineers use their knowledge of chemistry to design and build devices to remove oxides *before* they get into the air. **Catalytic converters,** such as the one shown in Figure 3.14, are required on most vehicles and are a good first step.

Figure 3.14 While catalytic converters are quite efficient, they work best when the catalysts are warmed up. It takes about 90 s, after a car starts, for the catalysts to be activated. Unfortunately, it is during this brief warm-up that the car produces about 70 percent of all the pollutants that it releases during its driving cycle.

DidYouKnow?

You might expect the pH of a lake to decrease gradually as acid water enters. However, this gradual decrease does not happen in a lake with a limestone bed. Such lakes are common in Southern Ontario, Southern Québec, and the Atlantic Provinces, but not on the Canadian Shield or the Prairies. Some lakes in the Rocky Mountains also have limestone beds. Calcium carbonate in the limestone bed of a lake reacts with acids, and so the pH stays fairly constant as acid water enters the lake. But when all of the limestone has reacted, the pH suddenly drops. The rapid change in pH is deadly to the ecology of this type of lake.

Catalytic converters contain a ceramic or wire honeycomb-like structure coated with a thin layer of metallic catalysts, such as platinum, rhodium, and palladium. A **catalyst** is a substance that speeds up a chemical reaction without being used up in the reaction. The large surface area of the honeycomb structure helps produce a complete combustion. A converter aids the formation of carbon dioxide and water from hydrocarbons, reducing the amounts of carbon monoxide and nitrogen oxides produced. The purpose of the converter is to encourage complete **oxidation**.

Word CONNECT

Look up the words "absorb" and "adsorb" in your dictionary. Explain the difference between them in your notebook.

Scrub Those Cares Away

The oxide emissions from industrial factories and power plants that burn coal can be a major source of oxides depending on the sulfur content of the coal being used. The installation of "**scrubbers**" (devices that use a **sorbent** — a substance that can adsorb, or capture oxides) is a good way to reduce oxide emissions.

Traditional "wet" scrubbers remove sulfur dioxide gas ($SO_{2(g)}$) by reacting heated gases with calcium oxide or lime (CaO). Figure 3.15 illustrates this process. The calcium oxide sorbent is used up in this reaction and the waste calcium sulfite ($CaSO_3$) is disposed of. A large power plant might produce millions of tonnes of waste calcium sulfite every year, most of which presently ends up in landfills.

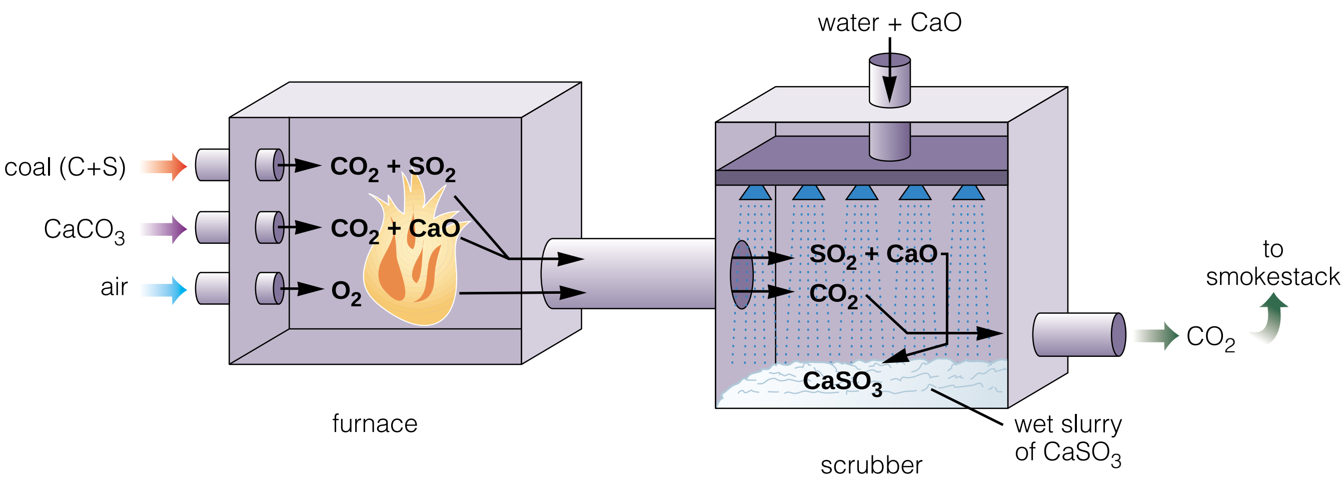


Figure 3.15 The key to "scrubbing" exhaust gases is the addition of calcium oxide (CaO), which reacts with the sulfur dioxide gas (SO_2) to form calcium sulfite ($CaSO_3$). The calcium sulfite can be washed away with water.

Figure 3.16 These little beads pack a big punch by removing sulfur dioxide and nitrogen oxides — pollutants responsible for acid precipitation — from gas given off during coal combustion.

Newer scrubber technologies have the potential to be more effective, environmentally friendly, and economical. The use of metal oxide sorbents (as shown in Figure 3.16) is the key. One such system, COBRA (copper oxide bed regenerable application), uses a sorbent of small beads of aluminum oxide impregnated with copper. The beads form clusters of copper oxide on their surface and as heated gases pass by, $SO_{2(g)}$ reacts with the copper oxide to form copper sulfate. Fresh beads are continuously added and "spent" beads are removed. The spent beads are then treated with methane gas to release the $SO_{2(g)}$ and restore the bead to its original state for reuse. Meanwhile the trapped $SO_{2(g)}$ can be treated to produce elemental sulfur, sulfuric acid, or even ammonium sulfate fertilizer.

INTERNET CONNECT

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During the formation of coal, large amounts of methane-rich gas are created and remain trapped within coal beds and the surrounding rocks. Mining of coal beds will allow this methane to escape into the atmosphere where it acts as a potent greenhouse gas. Find out how "Clean Coal Technology" may turn this problem into a profit — both economic and environmental! Go to the web site above, and click on Web Links to find out where to go next. Design an advertising logo, jingle, or print ad to sell this new technology.

All of these products have applications we can make use of! As a bonus, the addition of ammonia to the heated gases triggers a catalytic reaction that breaks down nitrogen oxides into nitrogen and oxygen gas and water vapour.

In tests, COBRA removed all nitrogen oxides and 95 percent of the sulfur dioxide from emissions. This is comparable to or better than the results obtained by traditional scrubbers without the landfill waste. The copper oxide sorbent is more expensive to produce than sorbents in traditional scrubbers. However, since it is reusable, costs are recovered over time. As well, there is an end product to sell instead of waste to throw away.

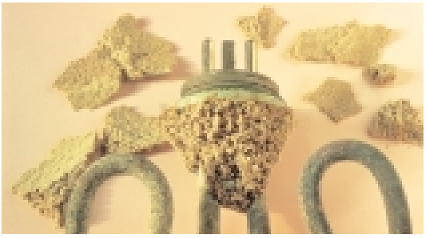
Finally, what about the small amounts of oxide gases that make it past these devices? How much of a problem do they pose? What about the mountains of waste calcium sulfate produced by traditional scrubbers every year? Are they a problem? Both are pollutants, but how do they compare? You will explore this question in Topics 5 and 6.

Did You Know?

Fossil fuels such as coal, oil or natural gas are the sedimentary remains of swamp vegetation. Burning fossil fuels releases solar energy, which was stored in plant matter through the process of photosynthesis millions of years ago. Intense heat and pressure exerted on the plant matter initially forms bituminous (soft) coal. Higher pressures and temperature change bituminous coal to the harder anthracite coal. Alberta contains 70 percent of Canada's coal reserves, mostly of the sub-bituminous category. Approximately four-fifths of the coal produced in Alberta is used as fuel for the generation of electricity. Alberta coal is low in sulfur and burns cleaner than most coal found in other areas of the world.

TOPIC 3 Review

1. Which human activity is the major cause of acid precipitation?
2. Which key property do all indicators possess?
3. It is thought that pain results from a change in the pH of the fluid that surrounds nerve cells. The fluid within your cells is slightly acidic, so a cut or burn releases this fluid and causes pain signals from your nerve endings. What would you expect to find if you tested the pH of creams and lotions used to treat cuts and burns?
4. Suppose you have two containers, one containing a dilute acid and the other a dilute base, but there are no labels on them. Describe how you could use red cabbage to determine which solution is which.
5. Hydrofluoric acid, $HF_{(aq)}$, reacts with sodium hydroxide, $NaOH_{(aq)}$, to form a compound that is used in toothpaste to prevent cavities. What is the name of this compound?
6. **Apply** Coffee makers and kettles eventually become clogged with a buildup of "scale" from deposits of calcium carbonate and magnesium carbonate. Explain how pouring vinegar into your coffee maker or kettle removes this scale.



7. **Thinking Critically** Give three reasons why eastern Canada is more affected by acid precipitation than western Canada. How might increased acidity levels affect the economy of eastern Canada? Consider tourism, factories, and taxes.

Wrap-up TOPICS 1-3

If you need to check an item, Topic numbers are provided below.

Key Terms

nutrient
macromineral
trace element
enzyme
vitamin
protein
lipid
carbohydrate
biological magnification
biomagnification
herbicide
insecticide
fungicide
pesticide
acidic
basic
acid
base
acid precipitation
indicator
litmus
oxidation
pH scale
pH paper
acid-base neutralization
leach
heavy metal
liming
catalyst
catalytic converter
scrubber

Reviewing Key Terms

1. In your notebook, write the description in column A beside the correct term in column B.

A	B
• a naturally occurring catalyst found in cells	• pH scale (3)
• the reaction of an acid and base to form a salt and water	• trace element (1)
• process where chemicals collect in the tissues of organisms, increasing in concentration toward the top of a food chain	• acid precipitation (3)
• a chemical substance that changes colour in response to changes in acidity or alkalinity	• enzyme (1)
• a mineral needed in amounts less than 100 mg per day	• catalyst (3)
• a substance that speeds up a chemical reaction but is not depleted or changed by the reaction	• biological magnification (2)
• a scale that measures the relative acidity or alkalinity of a substance	• acid-base neutralization (3)
• rain or snow that contains high levels of acid	• poison (2)
• a substance that causes illness or death when it enters the body in food or drink	• indicator (3)

Understanding Key Concepts

2. Modern food processing and refining used in the packaging of food products decreases the magnesium and potassium contained in those foods. Name some of the likely symptoms shown by a person eating only refined foods. (1)

3. What is the role of an enzyme in your body? (1)

4. What are the characteristics of DDT (and other "chlorinated" hydrocarbon pesticides) that make it both a valuable pesticide and an environmental problem? (2)

5. The figure below shows a field planted with hybrid wheat called triticale. It is richer in protein than wheat and is used for human food and livestock feed. List two risks and two benefits of planting only one crop, such as triticale. (2)

6. List the characteristic properties of acids and bases. (3)

7. Your brother has eaten too many doughnuts, and now he has acid indigestion. He cannot find a commercial antacid product. Could he use baking soda? Explain why or why not. (3)