

Unit B Chemistry and the Environment

Chapter 1: Acid Deposition

Practice, page 157

- $C_5H_{12}(l) + 8 O_2(g) \rightarrow 5 CO_2(g) + 6 H_2O(g)$
 - $C_4H_8(g) + 6 O_2(g) \rightarrow 4 CO_2(g) + 4 H_2O(g)$
 - $2 C_4H_{10}(g) + 13 O_2(g) \rightarrow 8 CO_2(g) + 10 H_2O(g)$ or $C_4H_{10}(g) + 6.5 O_2(g) \rightarrow 4 CO_2(g) + 5 H_2O(g)$
 - $2 C_8H_{18}(g) + 25 O_2(g) \rightarrow 16 CO_2(g) + 18 H_2O(g)$

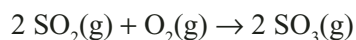
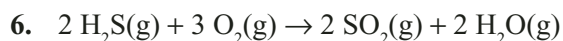
Practice, page 158

- An increase in combustion processes could result in an increase in the amount of carbon dioxide in the atmosphere if the speed at which carbon dioxide is produced is greater than the speed at which carbon dioxide can be removed from the atmosphere.
- Carbon sink* is a term used to describe a process that uses carbon dioxide, $CO_2(g)$. Increased forestation (planting trees) and growing crops (biomass) absorb carbon dioxide from the atmosphere and convert it into glucose. This process stimulates conversions in the carbon cycle.

Carbon sequestering involves placing carbon dioxide into caverns underground, where it will not enter the atmosphere. This process would not impact any process in the cycle; it simply removes carbon dioxide and places it in an area where it will not be converted further.

Practice, page 159

- complete combustion:** $CH_4(g) + 2 O_2(g) \rightarrow CO_2(g) + 2 H_2O(g)$
incomplete combustion: $2 CH_4(g) + 3 O_2(g) \rightarrow 2 CO(g) + 4 H_2O(g)$
- The complete combustion of methane uses more oxygen per molecule of methane, $2_{O_2} : 1_{CH_4}$, than the incomplete combustion of methane, $3_{O_2} : 2_{CH_4}$ or $1.5_{O_2} : 1_{CH_4}$.

Practice, page 160

The following table is useful when balancing chemical equations.

Initial Chemical Equation			
Reactants: $\text{H}_2\text{S}(\text{g}) + \text{O}_2(\text{g})$		Products: $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$	
H	2	H	2
S	1	S	1
O	2	O	3
Balanced Chemical Equation			
Reactants: $2 \text{H}_2\text{S}(\text{g}) + 3 \text{O}_2(\text{g})$		Products: $2 \text{SO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$	
H	$2 \times 2 = 4$	H	$2 \times 2 = 4$
S	$2 \times 1 = 2$	S	$2 \times 1 = 2$
O	$3 \times 2 = 6$	O	$2 \times 2 + 2 \times 1 = 6$

Practice, page 160

7. Emissions of NO_x are the result of vehicle emissions and combustion processes that use atmospheric air (e.g., furnaces). The higher concentration of people in urban areas—homes, vehicles, and so on—results in higher emissions. Also, large industries tend to be located near urban areas, which adds to NO_x emissions.
8. a. NO_x emissions will increase. There are more vehicles on the road during rush hour.
- b. NO_x emissions will increase. A cold snap in winter increases furnace use to heat homes. It also increases idling time of vehicles as they warm up.
- c. NO_x emissions will increase. A heat wave in summer increases the demand on power plants due to the electricity needed to operate air conditioners.

1.1 Questions, page 164**Knowledge**

1. a. Combustion is a chemical process involving a reaction of a substance with oxygen. Combustion is a major source of emissions.
- b. An oxide is a chemical substance consisting of oxygen and another element. Many chemical compounds are present as oxides (e.g., carbon dioxide, nitrogen oxides, and sulfur oxides) in emissions.
- c. Pollution consists of waste substances that contaminate or harm their surroundings. This lesson describes some of the sources and common forms of pollution.

- d. A greenhouse gas is a substance that is capable of absorbing infrared radiation (heat) and preventing its loss. Greenhouse gases act to trap energy in the atmosphere, contributing to global climate change. Carbon dioxide, a product of the combustion of hydrocarbons, is a greenhouse gas.
 - e. Hemoglobin is a molecule in blood that is responsible for the transport of oxygen. Emissions like carbon monoxide can bind to hemoglobin, affecting oxygen transport in the human body and, thus, affecting health.
 - f. Sour gas is a natural gas containing hydrogen sulfide, $\text{H}_2\text{S}(\text{g})$. A great deal of sour gas is extracted in Alberta, and there may be concerns about the effects of this process on the environment.
 - g. NO_x represents the oxides of nitrogen—nitrogen monoxide, $\text{NO}(\text{g})$, and nitrogen dioxide, $\text{NO}_2(\text{g})$ —and is a by-product of combustion processes. Nitrogen is usually not present in the fuel, but it can be a product of the process.
 - h. Particulate matter consists of tiny particles from emissions that are suspended in air. Particulate matter may consist of larger particles and may be visible. It is significant because it is a health hazard.
 - i. A carcinogen is a substance that may cause cancer. Carcinogens are a major threat to health and should be avoided.
2. Bonds between the atoms of the fuel are broken and new combinations between the atoms of the fuel and (most often) oxygen form, releasing energy.
 3. If carbon is in the substance being combusted, carbon monoxide and carbon dioxide may be produced. Likewise, if sulfur is in the substance being combusted, sulfur dioxide may be produced.
 4. Nitrogen oxides can appear in a variety of forms, like $\text{NO}(\text{g})$ and $\text{NO}_2(\text{g})$. The subscript x refers to the number of oxygen atoms that may be present.
 5.
 - a. $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$
 - b. $2 \text{C}_2\text{H}_6(\text{g}) + 7 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{g})$ or $\text{C}_2\text{H}_6(\text{g}) + 3.5 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g})$
 - c. $\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g})$

Applying Concepts

6. The air drawn into internal combustion engines consists mostly of nitrogen. Some of the energy released by the combustion process enables the combination of nitrogen and oxygen to form NO_x compounds.
7.
 - a. **thermal step:** $2 \text{H}_2\text{S}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{S}(\text{s}) + 2 \text{H}_2\text{O}(\text{g})$

$$2 \text{H}_2\text{S}(\text{g}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{SO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$$
catalytic step: $2 \text{H}_2\text{S}(\text{g}) + \text{SO}_2(\text{g}) \rightarrow 3 \text{S}(\text{s}) + 2 \text{H}_2\text{O}(\text{g})$
 - b. NO_x compounds are produced in the thermal step. The high-temperature combustion process uses atmospheric air in the combustion chamber (like most furnaces).
 - c. Using pure oxygen will remove nitrogen from the combustion chamber. If nitrogen is not present in the combustion chamber, the emission of NO_x compounds is avoided.

8. Your table should be similar to the following.

OXIDES

Element	Compound	Properties	Processes
carbon	carbon monoxide	<ul style="list-style-type: none"> toxic 	<ul style="list-style-type: none"> incomplete combustion of hydrocarbons
	carbon dioxide	<ul style="list-style-type: none"> greenhouse gas acid-forming substance 	<ul style="list-style-type: none"> complete combustion of hydrocarbons
sulfur	sulfur dioxide	<ul style="list-style-type: none"> acid-forming substance 	<ul style="list-style-type: none"> combustion of hydrogen sulfide combustion of elemental sulfur
	sulfur trioxide	<ul style="list-style-type: none"> acid-forming substance 	<ul style="list-style-type: none"> combustion of sulfur dioxide
nitrogen	nitrogen oxide	<ul style="list-style-type: none"> acid-forming substance 	<ul style="list-style-type: none"> high-temperature combustion in air
	nitrogen dioxide	<ul style="list-style-type: none"> acid-forming substance smog-forming substance 	<ul style="list-style-type: none"> high-temperature combustion in air

9. a. Your table should be similar to the following.

Location	Relative SO ₂ and NO _x Emissions	Reason
Fort McMurray	high	tar sands extraction
Edmonton	moderate	sour gas processing; petroleum refining; large urban area
Calgary	moderate	sour gas processing; large urban area

- b. Grande Prairie has high levels of NO_x emissions and low levels of SO₂ emissions. Power generation in this area does not use fuels containing sulfur. Electricity is produced outside the area, or it is produced using technologies that do not use combustion.
- c. Answers will vary. NO_x emissions will be high in major cities. SO₂ emissions are high, for example, in northern Manitoba due to metal extraction and in eastern Canada due to power generation that uses coal with a high sulfur content.

10. Your table should look like the following.

Source	Percentage	Mass of SO ₂ Emissions
transportation	4%	$2.4 \times 10^6 \times 4\% = 9.6 \times 10^4 \text{ t}$
electric utilities	27%	$2.4 \times 10^6 \times 27\% = 6.5 \times 10^5 \text{ t}$
fuel combustion	2%	$2.4 \times 10^6 \times 2\% = 4.8 \times 10^4 \text{ t}$
industrial sources	68%	$2.4 \times 10^6 \times 68\% = 1.6 \times 10^6 \text{ t}$
other	0.1%	$2.4 \times 10^6 \times 0.1\% = 2.4 \times 10^3 \text{ t}$

Practice, page 166

9. a. ionic compound
 b. acid
 c. molecular compound
 d. base
10. a. Your table should be similar to the following.

Apparatus	Used to Identify	Expected Result for a Positive Test	Expected Result for a Negative Test
conductivity meter	electrolytes	shows conductivity	does not show conductivity
red litmus paper	bases	paper turns blue	paper remains red
blue litmus paper	acids	paper turns red	paper remains blue

Note: Positive experimental controls demonstrating the intended results of a test are as valuable as negative experimental controls.

- b. **conductivity meter:** distilled water, non-conductive
red litmus: positive control: known basic solution, turns blue; negative control: distilled water or known acidic solution, remains red
blue litmus: positive control: blue litmus, turns red; negative control: distilled water or known basic solution, remains blue

Practice, page 169

11. Your table should look similar to the following.

Solution	Definition	Empirical Properties	Examples
acidic		<ul style="list-style-type: none"> • electrolytic • corrosive • turns blue litmus red • reacts with Mg(s) to produce hydrogen gas 	<ul style="list-style-type: none"> • HCl(aq) • HNO₃(aq) • H₂SO₄(aq) • CH₃COOH(aq)
basic		<ul style="list-style-type: none"> • electrolytic • corrosive • turns red litmus blue 	<ul style="list-style-type: none"> • NaOH(aq) • Na₂CO₃(aq)
neutral		<ul style="list-style-type: none"> • can be electrolytic • can be non-electrolytic • no reaction with litmus indicator 	<ul style="list-style-type: none"> • Na₂SO₄(aq) • NaCl(aq) • CH₃OH(aq)

Note: H₂S(aq) would be classified as a neutral solution based on the sample data provided in this TRG.

Practice, page 171

12. a. $\text{HNO}_3(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$
- b. $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow 2 \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$ or $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{HSO}_4^-(\text{aq})$
- c. $\text{H}_2\text{S}(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{HS}^-(\text{aq})$
- d. $\text{NaOH}(\text{aq}) \rightarrow \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq})$
- e. $\text{Na}_2\text{CO}_3(\text{aq}) \rightarrow 2 \text{Na}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- f. $\text{Na}_2\text{SO}_4(\text{aq}) \rightarrow 2 \text{Na}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$
- g. $\text{NaCl}(\text{aq}) \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$
13. $\text{HNO}_3(\text{aq})$, $\text{H}_2\text{SO}_4(\text{aq})$, and $\text{H}_2\text{S}(\text{aq})$ are acidic.

$\text{NaOH}(\text{aq})$ and $\text{Na}_2\text{CO}_3(\text{aq})$ are basic. Based on the equation in 12.e., this solution would be expected to be neutral because neither $\text{H}^+(\text{aq})$ nor $\text{OH}^-(\text{aq})$ are products. When tested, it was confirmed to be basic.

$\text{Na}_2\text{SO}_4(\text{aq})$ and $\text{NaCl}(\text{aq})$ are neutral.

Practice, page 175

14. a. $\text{HNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{NO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
acid base conjugate base conjugate acid
- b. $\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HCO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
acid base conjugate base conjugate acid

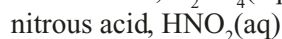
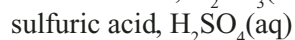
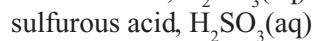
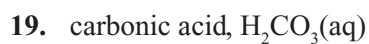
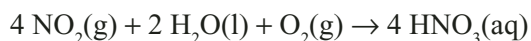
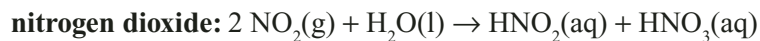
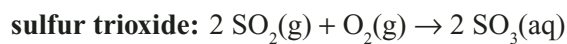
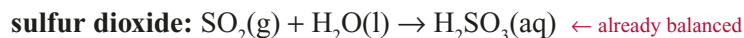
Practice, page 176

15. $\text{HOOC}(\text{COOH})(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{HOOC}(\text{COO}^-(\text{aq})) + \text{H}_2\text{O}(\text{l})$
acid base conjugate base conjugate acid

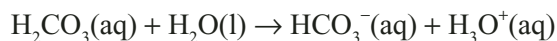
Practice, page 176

16. a. $\text{H}_2\text{SO}_4(\text{aq}) + \text{HCO}_3^-(\text{aq}) \rightarrow \text{HSO}_4^-(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq})$
acid base conjugate base conjugate acid
- b. $\text{NH}_3(\text{aq}) + \text{H}_3\text{PO}_4(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{H}_2\text{PO}_4^-(\text{aq})$
base acid conjugate acid conjugate base

17. The neutralization of an acid by a base occurs by the transfer of a hydrogen ion. By losing a hydrogen ion, the acid loses its acidic properties. The base becomes neutralized by gaining a hydrogen ion.

Practice, page 178

- 20.** All the products will react with water to produce hydronium ions, $\text{H}_3\text{O}^+(\text{aq})$, and make the precipitation acidic. Consider the following equation:



Practice, page 179

21. a. Your table may be similar to the following.

Latitude	Percentage of Emissions from . . .		Ratio (Anthropogenic to Natural)
	Anthropogenic Sources	Natural Sources	
75°N	34	66	1:2
60°N	90	10	9:1
45°N	92	8	11:1
30°N	87	13	7:1
15°N	41	59	8:3
0°	25	75	1:3
15°S	25	75	1:3
30°S	68	32	2:1
45°S	26	74	1:3
60°S	2	98	1:49
75°S	0	100	0:100

- b. Refer to the fourth column of the table in the answer to question 21.a.
- c. A ratio or percentage may not be sufficient information. Total emissions, not percentages or ratios, could identify areas where human-made or natural sources (e.g., volcanic eruptions) can overwhelm the environment. If only anthropogenic sources are considered, the possible areas of higher levels of acid deposition occur from 60°N to 30°N and 30°S. If only volcanic source are considered, a possible area is 0°.

Practice, page 183

22. a. $[\text{H}_3\text{O}^+(\text{aq})] = 0.001\ 00\ \text{mol/L}$ $\therefore \text{pH} = 3.000$
 $= 1.00 \times 10^{-3}\ \text{mol/L}$

This solution is acidic.

b. $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log_{10} (2.00 \times 10^{-4}\ \text{mol/L})$
 $= 3.699 \leftarrow 3\ \text{significant digits}$

The solution is acidic.

$$\begin{aligned} \text{c. } \text{pH} &= -\log_{10} [\text{H}_3\text{O}^+ (\text{aq})] \\ &= -\log_{10} (1.5 \times 10^{-6} \text{ mol/L}) \\ &= 5.82 \quad \leftarrow 2 \text{ significant digits} \end{aligned}$$

This solution is acidic.

$$\begin{aligned} \text{d. } \text{pH} &= -\log_{10} [\text{H}_3\text{O}^+ (\text{aq})] \\ &= -\log_{10} (1.35 \times 10^{-8} \text{ mol/L}) \\ &= 7.870 \quad \leftarrow 3 \text{ significant digits} \end{aligned}$$

This solution is approximately neutral or slightly basic.

$$\begin{aligned} \text{e. } \text{pH} &= -\log_{10} [\text{H}_3\text{O}^+ (\text{aq})] \\ &= -\log_{10} (1.54 \times 10^{-12} \text{ mol/L}) \\ &= 11.812 \quad \leftarrow 3 \text{ significant digits} \end{aligned}$$

This solution is basic.

$$\begin{aligned} 23. \text{ a. } [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\ &= 10^{-7.00} \\ &= 1.0 \times 10^{-7} \text{ mol/L} \quad \leftarrow 2 \text{ significant digits} \end{aligned}$$

$$\begin{aligned} \text{b. } [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\ &= 10^{-2.98} \\ &= 1.0 \times 10^{-3} \text{ mol/L} \quad \leftarrow 2 \text{ significant digits} \end{aligned}$$

$$\begin{aligned} \text{c. } [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\ &= 10^{-8.912} \\ &= 1.22 \times 10^{-9} \text{ mol/L} \quad \leftarrow 3 \text{ significant digits} \end{aligned}$$

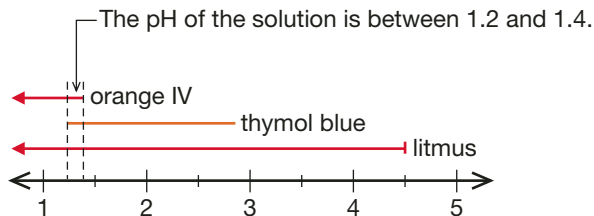
$$\begin{aligned} \text{d. } [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\ &= 10^{-13.1} \\ &= 8 \times 10^{-14} \text{ mol/L} \quad \leftarrow 1 \text{ significant digit} \end{aligned}$$

24. pH and Hydronium-Ion Concentration

		[H ₃ O ⁺ (aq)]	Relative Change in Hydronium-Ion Concentration with pH Value Below	Change in Hydronium-Ion Concentration over Entire Table	
Acidic	pH=0	battery acid	1 mol/L	10x more concentrated than next level below	
	pH=1	stomach lining	1×10^{-1} mol/L	10x more concentrated than next level below	
	pH=2	lemon juice	1×10^{-2} mol/L	10x more concentrated than next level below	
	pH=3	vinegar, orange juice, cola	1×10^{-3} mol/L	10x more concentrated than next level below	
	pH=4	tomato juice, acid rain	1×10^{-4} mol/L	10x more concentrated than next level below	
Neutral	pH=5	coffee (black), rain	1×10^{-5} mol/L	10x more concentrated than next level below	
	pH=6	urine, saliva (healthy), cow's milk	1×10^{-6} mol/L	10x more concentrated than next level below	
	pH=7	distilled water, human blood	1×10^{-7} mol/L	10x more concentrated than next level below	
Basic	pH=8	sea water	1×10^{-8} mol/L	10x more concentrated than next level below	
	pH=9	baking soda	1×10^{-9} mol/L	10x more concentrated than next level below	
	pH=10	milk of magnesia, detergent	1×10^{-10} mol/L	10x more concentrated than next level below	
	pH=11	ammonia solution, household cleaners	1×10^{-11} mol/L	10x more concentrated than next level below	
	pH=12	handsoap	1×10^{-12} mol/L	10x more concentrated than next level below	
	pH=13	bleaches, oven cleaner, household lye	1×10^{-13} mol/L	10x more concentrated than next level below	
	pH=14	liquid drain cleaner	1×10^{-14} mol/L		lowest [H ₃ O ⁺] concentration

Practice, page 186

25. Indicators are molecules that change colour as a response to different pH conditions. The pH at which an indicator undergoes a colour change is characteristic of that indicator. Generally, more than one indicator must be used to determine the pH of a solution. Matching indicator colours to pH ranges enables you to estimate a solution's pH.
26. Methyl orange appears red at pH values below 3.2. Since a pH below 7 is considered to be acidic, the statement is incorrect.
27. a.



The estimated pH of the solution is between 1.2 and 1.4.

$$\begin{array}{ll}
 \text{b. } \left[\text{H}_3\text{O}^+ (\text{aq}) \right] = 10^{-\text{pH}} & \left[\text{H}_3\text{O}^+ (\text{aq}) \right] = 10^{-\text{pH}} \\
 = 10^{-1.2} & = 10^{-1.4} \\
 = 0.06 \text{ mol/L} & = 0.04 \text{ mol/L}
 \end{array}$$

The hydronium-ion concentration is between 0.04 mol/L and 0.06 mol/L.

28. Bromocresol green is blue when the pH is 5.6, and thymol blue is yellow when the pH is 5.6. Mixing these two colours should produce a green solution.

1.2 Questions, page 187

Knowledge

1.
 - a. An acid is a substance that reacts with water to produce hydronium ions. It is a substance that transfers a hydrogen ion to a base during an acid-base reaction.
 - b. A base is a substance that reacts with water to produce hydroxide ions. It is a substance that accepts a hydrogen ion during an acid-base reaction.
 - c. Dissociation is the separation of ions in an ionic compound as it dissolves in water.
 - d. A hydrogen ion, $\text{H}^+(\text{aq})$, is the particle transferred from an acid to a base during an acid-base reaction, or it is a single proton.
 - e. A hydronium ion, $\text{H}_3\text{O}^+(\text{aq})$, is the particle produced when acids react with water.
 - f. The pH scale is a scale from 0 to 14 that ranks solutions according to their hydronium-ion concentration, where 0 represents the highest concentration (1.0 mol/L) and 14 represents the lowest concentration of hydronium ions (1.0×10^{-14} mol/L). **Note:** Highly concentrated solutions of some acids can have pH values that are negative.
 - g. Wet deposition consists of gases or particles removed from the atmosphere that dissolve in water (liquid or solid).
 - h. Acid deposition consists of airborne particles containing acids or acid-forming substances contained within precipitation (wet deposition) or that absorb directly into parts of Earth's surface (dry deposition).
 - i. Acid rain is any form of precipitation with a pH of 5.6 or less.
2.
 - a. $\text{H}_3\text{O}^+ (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{H}_2\text{O} (\text{l}) + \text{H}_2\text{O} (\text{l})$
 acid base conjugate conjugate
 base acid
 - b. $\text{CH}_3\text{COOH} (\text{aq}) + \text{NH}_3 (\text{aq}) \rightarrow \text{CH}_3\text{COO}^- (\text{aq}) + \text{NH}_4^+ (\text{aq})$
 acid base conjugate conjugate
 base acid

3.

Similarities	Differences
Solutes change in water to produce ions that make acidic and basic solutions conductive.	Arrhenius: ions are $\text{H}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$ Brønsted-Lowry: ions are $\text{H}_3\text{O}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$
Basic solutions contain $\text{OH}^-(\text{aq})$.	Arrhenius: $\text{OH}^-(\text{aq})$ produced Brønsted-Lowry: $\text{OH}^-(\text{aq})$ produced by a reaction of solute with water
Acidity involves the hydrogen ion, $\text{H}^+(\text{aq})$.	Arrhenius: $\text{H}^+(\text{aq})$ produced Brønsted-Lowry: $\text{H}_3\text{O}^+(\text{aq})$ produced by a reaction of solute to donate $\text{H}^+(\text{aq})$ to water
Both explain how some solutes can produce acidic and basic solutions.	Brønsted-Lowry: explains how a larger number of solutes can produce acidic or basic solutions

4. a. $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log_{10} (0.00125 \text{ mol/L})$
 $= 2.903 \leftarrow 3 \text{ significant digits}$

This solution is acidic.

c. $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log (4.42 \times 10^{-13} \text{ mol/L})$
 $= 12.355 \leftarrow 3 \text{ significant digits}$

This solution is basic.

e. $\text{pH} = -\log [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log (8.10 \times 10^{-8} \text{ mol/L})$
 $= 7.092 \leftarrow 3 \text{ significant digits}$

This solution is neutral.

5. a. $[\text{H}_3\text{O}^+(\text{aq})] = 10^{-\text{pH}}$
 $= 10^{-2.14}$
 $= 7.2 \times 10^{-3} \text{ mol/L} \leftarrow 2 \text{ significant digits}$

b. $[\text{H}_3\text{O}^+(\text{aq})] = 10^{-\text{pH}}$
 $= 10^{-7.1}$
 $= 8 \times 10^{-8} \text{ mol/L} \leftarrow 1 \text{ significant digit}$

c. $[\text{H}_3\text{O}^+(\text{aq})] = 10^{-\text{pH}}$
 $= 10^{-9.437}$
 $= 3.66 \times 10^{-10} \text{ mol/L} \leftarrow 3 \text{ significant digits}$

b. $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log_{10} (2.3 \times 10^{-9} \text{ mol/L})$
 $= 8.64 \leftarrow 2 \text{ significant digits}$

This solution is basic.

d. $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$
 $= -\log^{10} (5.6 \times 10^{-2} \text{ mol/L})$
 $= 1.25 \leftarrow 2 \text{ significant digits}$

This solution is acidic.

$$\begin{aligned} \text{d. } [\text{H}_3\text{O}^+(\text{aq})] &= 10^{-\text{pH}} \\ &= 10^{-11.00} \\ &= 1.0 \times 10^{-11} \text{ mol/L} \quad \leftarrow 2 \text{ significant digits} \end{aligned}$$

Applying Concepts

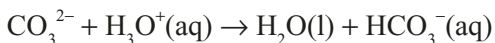
6. Similarities

- used when explaining the acidity of solutions
- contains a hydrogen nucleus
- particles have a net positive charge

Differences

- Arrhenius predicted the presence of hydrogen ions or protons in solution.
 - Hydrogen ions are dissociated by attractive forces to water molecules, not by bonds that involve the sharing of electrons.
 - Brønsted-Lowry predicted the presence of hydronium ions in acidic solutions.
 - A hydronium ion is formed by the sharing of electrons between a proton and an oxygen atom in a water molecule.
7. The carbonate ion, CO_3^{2-} , and the hydroxide ion, $\text{OH}^-(\text{aq})$, are both bases and are listed in the Conjugate Base Formula column of the “Table of Acids and Bases.” Empirical properties of bases include the ability to neutralize acids, form electrolytic solutions, and turn red litmus blue; feeling slippery; and tasting bitter.

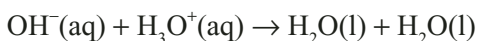
Reaction with Calcium Carbonate



OR



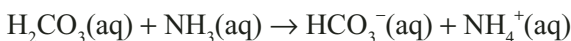
Reaction with Aluminium Hydroxide



8. Answers will vary. A sample answer is given.

Concentrated ammonia is corrosive, has a high pH, and can be neutralized by an acid. Ammonia also has a distinct and noxious odour that can overwhelm people. Possible actions to treat the spill include evacuating people downwind of the spill, ensuring proper safety equipment (such as breathing apparatus) for the cleanup crew, and neutralizing the spill with an acidic substance (most likely in solid form so as to not to add to the volume of the spill).

A variety of acids can be used. One example uses carbonic acid, $\text{H}_2\text{CO}_3(\text{aq})$.



9. If thymol blue is yellow, the pH of the solution is between 2.8 and 8.0. If bromocresol green is blue, the pH of the solution is greater than 5.4. Therefore, the pH of the solution is between 5.4 and 8.0.
- Methyl violet is blue between 5.4 and 8.0.
 - Indigo carmine is blue between 5.4 and 8.0.
 - Methyl orange is yellow between 5.4 and 8.0.
 - Alizarin yellow R is yellow between 5.4 and 8.0.
10. The statement is correct. Acids can be deposited as wet or dry deposition.
11.
 - Repeating an experiment and obtaining the same result demonstrates the reliability of the procedure.
 - Having a similar result to others who performed the same experiment using the same method demonstrates reliability.
 - Arriving at the same answer even though different approaches were taken demonstrates that the approaches are valid methods to use.
12. Your table should be similar to the following.

Solution	Definition	Empirical Properties	Examples
acidic	<ul style="list-style-type: none"> solution with a pH less than 7 substance that dissociates to produce $H^+(aq)$ substance that reacts with water to produce $H_3O^+(aq)$ substance that transfers a $H^+(aq)$ 	<ul style="list-style-type: none"> electrolytic corrosive turns blue litmus red reacts with $Mg(s)$ to produce hydrogen gas 	<ul style="list-style-type: none"> $HCl(aq)$ $HNO_3(aq)$ $H_2SO_4(aq)$ $CH_3COOH(aq)$
basic	<ul style="list-style-type: none"> solution with a pH greater than 7 substance that dissociates to produce $OH^-(aq)$ substance that reacts with water to produce $OH^-(aq)$ substance that accepts a $H^+(aq)$ 	<ul style="list-style-type: none"> electrolytic corrosive turns red litmus blue 	<ul style="list-style-type: none"> $NaOH(aq)$ $Na_2CO_3(aq)$
neutral	<ul style="list-style-type: none"> solution with a pH equal to 7 substance that does not produce $H^+(aq)$ or $OH^-(aq)$ when it dissociates substance that does not react with water to produce $H^+(aq)$ or $OH^-(aq)$ 	<ul style="list-style-type: none"> can be electrolytic can be non-electrolytic no reaction with litmus indicator 	<ul style="list-style-type: none"> $Na_2SO_4(aq)$ $NaCl(aq)$ $CH_3OH(aq)$

Practice, page 193

29. No, there is a range of abilities to neutralize acid deposition across Canada.
30. The highest potential for reducing acid deposition occurs in Alberta (except in the extreme north), the southern half of Saskatchewan, the southern half of Manitoba, part of northern Ontario, and Quebec.
31. Yes, there is a correlation between rock type (sedimentary) and higher potential to reduce acid input.
32. Regions in Canada with the least ability to reduce acid deposition include the coastal mountains of British Columbia, Districts of Mackenzie and Nunavut, southern Ontario, Quebec, most of Newfoundland and Labrador (except the west coast of Labrador), Nova Scotia, and parts of New Brunswick and Prince Edward Island.
33. Yes, rock types in more sensitive areas tend to be volcanic, intrusive, or metamorphic.
34. No, southern Alberta has a high potential, whereas northern Alberta has moderate potential and, in a few extreme northern locations, low acid-reducing potential.
35. Answers will vary. In areas with a high neutralizing capacity, pH should remain constant. In regions with a low neutralizing potential, there may be a lowering of soil and lake-water pH.
36.
 - a. Quebec, 82%
 - b. Alberta, 6%
 - c. Yes, Alberta has soils that are, for the most part, highly tolerant to acid inputs and few lakes that are sensitive. Quebec has few regions with soils that are highly tolerant and has a very high percentage of sensitive lakes.
 - d. Composition of soils and bedrock provide the ability to neutralize acid deposition. If substances are not present, then sensitivity to acid deposition will increase.

Practice, page 198

37.
 - a. chlorosis
 - b. The plant leaves are yellowing because the production of chlorophyll, a green pigment, is affected.
 - c. There are many possible reasons. Responses should generally indicate that there is a deficiency of the nutrients needed in the production of chlorophyll.
 - d. At a pH of 5.5, absorbable forms of many nutrients used in plant production are reduced. Therefore, it is possible that the yellowing is due to a lack of chlorophyll being produced by the plant.

$$38. \frac{\text{seal}}{\text{fish}} = \frac{3.0 \mu\text{g/g body mass}}{0.081 \mu\text{g/g body mass}} = 37 \qquad \frac{\text{polar bear}}{\text{seal}} = \frac{15 \mu\text{g/g body mass}}{3.0 \mu\text{g/g body mass}} = 5$$

The mercury in the seal is 37 times more concentrated than its prey (the fish), and the mercury concentration in the polar bear is 5 times more concentrated than its prey (the seal). Therefore, predator organisms in the food chain have concentrations much greater than that of their prey.

$$39. \text{ a. } \frac{\text{mercury in fish}}{\text{mercury in krill}} = 500$$

$$\text{mercury in krill} = \frac{\text{mercury in fish}}{500}$$

$$= \frac{0.081 \mu\text{g/g body mass}}{500}$$

$$= 1.6 \times 10^{-4} \mu\text{g/g body mass}$$

$$\text{ b. } \frac{\text{mercury in krill}}{\text{mercury in phytoplankton}} = 1000$$

$$\text{mercury in phytoplankton} = \frac{\text{mercury in krill}}{1000}$$

$$= \frac{1.6 \times 10^{-4} \mu\text{g/g body mass}}{1000}$$


$$= 1.6 \times 10^{-7} \mu\text{g/g body mass}$$

40. a. The data shows that the concentrations of mercury are higher in longer fish. It is assumed that the longer fish were older fish, since fish will increase in size over their lifetime.
- b. Older fish have been eating prey that may contain mercury over a longer period of time. Therefore, the older fish have had the opportunity to accumulate more mercury.
- c. One experimental control is that the fish are the same species. Another is that all the fish are from the same lake. The importance of the control is to ensure that the mercury level is due to the age, not the type of fish or the particular lake where the fish are found.

1.3 Questions, pages 201 and 202

Knowledge

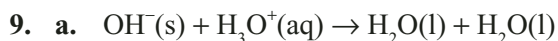
1. a. The jet stream is the border between air masses along which wind patterns travel.
- b. Alkaline means having the properties of a base.
- c. Minerals are inorganic chemical components within the soil that are usable by plants.
- d. Buffering is the neutralization of an acid or a base by a substance.
- e. Buffering capacity is the relative amount of acid or base that can be neutralized by a buffer.
- f. Biogeochemical cycles are a series of reactions and conversions of certain elements within ecosystems.

- g. Leaching is the removal by water of metal ions from topsoil. Leaching involves the reaction of minerals in the soil with acids to make metal ions soluble in runoff water.
 - h. Biomagnification is the process by which the concentration of a substance successively increases as you move up a food chain.
 - i. Biodiversity is the range of organisms within an ecosystem.
2. An inverse relationship exists. As the concentration of $\text{SO}_2(\text{g})$ increases, there is an increase in the concentration of sulfuric acid in rainfall. The increased concentration of sulfuric acid results in a higher concentration of hydronium ions in rainwater. Because pH is calculated as $-\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$, a higher concentration of $[\text{H}_3\text{O}^+(\text{aq})]$ results in a lower pH.
 3.
 - a. Sedimentary rock has a high buffering capacity.
 - b. Sedimentary rock contains calcium carbonate (limestone) or magnesium carbonate (gypsum).
 - c. $\text{H}_3\text{O}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$

 4. Contributions to the occurrence of acid deposition in eastern Canada are
 - soil with a low ability to neutralize acid deposition
 - large population and industry in the area
 - wind patterns that draw pollution from northeastern US
 5. No, natural mechanisms, like gases emitted from volcanic activity, produce emissions of SO_2 .

Applying Concepts

6.
 - a. Answers will vary. One possibility is that an increase in the emission of $\text{SO}_2(\text{g})$ will result in a lowering of the pH of precipitation downwind of the emission's source.
 - b. The collection and measurement of pH of rainfall in areas upwind and downwind of the source would need to be done. Plant life in areas upwind and downwind could be compared to identify any differences in abundance or type.
 - c. You can consult with individuals from First Nations, Métis, or Inuit groups in your community.
 - d. The information will most likely be descriptive and reflect observations of subtle and larger changes. The information may also contain interpretations of how aspects might be connected or may influence one another.
7. Nutrient availability is dependent on pH. At certain soil pH ranges, nutrients exist in forms that are available for plants. At pH levels outside these ranges, nutrients may be present in the soil but may not be available in a form that can be absorbed by the roots of plants. As a result, they are not able to assist plant growth and development. Another possibility is that it is too dry. A third possibility is that it contains chemicals that discourage the growth of plants.

8. a. $\text{CaCO}_3(\text{s})$ in soil was reacting with the acids in the acid rain. The carbonate ions react, leaving the Ca^{2+} ions in the soil.
- b. Soil sample 3, late stages of acidification, has a ratio of 0.2:1. This is the same as stating a ratio of 1:5, indicating that the concentration of Al^{3+} ions is five times higher than the concentration of Ca^{2+} ions. Ratios here can be misleading as they do not provide exact concentrations.



- b. The combination of OH^- and H_3O^+ leave the aluminium unbound and soluble. Once dissolved in water, aluminium ions are able to leach as water moves.

10. a. **Liver Concentrations**

$$\frac{\text{liver of seal}}{\text{liver of fish}} = \frac{3.0 \mu\text{g/g body mass}}{0.080 \mu\text{g/g body mass}}$$

$$= 38$$

$$\frac{\text{liver of polar bear}}{\text{liver of seal}} = \frac{15 \mu\text{g/g body mass}}{3.0 \mu\text{g/g body mass}}$$

$$= 5.0$$

Kidney Concentrations

$$\frac{\text{kidney of seal}}{\text{kidney of fish}} = \frac{1.2 \mu\text{g/g body mass}}{0.080 \mu\text{g/g body mass}}$$

$$= 15$$

$$\frac{\text{kidney of polar bear}}{\text{kidney of seal}} = \frac{15 \mu\text{g/g body mass}}{1.2 \mu\text{g/g body mass}}$$

$$= 13$$

Liver and kidney concentrations show that biomagnification occurs.

- b. Certain tissues or organs may accumulate the substance. In this example, it appears the kidney and liver accumulate mercury at a higher rate than muscle does.
- c. Other scientists studying biomagnifications may choose to test kidneys and livers for mercury. Other scientists may choose to investigate whether other organs demonstrate bioaccumulation.
11. Decomposers perform a vital function within ecosystems. Decomposition is an important part of the cycling of matter. Without the conversion of matter into forms usable by producers and other organisms, reactions involving certain forms of matter may be impacted.

Practice, page 203

41. Your answer can be summarized in a table.

Information	Qualitative Data	Quantitative Data
spots present on surfaces of leaves	✓	
population sizes of organisms within the ecosystem		✓
information from hunters and inhabitants within the area	✓	
number of plants demonstrating chlorosis		✓
soil pH		✓
concentration of $\text{Al}^{3+}(\text{aq})$ in soil and water		✓
population of young fish		✓
observations of fish health	✓	
list of insect populations within the area	✓	
list of plant species within the area	✓	

Practice, page 211

42. a. **Burette I:** 4.34 mL
Burette II: 20.55 mL
Burette III: 25.11 mL
Burette IV: 45.94 mL

Note: Acceptable readings include those within ± 0.01 mL of the values given here.

b.
$$V_{\text{used}} = V_{\text{II}} - V_{\text{I}}$$

$$= 20.55 \text{ mL} - 4.34 \text{ mL}$$

$$= 16.21 \text{ mL}$$

c.
$$V_{\text{used}} = V_{\text{IV}} - V_{\text{III}}$$

$$= 45.94 \text{ mL} - 25.11 \text{ mL}$$

$$= 20.83 \text{ mL}$$

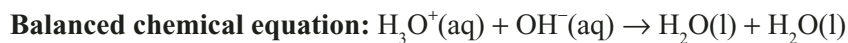
The volumes of solution delivered from the burette in the two trials are not similar. Trials should agree within 0.2 mL in a titration if the technique has been done in a similar manner for both trials.

$$43. \quad V_{\text{OH}^-} = 12.13 \text{ mL} - 2.25 \text{ mL} \qquad V_{\text{H}_3\text{O}^+} = 10.00 \text{ mL} - \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 9.88 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \qquad = 0.01000 \text{ L}$$

$$= 0.00988 \text{ L} \qquad C_{\text{H}_3\text{O}^+} = ?$$

$$C_{\text{OH}^-} = 0.000125 \text{ mol/L}$$



Since the ratio of hydronium reacted to hydroxide reacted is 1:1,

$$n_{\text{H}_3\text{O}^+} = n_{\text{OH}^-}$$

$$C_{\text{H}_3\text{O}^+} V_{\text{H}_3\text{O}^+} = C_{\text{OH}^-} V_{\text{OH}^-}$$

$$C_{\text{H}_3\text{O}^+} = \frac{C_{\text{OH}^-} V_{\text{OH}^-}}{V_{\text{H}_3\text{O}^+}}$$

$$= \frac{(0.000125 \text{ mol/L})(0.00988 \text{ L})}{0.01000 \text{ L}}$$

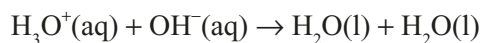
$$= 1.24 \times 10^{-4} \text{ mol/L}$$

The hydronium-ion concentration in the lake water is $1.24 \times 10^{-4} \text{ mol/L}$.

$$44. \quad \text{a.} \quad V_{\text{OH}^-} = 44.5 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \qquad V_{\text{H}_3\text{O}^+} = 75.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.0445 \text{ L} \qquad = 0.075 \text{ L}$$

$$C_{\text{OH}^-} = 0.125 \text{ mol/L} \qquad C_{\text{H}_3\text{O}^+} = ?$$



Since the ratio of hydronium reacted to hydroxide reacted is 1:1,

$$n_{\text{H}_3\text{O}^+} = n_{\text{OH}^-}$$

$$C_{\text{H}_3\text{O}^+} V_{\text{H}_3\text{O}^+} = C_{\text{OH}^-} V_{\text{OH}^-}$$

$$C_{\text{H}_3\text{O}^+} = \frac{C_{\text{OH}^-} V_{\text{OH}^-}}{V_{\text{H}_3\text{O}^+}}$$

$$= \frac{(0.125 \text{ mol/L})(0.0445 \text{ L})}{0.0750 \text{ L}}$$

$$= 0.0741666667 \text{ mol/L}$$

$$= 0.0742 \text{ mol/L}$$

The hydronium-ion concentration in the lake water is 0.0742 mol/L .

$$\begin{aligned}
 \text{b. } \text{pH} &= -\log_{10} [\text{H}_3\text{O}^+ (\text{aq})] \\
 &= -\log_{10} (0.074\ 166\ 666\ 7\ \text{mol/L}) \\
 &= 1.130 \quad \leftarrow 3 \text{ significant digits}
 \end{aligned}$$

The waste-water sample has a pH of 1.130.

Practice, page 215

45. **strong acids:** sulfuric acid, $\text{H}_2\text{SO}_4(\text{aq})$; nitric acid, $\text{HNO}_3(\text{aq})$

weak acids: sulfurous acid, $\text{H}_2\text{SO}_3(\text{aq})$; nitrous acid, $\text{HNO}_2(\text{aq})$

46. **Ethanoic Acid:** Answers may vary depending on the results obtained in the activity.

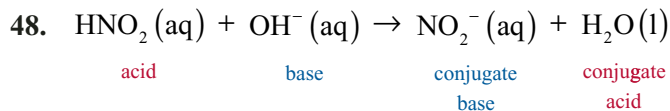
$$\begin{aligned}
 \text{pH} &= 2.5 & [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\
 [\text{H}_3\text{O}^+ (\text{aq})] &= ? & &= 10^{-2.5} \\
 & & &= 0.003\ \text{mol/L or } 3 \times 10^{-3}\ \text{mol/L} \quad \leftarrow 1 \text{ significant digit}
 \end{aligned}$$

Hydrochloric Acid

$$\begin{aligned}
 \text{pH} &= 0 & [\text{H}_3\text{O}^+ (\text{aq})] &= 10^{-\text{pH}} \\
 [\text{H}_3\text{O}^+ (\text{aq})] &= ? & &= 10^{-0} \\
 & & &= 1\ \text{mol/L} \quad \leftarrow 1 \text{ significant digit}
 \end{aligned}$$

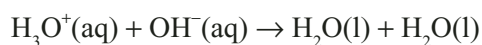
47. The statement is supported. The hydronium-ion concentrations calculated in question 46 demonstrate the difference.

Acid	Type of Acid	pH	Relative H_3O^+ Concentration
hydrochloric acid $\text{HCl}(\text{aq})$	strong	0	higher (1 mol/L)
ethanoic acid $\text{CH}_3\text{COOH}(\text{aq})$	weak	2.5	lower (3×10^{-3} mol/L)

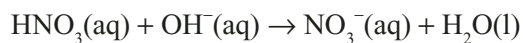


Practice, page 217

49. Nitric acid is a strong acid and reacts completely with water to produce hydronium ions. The balanced chemical equation for this reaction could be expressed as either



OR



The proportion of acid reacted to base reacted is 1:1.

Calculate the concentration of the hydronium ions, or nitric acid.

$$C_{\text{OH}^-} = 0.0130 \text{ mol/L}$$

$$V_{\text{OH}^-} = 27.3 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ = 0.0273 \text{ L}$$

$$V_{\text{HNO}_3} = 50.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ = 0.0500 \text{ L}$$

$$C_{\text{HNO}_3} = ?$$

$$n_{\text{OH}^-} = n_{\text{HNO}_3}$$

$$C_{\text{OH}^-} V_{\text{OH}^-} = C_{\text{HNO}_3} V_{\text{HNO}_3}$$

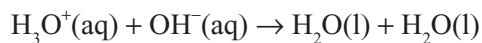
$$C_{\text{HNO}_3} = \frac{C_{\text{OH}^-} V_{\text{OH}^-}}{V_{\text{HNO}_3}}$$

$$= \frac{(0.0130 \text{ mol/L})(0.0273 \text{ L})}{(0.0500 \text{ L})}$$

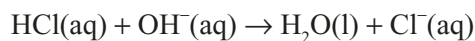
$$= 0.00710 \text{ mol/L or } 7.10 \times 10^{-3} \text{ mol/L}$$

The concentration of the hydronium ions and the nitric acid is $7.10 \times 10^{-3} \text{ mol/L}$.

50. Hydrochloric acid is a strong acid and reacts completely with water to produce hydronium ions. The balanced chemical equation for this reaction could be expressed as either



OR



The proportion of acid reacted to base reacted is 1:1.

Calculate the concentration of the sodium hydroxide.

$$C_{\text{HCl}} = 0.0200 \text{ mol/L}$$

$$V_{\text{HCl}} = 33.6 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.0336 \text{ L}$$

$$V_{\text{OH}^-} = 25.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.0250 \text{ L}$$

$$C_{\text{OH}^-} = ?$$

$$n_{\text{HCl}} = n_{\text{OH}^-}$$

$$C_{\text{HCl}} V_{\text{HCl}} = C_{\text{OH}^-} V_{\text{OH}^-}$$

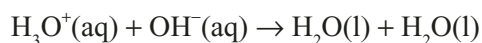
$$C_{\text{OH}^-} = \frac{C_{\text{HCl}} V_{\text{HCl}}}{V_{\text{OH}^-}}$$

$$= \frac{(0.0200 \text{ mol/L})(0.0336 \text{ L})}{(0.0250 \text{ L})}$$

$$= 0.0269 \text{ mol/L}$$

The concentration of the sodium hydroxide is 0.0269 mol/L.

51. Assume the acid is $\text{H}_3\text{O}^+(\text{aq})$.



The proportion of acid reacted to base reacted is 1:1.

Calculate the volume of sodium hydroxide required.

$$C_{\text{H}_3\text{O}^+} = 0.100 \text{ mol/L}$$

$$V_{\text{H}_3\text{O}^+} = 2.00 \text{ L}$$

$$C_{\text{OH}^-} = 0.150 \text{ mol/L}$$

$$V_{\text{OH}^-} = ?$$

$$n_{\text{H}_3\text{O}^+} = n_{\text{OH}^-}$$

$$C_{\text{H}_3\text{O}^+} V_{\text{H}_3\text{O}^+} = C_{\text{OH}^-} V_{\text{OH}^-}$$

$$V_{\text{OH}^-} = \frac{C_{\text{H}_3\text{O}^+} V_{\text{H}_3\text{O}^+}}{C_{\text{OH}^-}}$$

$$= \frac{(0.100 \text{ mol/L})(2.00 \text{ L})}{0.150 \text{ mol/L}}$$

$$= 1.33 \text{ L}$$

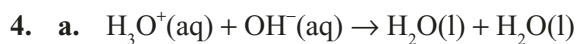
The volume of sodium hydroxide required is 1.33 L.

1.4 Questions, page 221

Knowledge

1.
 - a. An indicator is a substance that undergoes a colour change as a response to a change in the pH.
 - b. A titration is a technique used to find the concentration of a substance in a solution by adding measured quantities of another substance that it is known to react with until an endpoint is reached.
 - c. A burette is specialized glassware that is graduated to measure the volume of a standardized solution added to a test solution during a titration.
 - d. An Erlenmeyer flask is a conical-shaped flask in which the test solution and indicator are placed during a titration.
 - e. An endpoint is the point in a titration where the indicator changes colour. The endpoint signals the addition of enough standard solution to completely neutralize the reactant in the test solution.
 - f. A pH meter is a device used to measure pH based on conductivity as determined by the concentration of hydronium ions.
2. Acids react with water to different extents. Strong acids react completely with water, whereas weak acids only react partially, producing solutions with higher pH values than would be predicted by the molar concentration of acid in the solution.
3. The strong acids listed on the “Table of Acids and Bases” are HCl(aq), H₂SO₄(aq), and HNO₃(aq). Strong acids react completely with most bases. This allows for the use of titration data to obtain information about the base solution being tested.

Applying Concepts



The proportion of acid reacted to base reacted is 1:1.

Calculate the hydronium-ion concentration.

$$C_{\text{OH}^-} = 0.100 \text{ mol/L}$$

$$V_{\text{OH}^-} = 16.7 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ = 0.0167 \text{ L}$$

$$V_{\text{H}_3\text{O}^+} = 10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ = 0.0100 \text{ L}$$

$$C_{\text{H}_3\text{O}^+} = ?$$

$$n_{\text{OH}^-} = n_{\text{H}_3\text{O}^+}$$

$$C_{\text{OH}^-} V_{\text{OH}^-} = C_{\text{H}_3\text{O}^+} V_{\text{H}_3\text{O}^+}$$

$$C_{\text{H}_3\text{O}^+} = \frac{C_{\text{OH}^-} V_{\text{OH}^-}}{V_{\text{H}_3\text{O}^+}}$$

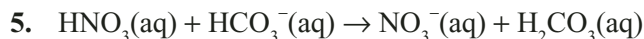
$$= \frac{(0.100 \text{ mol/L})(0.0167 \text{ L})}{(0.0100 \text{ L})}$$

$$= 0.167 \text{ mol/L}$$

The hydronium-ion concentration is 0.167 mol/L.

$$\begin{aligned} \text{b. } \text{pH} &= -\log_{10} [\text{H}_3\text{O}^+(\text{aq})] \\ &= -\log_{10} (0.167 \text{ mol/L}) \\ &= 0.777 \end{aligned}$$

The pH of the acid is 0.777.



The proportion of acid reacted to base reacted is 1:1.

Calculate the volume of base needed.

$$C_{\text{HNO}_3} = 2.50 \text{ mol/L}$$

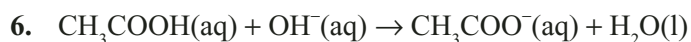
$$\begin{aligned} V_{\text{HNO}_3} &= 60.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ &= 0.0600 \text{ L} \end{aligned}$$

$$C_{\text{HCO}_3^-} = 0.145 \text{ mol/L}$$

$$V_{\text{HCO}_3^-} = ?$$

$$\begin{aligned} n_{\text{HNO}_3} &= n_{\text{HCO}_3^-} \\ C_{\text{HNO}_3} V_{\text{HNO}_3} &= C_{\text{HCO}_3^-} V_{\text{HCO}_3^-} \\ V_{\text{HCO}_3^-} &= \frac{C_{\text{HCO}_3^-} V_{\text{HCO}_3^-}}{C_{\text{HNO}_3}} \\ &= \frac{(2.50 \text{ mol/L})(0.0600 \text{ L})}{(0.145 \text{ mol/L})} \\ &= 1.03 \text{ L} \end{aligned}$$

The volume of base needed is 1.03 L.



The proportion of acid reacted to base reacted is 1:1.

Calculate the concentration of the ethanoic acid.

$$C_{\text{OH}^-} = 0.108 \text{ mol/L}$$

$$\begin{aligned} V_{\text{OH}^-} &= 7.55 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ &= 0.00755 \text{ L} \end{aligned}$$

$$\begin{aligned} V_{\text{CH}_3\text{COOH}} &= 10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ &= 0.0100 \text{ L} \end{aligned}$$

$$C_{\text{CH}_3\text{COOH}} = ?$$

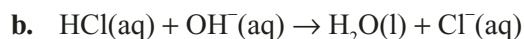
$$\begin{aligned} n_{\text{OH}^-} &= n_{\text{CH}_3\text{COOH}} \\ C_{\text{OH}^-} V_{\text{OH}^-} &= C_{\text{CH}_3\text{COOH}} V_{\text{CH}_3\text{COOH}} \\ C_{\text{CH}_3\text{COOH}} &= \frac{C_{\text{OH}^-} V_{\text{OH}^-}}{V_{\text{CH}_3\text{COOH}}} \\ &= \frac{(0.108 \text{ mol/L})(0.00755 \text{ L})}{(0.0100 \text{ L})} \\ &= 0.0815 \text{ mol/L} \end{aligned}$$

The concentration of ethanoic acid in the vinegar solution is 0.0815 mol/L.

7. a. Complete the table.

Trial	Volume of Standard Solution (mL)			Endpoint Colour
	Final	Initial	Added	
1	13.61	1.72	11.89	dark pink
2	25.68	13.67	12.01	light pink
3	37.55	25.64	11.91	light pink

$$\begin{aligned} \text{average volume added} &= \frac{11.89 \text{ mL} + 12.01 \text{ mL} + 11.91 \text{ mL}}{3} \\ &= 11.966\ 666\ 7 \text{ mL} \\ &= 11.9 \text{ mL} \end{aligned}$$



The proportion of acid reacted to base reacted is 1:1.

Calculate the concentration of the hydrochloric acid.

$$C_{\text{OH}^{\text{-}}} = 0.0567 \text{ mol/L}$$

$$\begin{aligned} V_{\text{OH}^{\text{-}}} &= 11.936\ 666\ 67 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ &= 0.011\ 936\ 666\ 67 \text{ L} \end{aligned}$$

$$\begin{aligned} V_{\text{HCl}} &= 10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \\ &= 0.0100 \text{ L} \end{aligned}$$

$$C_{\text{HCl}} = ?$$

$$\begin{aligned} n_{\text{OH}^{\text{-}}} &= n_{\text{HCl}} \\ C_{\text{OH}^{\text{-}}} V_{\text{OH}^{\text{-}}} &= C_{\text{HCl}} V_{\text{HCl}} \\ C_{\text{HCl}} &= \frac{C_{\text{OH}^{\text{-}}} V_{\text{OH}^{\text{-}}}}{V_{\text{HCl}}} \\ &= \frac{(0.0567 \text{ mol/L})(0.011\ 936\ 666\ 67 \text{ L})}{(0.0100 \text{ L})} \\ &= 0.0677 \text{ mol/L} \end{aligned}$$

The concentration of the hydrochloric acid is 0.0677 mol/L.

8. The data from Titration 1 has more consistent results. Consistent results increase the confidence of the data obtained during a titration. Obtaining a similar result for each trial suggests that the result obtained is correct.
9. Answers will vary. Two ways of improving your titration techniques are given.
- taking careful measurements of the volumes added in each trial by paying close attention to the position of the meniscus and properly reading the measured volume
 - ensuring that the trials have a similar colour intensity and shade when detecting the endpoint of a titration

Practice, page 222

52. sulfur produced = tar sand extracted \times 5%

$$\begin{aligned} \text{tar sand extracted} &= \frac{\text{sulfur produced}}{5\%} \\ &= \frac{15\,000\,000\text{ t}}{0.05} \\ &= 300\,000\,000\text{ t} \end{aligned}$$

Approximately 300 million tonnes of tar sand are extracted yearly.

Practice, page 229

53. Lead is a substance that accumulates within organisms and can undergo biomagnification within a food chain. At higher concentrations, lead can be toxic. Evidence has shown that lead affects brain function in children, resulting in learning disabilities to those who are exposed to it.

Sulfur reduction lowers SO₂ emissions, particulate emissions, and hydrocarbon emissions from automobiles.

54. The behaviour that provides the best pollution reduction is parking the car and turning off the engine while waiting for a friend.
55. The combustion of fuels in any high-temperature engine produces NO_x, hydrocarbons, and carbon monoxide. Prolonged exposure to these compounds will cause adverse health effects, such as reducing the oxygen-carrying capability of red blood cells. Catalytic converters will reduce the concentration of these substances in the air at the workplace, thereby preventing exposure to workers.
56. a. Your table should look like the following.

Substance	Relative Concentration of Substance in Exhaust	
	Before Catalytic Converter	After Catalytic Converter
CO	high	low
NO _x	high	low
H ₂ O	low	high

- b. Testing for one substance is more efficient and requires less calibration and set-up for the sensors. Since the catalytic converter uses oxygen present in the system to convert CO into CO₂ and hydrogen into H₂O, a change in oxygen levels indicates this function is being performed. The change in the concentration of oxygen before and after the catalytic converter is an indirect test of the device's performance, but is significant in demonstrating that the device is functioning and performing its task.

Practice, page 230

57. a. The exhaust produced during morning rush hour causes an increase in the concentration of NO and some increase to the concentration of NO₂. The increase in concentration of hydrocarbons is due to unburned hydrocarbons (also from automobile exhaust).

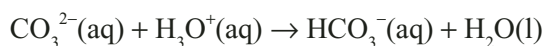
- b. The reaction that converts NO into NO₂ requires energy from sunlight. Later in the morning, sufficient energy from sunlight is available to cause the NO that has accumulated to react.
- c. The reaction that forms ozone consumes the other substances. As in most chemical reactions, to form products you must use up reactants; and during such processes, the concentration of reactants normally decreases.
- d. In the late afternoon and evening, the intensity of solar radiation decreases; therefore, it would be expected that less photochemical smog and ground-level ozone would be produced. On days when the air over a city does not move, higher-than-normal amounts of photochemical smog and ground-level ozone can be created because of the accumulation of NO_x and hydrocarbons from many days.

Practice, page 231

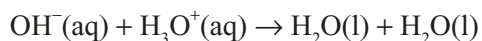
58. The bases used for liming include

- calcium oxide, CaO(s)
- calcium carbonate, CaCO₃(s)
- calcium hydroxide, Ca(OH)₂(s)
- magnesium carbonate, MgCO₃(s)

59. a. This neutralization reaction involves carbonate.



b. This neutralization reaction involves hydroxide.



Note: Oxides are basic compounds that react first with water to produce hydroxide ions. The hydroxide ions then react with hydronium ions as described in the preceding reaction.

1.5 Questions, page 235

Knowledge

- Answers will vary. Examples include heating your home, driving a car, and using electrical devices.
- Since most of the energy produced for society comes from combustion reactions, conserving energy will reduce the need to combust fuels that produce SO₂ and NO_x emissions. Likewise, supporting the development of technologies that produce electricity through non-combustion processes will also reduce the need to combust fuels that produce SO₂ and NO_x emissions.

Technologies like scrubbers have made a considerable impact on reducing emissions. Supporting companies and facilities that use processes like these may result in reducing emissions even more.

Tremendous quantities of paper, metal, and plastic are used by society. The processes used to make these products require a great deal of energy and, thus, the combustion of a large amount of fossil fuels. Recycling these products requires less energy than producing them from raw materials.

3. The conditions and substances necessary for the development of photochemical smog are NO, NO₂, and sunlight.
4. Technologies that reduce SO₂ emissions include scrubbers and washing (reducing sulfur in coal). Technologies that reduce NO_x emissions involve decreasing the temperature of combustion and the use of catalysts.

Applying Concepts

5.
 - a. Sulfate levels are the result of reactions that occur between SO₂ and water to form sulfuric acid.
 - b. Ontario and Quebec appear to have benefited the most. Atlantic Canada appears to have shown little improvement. One possible reason is that the emitting industries in Canada are most likely located in Ontario and Quebec. The Atlantic provinces may be receiving emissions from the United States via the jet stream. If emission reductions have not occurred in the United States, it would be reasonable to expect little change to the amount of deposition in the Atlantic provinces.
 - c. Detailed data describing both biotic and abiotic factors would need to be seen. All aspects of the ecosystem must be assessed in order to determine whether the ecosystem has recovered.
 - d. The pH in some lakes is still decreasing (increasing the concentration of hydronium ions).
 - e. Since sulfate levels are used to provide information regarding the level of acid deposition (from sulfuric acid), changes to sulfate levels present in lake water should correlate with a change in acidity of the lake. The change in acidity is a sign of improving or declining quality of the lake water.

The data for the Ontario lakes indicates that sulfate levels are improving or are stable (interpreted as decreasing or remaining constant but not increasing in concentration), which correlates with the data showing that over 80% of the lakes are improving with respect to acidity (assumed pH is not increasing or decreasing). A weaker correlation is seen in the lakes in Quebec, with fewer lakes improving in terms of acidity. It could be assumed that the lack of improvement is due to the larger number of “stable lakes.” (Acidity is not changing. This is probably because sulfate levels have not reduced; they have just remained the same.)

6.
 - a. Answers will vary. Some advantages and disadvantages are given.

advantages: The program focuses on automobiles that would be a significant source of NO_x due to Calgary’s large area (the need to drive to conduct business and other activities) and population. The program offers incentives (monetary) that are often effective in promoting participation.

disadvantages: The incentives may not be relevant to reducing emissions (reducing the cost of auto repairs and tune-ups or increasing the use of public transport or other means of transport that reduces emissions).
 - b. Answers will vary. Reasons for the program to no longer exist may include a lack of purpose or a lack of perceived benefit on the part of participants.
 - c. This program was voluntary. A similar program may work if there are proper rewards or incentives and if it captures public interest through effective advertising.
7. The ability to access up-to-date air-quality information is important to people who have respiratory conditions, such as asthma. The information could be used to make decisions about the level of risk in participating in outdoor activities, where breathing difficulties may occur.

8. The Air Quality Index (AQI) is calculated every hour for each substance using the formulas indicated in the table. The highest number calculated for a specific hour is used as the AQI for that hour.

Substance	Concentration	Units	Formula
carbon monoxide	if ≤ 13	ppm	$AQI = 19.2 \times \text{concentration}$
	if > 13	ppm	$AQI = 1.47 \times \text{concentration} + 5.88$
ozone	if ≤ 0.05	ppm	$AQI = 500 \times \text{concentration}$
	if > 0.05 and ≤ 0.08	ppm	$AQI = 833 \times \text{concentration} - 16.67$
	if > 0.08	ppm	$AQI = 714 \times \text{concentration} - 7.14$
sulfur dioxide	all	ppm	$AQI = 147.06 \times \text{concentration}$
nitrogen dioxide	if ≤ 0.21	ppm	$AQI = 238.09 \times \text{concentration}$
	if > 0.21	ppm	$AQI = 156.24 \times \text{concentration} + 17.19$
respirable particulate matter ($PM_{2.5}$)	if ≤ 30	$\mu\text{g}/\text{m}^3$	$AQI = 0.8333 \times \text{concentration}$
	if > 30	$\mu\text{g}/\text{m}^3$	$AQI = 0.5 \times \text{concentration} + 10$

Values for AQI can be categorized as

- Good: 0 to 31
- Moderate: 32 to 49
- Poor: 50+

If poor readings are predicted to be sustained over a period of time and over a wide area, a smog alert is issued for that area. There are two kinds of smog alerts: a smog watch and a smog advisory. A smog watch is issued when there is at least a 50% probability that smog conditions will occur within the next three days. A smog advisory is issued when there is a high probability of elevated smog levels occurring within the next 24 hours or if smog conditions happen without warning.

For further information, visit

- <http://www.weathernetwork.ca>
- <http://www.casahome.org/>
- <http://www3.gov.ab.ca/env/air/AmbientAirMonitoring/currentairquality.html>

9. Answers will vary. Responses should indicate an acceptance that as long as processes that produce pollution are used, there is a responsibility to attempt to protect the environment. Rather than investing in developing processes that clean up emissions, alternatives are to invest in developing processes that do not generate emissions or in processes that use wastes from one process to make other desirable products.