TOPIC 4:
CHEMICAL EQUILIBRIUM

Topic 4: Chemical Equilibrium

C12-4-01 Relate the concept of equilibrium to physical and chemical systems.

Include: conditions necessary to achieve equilibrium

C12-4-02 Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems.

Include: mass action expression

C12-4-03 Use the value of the equilibrium constant (K_{eq}) to explain how far a system at equilibrium has gone towards completion.

C12-4-04 Solve problems involving equilibrium constants.

C12-4-05 Perform a laboratory activity to determine the equilibrium constant of an equilibrium system.

C12-4-06 Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentration, the addition of a catalyst, the addition of an inert gas, and the effects of various stresses on the equilibrium constant

C12-4-07 Perform a laboratory activity to demonstrate Le Châtelier's principle.

C12-4-08 Interpret concentration versus time graphs.

Include: temperature changes, concentration changes, and the addition of a catalyst

C12-4-09 Describe practical applications of Le Châtelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, arrangement of produce, carbonated beverages in a hen's diet . . .

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11 Solve problems involving K_{sp}.

Include: common ion problems

C12-4-12 Describe examples of the practical applications of salts with low solubility.

Examples: kidney stones, limestone caverns, osteoporosis, tooth decay . . .

C12-4-13 Perform a laboratory activity to determine the K_{sp} of a salt with low solubility.

Suggested Time: 17 hours

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-01: Relate the concept of equilibrium to physical and chemical systems.

Include: conditions necessary to achieve equilibrium

(1 hour)

SLO: C12-4-01

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 9 Science (S1-2-12), students were introduced to the difference between physical and chemical changes. In Grade 11 Chemistry (C11-1-05, C11-1-06), students were introduced to the concept of equilibrium with respect to the rates of evaporation and condensation of a liquid in a closed container. They further developed analogies to help them understand the concept.

Assessing Prior Knowledge

Check for students' prior knowledge, and review concepts as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

Activation Demonstration: Blue Bottle Reaction

Introduce the topic of chemical equilibrium with a demonstration showing the reversibility of chemical reactions. The classic blue bottle reaction demonstration clearly shows a reversible reaction. In a 1000 mL Erlenmeyer flask, dissolve 14 g of sodium hydroxide (NaOH) in 700 mL distilled water. Add 14 g of dextrose (or glucose) and 1 mL methylene blue to the NaOH solution. Stopper the flask tightly. Shake it vigorously and observe that the solution turns blue. Allow the solution to sit, and observe that the colour clears. This system involves the oxidation of dextrose (or glucose) by oxygen (caused by shaking the flask). The methylene blue acts as a catalyst for this reaction. Have students describe the reaction in the flask and speculate why the solution does not stay blue.

Demonstrations of the blue bottle reaction can be viewed on various websites.

Sample Website:

The North Carolina School of Science and Mathematics (NCSSM). "Chapter 14: Gas Phase, Solubility, Complex Ion Equilibria." *Chemistry Online Resource Essentials (CORE).* <www.dlt.ncssm.edu/core/c14.htm> (15 Feb. 2012).

A video entitled *Blue Bottle Equilibrium* can be viewed on this website.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

TEACHER NOTES

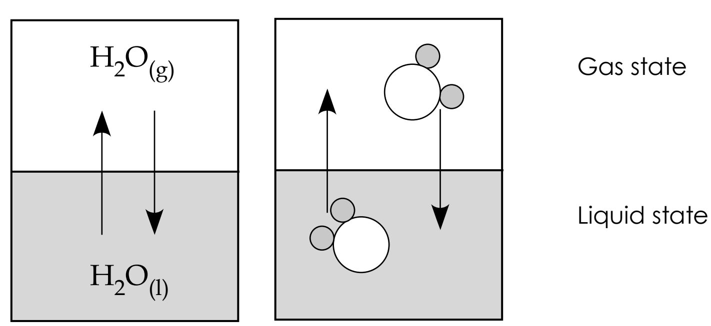
Reversible Reactions for Physical Equilibrium

Up to this point, this chemistry curriculum has addressed reversibility in physical systems (i.e., phase changes and dissociation). Students will now be introduced to the potential for reversibility in chemical systems. Discuss the conditions that are necessary to achieve equilibrium in physical and chemical systems and emphasize the differences between the two systems.

Physical equilibria require a closed system at constant temperature. Examples of physical equilibria are evaporation and dissolving.

Examples:

In the diagram below, water ($H_2O_{(l)}$) is in equilibrium with its vapour ($H_2O_{(g)}$). The rate of evaporation is equal to the rate of condensation in a closed container at a constant temperature. At the particulate level, for every one molecule of water ($H_2O_{(l)}$) that evaporates, another water vapour molecule ($H_2O_{(g)}$) condenses to the liquid state. This is an example of a reversible reaction for a physical equilibrium.



Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-01: Relate the concept of equilibrium to physical and chemical systems.

Include: conditions necessary to achieve equilibrium

(continued)

Animation

Have students view an equilibrium animation online.

Sample Website:

Chemical Education Research Group, Iowa State University. "Chemistry Experiment Simulations and Conceptual Computer Animations." *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

In the General Equilibria section, download and unzip the following animation:

- Bromine Liquid-Gas Equilibrium Animation

  This animation shows the molecular nature between liquid bromine and gaseous bromine. Have students count the number of molecules in the gas phase and in the liquid phase.

Reversible Reaction for Chemical Equilibrium

The conditions required for chemical equilibria include constant observable macroscopic properties (e.g., temperature, pressure, concentration), a closed system, constant temperature, reversibility, and equal rates of opposing change (Chastko 637).

Example:

An example of a reversible reaction for a chemical equilibrium is

$$H_{2(g)} + Cl_{2(g)} \rightleftharpoons 2HCl_{(g)}$$

At the particulate level for this reaction, the rate of forward reaction is equal to the rate of the reverse reaction. This means that for every molecule of H_2 that combines with a molecule of Cl_2, there is one molecule of HCl that reacts with another molecule of HCl, which reform to make the reactants H_2 and Cl_2. For a particulate representation of this reversible reaction, see the following diagram.

SKILLS AND ATTITUDES OUTCOMES

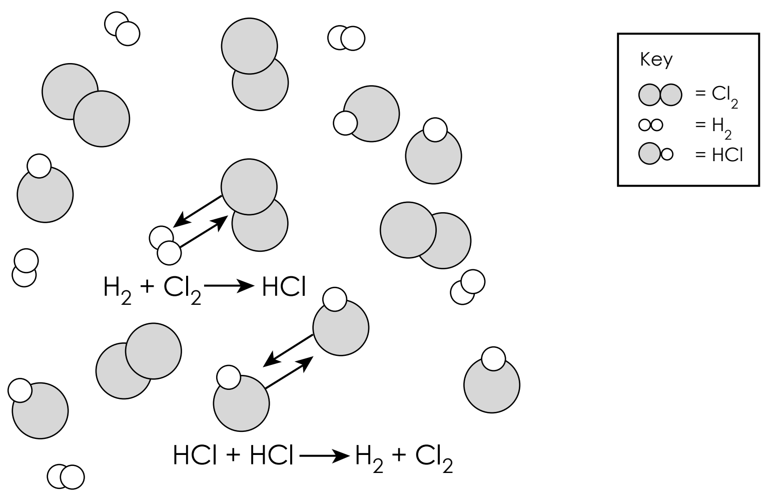
C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

Reversible Reaction



The diagram shows H_2 + Cl_2 combining to form two molecules of HCl, and two molecules of HCl combining to reform H_2 + Cl_2.

Demonstration/Animation

Demonstrate a chemical equilibrium with an $NO_2 - N_2O_4$ system or a $CoCl_4^{2-}$ – $Co(H_2O)_6^{2+}$ system. See Appendix 4.1: Preparation of Equilibrium Systems (Demonstration) for preparation instructions. Sealed units of $NO_2 - N_2O_4$ can be purchased from science supply companies rather than preparing the tubes for classroom demonstration.

Have students view an online demonstration or animation of a chemical equilibrium.

Sample Website:

Chemical Education Research Group, Iowa State University. "Chemistry Experiment Simulations and Conceptual Computer Animations." *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

In the General Equilibria section, download and unzip the following animation:

- NO_2–N_2O_4 Equilibrium Animation

This animation shows the NO_2–N_2O_4 reaction at the particulate level.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

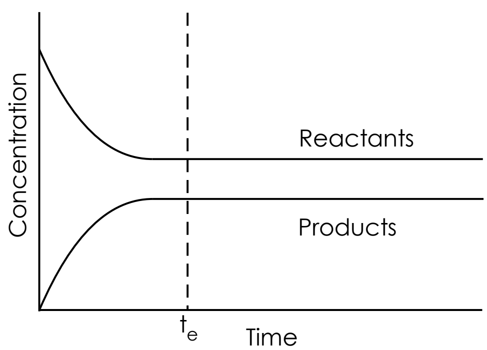
C12-4-01: Relate the concept of equilibrium to physical and chemical systems.
Include: conditions necessary to achieve equilibrium

(continued)

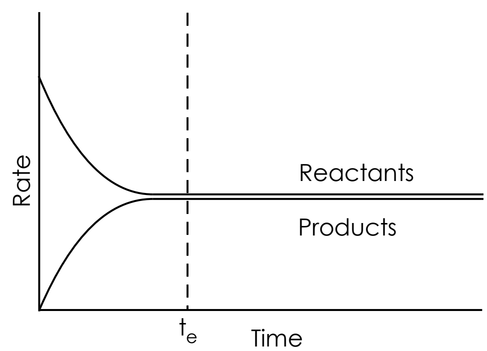
Graphs

How systems achieve equilibrium can be demonstrated through concentration versus time graphs and rate versus time graphs, such as the following.

Concentration versus Time



Rate versus Time



To prevent the misconception that equilibrium has been achieved by the end of the plateau, point out to students that equilibrium occurs as soon as the plateau begins.

Avoid a quantitative discussion of these graphs at this point.

Learning Activity: The Process of Achieving Equilibrium

Have a group of students represent sodium and chloride ions in the following reaction:

$$NaCl_{(s)} + heat \rightleftharpoons Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

For example, in a class of 20 students, 10 students could represent sodium ions and 10 students could represent chloride ions. Have 4 sodium ions and 4 chloride ions link arms on the left side of the room to represent sodium chloride particles. Have the remaining 12 students stand on the right side of the room. Ask a student to record on the board the number of each type of particles.

At this point, explain that in order for sodium chloride to break apart, heat is required. Place on the floor four pieces of red construction paper (to represent the heat), which can be picked up by the students representing the sodium chloride particles so that they can break up into sodium and chloride ions and move to the right side of the room. (The sodium ions in the sodium chloride particle should hold onto the heat). Students on the right side of the room could use the heat to join together to form a sodium chloride particle and move to the left side of the room.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

Allow this movement to continue for a few minutes, and then have a student record the number of each particle a second time. Repeat this process once more so that students can see that equilibrium has occurred.

Emphasize that the process of equilibrium is not finished. The forward and reverse processes continue to occur.

Laboratory Activity

Have students perform the Discovery Lab: What's equal about equilibrium? (Dingrando, et al. 559).

For this lab activity, students pour 20 mL of water into a graduated cylinder and 20 mL into a beaker. They then place one glass tube in the cylinder and another glass tube in the beaker. Students cover the end of each glass tube with their index fingers and simultaneously transfer water from the cylinder to the beaker, and from the beaker to the cylinder. The heights will even out after a number of transfers.

Equilibrium is established with 30 mL in the beaker and 10 mL in the graduated cylinder.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. Students can complete a Compare and Contrast think sheet for the following: physical and chemical systems and open and closed systems.
2. Present students with examples of situations showing systems that are at equilibrium and systems that are not at equilibrium. Have them identify both types of systems.
3. Provide students with data tables and ask them to identify whether or not the reactions are at equilibrium.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-01: Relate the concept of equilibrium to physical and chemical systems.

Include: conditions necessary to achieve equilibrium

(continued)

Journal Writing

1. Ask students to list reactions that are reversible (e.g., dissolving salt in water) and reactions that are not reversible (e.g., burning paper).

2. Have students answer the following question:

   At equilibrium, does the concentration of reactant have to equal the concentration of product? Explain your answer.

   Answer:

   No, the concentrations must be constant over time. They will not necessarily be equal.

LEARNING RESOURCES LINKS

Chemistry (Chang 586)

Chemistry (Zumdahl and Zumdahl 612)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 211)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 559, 560)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 489, 492)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 634, 636)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 424)

Prentice Hall Chemistry (Wilbraham, et al. 549)

Investigation

Glencoe Chemistry: Matter and Change (Dingrando, et al.)
Discovery Lab: What's equal about equilibrium? 559

Website

Chemical Education Research Group, Iowa State University. "Chemistry Experiment Simulations and Conceptual Computer Animations." *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

Animations: Bromine Liquid-Gas Equilibrium Animation
NO_2–N_2O_4 Equilibrium Animation

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

Appendix

Appendix 4.1: Preparation of Equilibrium Systems (Demonstration)

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-02: Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems.
Include: mass action expression

C12-4-03: Use the value of the equilibrium constant (K_{eq}) to explain how far a system at equilibrium has gone towards completion.

C12-4-04: Solve problems involving equilibrium constants.

(3.5 hours)

SLO: C12-4-02
SLO: C12-4-03
SLO: C12-4-04

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 7 Science (7-2-14), students were introduced to heterogeneous and homogeneous solutions.

Assessing Prior Knowledge

Check for students' prior knowledge, and review concepts as necessary.

TEACHER NOTES

Equilibrium Expressions

The ratio of product concentrations (raised to the value of the coefficient from the balanced equation) to reactant concentrations (raised to the value of the coefficient from the balanced equation) in a reaction at equilibrium is represented by the *equilibrium law expression* (*mass action expression*). The law of mass action was introduced in 1864 by Cato Maximilian Guldberg and Peter Waage, two Norwegian chemists who "analyzed the results of many different experiments and tested a variety of mathematical relationships until they discovered the relationship that always gave consistent results" (Chastko 640).

"Equilibrium Law Expression

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Where [A], [B], [C], and [D] represent the concentrations of the reactants and products after the reaction has reached equilibrium and the concentrations no longer change. The exponents, *a*, *b*, *c*, and *d*, are the stoichiometric coefficients from the equation" (Chastko 641).

A general equilibrium reaction can be written as follows:

$$aA + bB \rightleftharpoons cC + dD$$

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

Equilibrium Constants

Solids and liquids are not included in the mass action expression, as their concentrations are constant. Regardless of how much of the solid or liquid is present, the concentration (mol/L) of the solid and liquid remains the same. The value of the mass action expression at any point in time is called the *reaction quotient* (Q). At equilibrium, it is called the *equilibrium constant* (K_{eq}). Inform students that equilibrium constants are specific for only one reaction at a particular temperature.

The equilibrium constant provides information such as how far a reaction has gone toward completion before it reaches equilibrium. Because the equilibrium constant is the ratio of products to reactants, a K_{eq} value greater than 1 (K_{eq}> 1) means that there were more products than reactants, so the reaction was close to completion when equilibrium was achieved (and vice versa).

Many chemistry textbooks use the symbol K_{eq} to represent the equilibrium constant. Unless the value is given with appropriate units, this symbol does not distinguish between a constant equilibrium value calculated from equilibrium concentrations (K_c) and that calculated from equilibrium pressure (K_p). In textbooks, units are not used because they would vary depending on the powers to which the concentrations are raised. In some cases, all units would cancel.

Problems Involving Equilibrium Constants

Problems should be limited to

- solving for K_{eq}, given equilibrium concentrations of all reactants and products
- solving for an equilibrium concentration when K_{eq} and the equilibrium concentrations of all remaining reactants and products are given
- using an ICE table to solve for K_{eq}, given an initial concentration or an equilibrium concentration of one of the products (see Appendix 4.2: Solving Equilibrium Problems Using the ICE Table Method and Appendix 4.3: Solving for K_{eq} Using the BIR/PEC Accounting Method).

ICE Table

I	Initial—the initial concentrations of the reactants and products
C	Change—the change in reactants and products from the initial conditions
E	Equilibrium—the concentrations of the reactants and products at equilibrium

BIR/PEC Accounting Method

B	Balanced equation
I	Initial (moles)
R/P	Reacted or produced (moles)
E	Equilibrium (moles)
C	Concentration (mol/L)

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-02: Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems.
Include: mass action expression

C12-4-03: Use the value of the equilibrium constant (K_{eq}) to explain how far a system at equilibrium has gone towards completion.

C12-4-04: Solve problems involving equilibrium constants.

(continued)

Note that

> . . . students need extra practice using their calculators to solve problems involving scientific notation. In particular, students commonly make the mistake of using the times (×) sign when entering scientific-notation numbers. Point out that the exponent key ([EXP] on most calculators . . . or [EE] on others) actually represents '× 10.' To help students with this process, lead them through entering several numbers in scientific-notation and carrying out calculations with the numbers. (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 579)

Learning Activity: Determining Mathematical Relationships

Students can work in groups to determine a mathematical relationship between the equilibrium concentrations of reactants and products in a given data set.

Sample Problem: Mathematical Relationships

Your supervisor in the chemistry lab wants you to determine a mathematical relationship for the data found from studying the following chemical equilibrium:

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

What mathematical formula using equilibrium concentrations of reactants and products gives a constant (K) for the hydrogen iodide reaction system?

Hints:

- Be sure to analyze all your data to test your formula.
- Remember that the rate of the forward reaction is equal to the rate of the reverse reaction at equilibrium.

Skills and Attitudes Outcome

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

Trial	$[H_2]$ (mol/L)	$[I_2]$ (mol/L)	[HI] (mol/L)	$\frac{[\text{reactants}]}{[\text{products}]^2}$	$\frac{[\text{products}]^2}{[\text{reactants}]}$
1	0.0032583	0.0012949	0.015869	0.02	60
2	0.0046981	0.0007014	0.013997	0.02	60
3	0.0010084	0.0010084	0.007816	0.02	60
4	0.0007106	0.0007106	0.005468	0.02	60
5	0.0013953	0.0013953	0.010791	0.02	60

Solution:

$\text{Rate}_{\text{forward}} = k_f[H_2][I_2]$

$\text{Rate}_{\text{reverse}} = k_r[HI]^2$

At equilibrium,

$\text{Rate}_{\text{forward}} = \text{Rate}_{\text{reverse}}$

So,

$k_f[H_2][I_2] = k_r[HI]^2$

Note: We can't cancel the k values, as they are not identical to one another.

$$\frac{k_f}{k_r} = \frac{[HI]^2}{[H_2][I_2]}$$

or

$$\frac{k_r}{k_f} = \frac{[H_2][I_2]}{[HI]^2}$$

If the concentrations for the first trial are substituted into this equation, the value obtained is

$$\frac{k_f}{k_r} = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.015869)^2}{(0.0032583)(0.0012949)} = 59.6$$

Using the same concentrations for the first trial and substituting these values into the second equation, the result is

$$\frac{k_r}{k_f} = \frac{[H_2][I_2]}{[HI]^2} = \frac{(0.0032583)(0.0012949)}{(0.015869)^2} = 0.017$$

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-02: Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems.
Include: mass action expression

C12-4-03: Use the value of the equilibrium constant (K_{eq}) to explain how far a system at equilibrium has gone towards completion.

C12-4-04: Solve problems involving equilibrium constants.

(continued)

Student groups should obtain answers in the order of 60 or 0.02 when using the concentrations given in the other trials. Inform students that scientists have collectively agreed that the equilibrium constants would be reported in texts such as the *CRC Handbook of Chemistry and Physics* (CRC Press), using the ratio of product to reactant concentrations, or

$$\frac{k_f}{k_r} = \frac{[\mathrm{HI}]^2}{[\mathrm{H_2}][\mathrm{I_2}]} = K_{eq}$$

Sample Problem: Heterogeneous Equilibrium

Write the mass action expression for the decomposition of solid calcium carbonate.

$$\mathrm{CaCO_{3(s)}} \rightleftharpoons \mathrm{CaO_{(s)}} + \mathrm{CO_{2(g)}}$$

Solution:

In applying the standard form of the mass action expression, the equation would be written as follows:

$$K_{eq} = \frac{[\mathrm{CaO}][\mathrm{CO_2}]}{[\mathrm{CaCO_3}]}$$

However, the concentrations of pure solids and liquids are constant (i.e., they cannot change). They are not included in the mass action expression, so the mass action expression for the decomposition of calcium carbonate is

$$K_{eq} = [\mathrm{CO_2}]$$

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. Students can write equilibrium law expressions from given chemical equations and write chemical equations from equilibrium law expressions.
2. Have students use process notes to show the derivation of a mass action expression for a reaction that involves solids and/or liquids.
3. Provide students with various K_{eq} values and have them identify which reactions were close to completion when equilibrium was achieved and which were not.
4. Have students solve problems involving equilibrium constants (see Appendix 4.4: Equilibrium Problems).

Journal Writing

Ask students to "research the work of the Norwegian chemists Cato Maximilian Guldberg and Peter Waage that led them to propose the law of mass action. Have them describe how the law of mass action results in the formatting of equilibrium constant expressions" (Dingrando, et al., *Chemistry: Matter and Change, Teacher Wraparound Edition* 563).

LEARNING RESOURCES LINKS

Chemistry (Chang 587, 588, 600)

Chemistry (Zumdahl and Zumdahl 615)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 723, 736)

CRC Handbook of Chemistry and Physics (CRC Press)—"The Rubber Book"

Glencoe Chemistry: Matter and Change (Dingrando, et al. 563)

Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition (Dingrando, et al. 563, 579)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 494, 505)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 639–641, 656)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 433, 439)

Prentice Hall Chemistry (Wilbraham, et al. 556)

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-02: Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems.
Include: mass action expression

C12-4-03: Use the value of the equilibrium constant (K_{eq}) to explain how far a system at equilibrium has gone towards completion.

C12-4-04: Solve problems involving equilibrium constants.

(continued)

Appendices

Appendix 4.2: Solving Equilibrium Problems Using the ICE Table Method

Appendix 4.3: Solving for K_{eq} Using the BIR/PEC Accounting Method

Appendix 4.4: Equilibrium Problems

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

NOTES

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-05: Perform a laboratory activity to determine the equilibrium constant of an equilibrium system.

(1.5 hours)

SLO: C12-4-05

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In addressing specific learning outcome C12-4-04, students solved problems involving equilibrium constants. They will now have an opportunity to use experimental data to calculate the value of K_{eq} for a reversible reaction.

TEACHER NOTES

It is not intended that students perform all the lab activities suggested below (and in the Learning Resources Links). Select a lab activity appropriate for students' skill level and the equipment available at the school.

Laboratory Activities: Investigating Chemical Equilibrium

Have students perform lab activities, such as the following, to determine the equilibrium constant of an equilibrium system.

- **Lab 16: Exploring Chemical Equilibrium** (Dingrando, et al. 61)

  In this experiment, students calculate K_{eq} for a reaction between Fe^{3+} and SCN^{-}. They investigate the reaction in which colourless Fe^{3+} and SCN^{-} ions combine to form a red $FeSCN^{2+}$ ion. They prepare serial dilutions of $Fe(NO_3)_2$ and estimate the colour intensity of solutions at equilibrium. Students then relate colour-intensity values to the concentration of $FeSCN^{2+}$ at equilibrium.

General Learning Outcome Connections

GLO B3: Identify the factors that affect health, and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social.

GLO B5: Identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally.

GLO C1: Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S6: Estimate and measure accurately using Système International (SI) and other standard units.

Include: SI conversions and significant figures

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C12-0-S8: Evaluate data and data-collection methods for accuracy and precision.

Include: discrepancies in data, sources of error, and percent error

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- **Investigation 16.C: Using Experimental Data to Determine an Equilibrium Constant** (Chastko, et al. 662).

  This investigation studies the equilibrium between iron(III) ions, thiocyanate ions, and iron(III) thiocyanate ions. Four different equilibrium mixtures with different initial concentrations of $Fe^{2+}_{(aq)}$ and $SCN^{-}_{(aq)}$ are prepared. The initial concentrations of these ions are calculated from the volumes and concentrations of the stock solution used and the total volumes of the equilibrium mixtures. The concentration of $Fe(SCN)^{2+}_{(aq)}$ in each mixture is determined by comparing the colour intensity of the mixture with the colour intensity of a solution with known concentration. The concentrations of $Fe^{2+}_{(aq)}$) and $SCN^{-}_{(aq)}$ are calculated from the known concentration of $Fe(SCN)^{2+}_{(aq)}$. Then these values are substituted into the equilibrium expression to solve for K_{eq}.

- **Investigation 13–A: Measuring an Equilibrium Constant** (Mustoe, et al. 501).

  This investigation is very similar to Investigation 16.C: Using Experimental Data to Determine an Equilibrium Constant.

- **Lab Exercise 7.2.1: Develop an Equilibrium Law** (van Kessel, et al. 514).

  Have students use experimental data and apply mathematical relationships to see which gives a constant value.

- **Using a Colorimeter or Spectrometer**

  Have students perform the experiment outlined in Appendix 4.5: Chemical Equilibrium: Lab Activity. In this experiment, students add together varying concentrations of SCN^{-} and Fe^{3+} to achieve an equilibrium system between the two ions and the $FeSCN^{2+}$ ion. Students should note that the higher the concentration of the Fe^{3+} is, the darker the orange-red colour of the complex will be. They then use spectrometers or colorimeters to determine the optical density (absorbance) of each system, and then use the information to determine the equilibrium concentrations of all reactants and products in order to solve for the value of K_{eq}.

  Also refer to "Chemical Equilibrium: Finding a Constant, K_c" (Holmquist, Randall, and Volz, *Chemistry with CBL* 20–1 to 20–2GT).

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-05: Perform a laboratory activity to determine the equilibrium constant of an equilibrium system.

(continued)

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

Students can use the Laboratory Report Format to write their lab reports (see *SYSTH* 14.12). Word processing and spreadsheet software could be used to prepare reports. Also refer to the Lab Report Assessment rubric in Appendix 11.

Laboratory Skills

Periodically and randomly review the lab skills of individual students, so that eventually all students are assessed. Pay particular attention to skills related to serial dilutions from stock solutions. Sample checklists for assessing lab skills and work habits are available in *SYSTH* (6.10, 6.11).

LEARNING RESOURCES LINKS

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 501)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 662)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 514)

Investigations

Chemistry with CBL (Holmquist, Randall, and Volz).
Chemical Equilibrium: Finding a Constant, Kc, 20–1 to 20–2T

Glencoe Chemistry: Matter and Change: Small-Scale Laboratory Manual, Teacher Edition (Dingrando et al.)
Lab 16: Exploring Chemical Equilibrium, 61

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al.)
Investigation 13–A: Measuring an Equilibrium Constant, 501

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al.)
Investigation 16.C: Using Experimental Data to Determine an Equilibrium Constant, 662

Nelson Chemistry 12, Ontario Edition (van Kessel, et al.)
Lab Exercise 7.2.1: Develop an Equilibrium Law, 514

Appendix

Appendix 4.5: Chemical Equilibrium: Lab Activity

Skills and Attitudes Outcomes

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S6: Estimate and measure accurately using Système International (SI) and other standard units.

Include: SI conversions and significant figures

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C12-0-S8: Evaluate data and data-collection methods for accuracy and precision.

Include: discrepancies in data, sources of error, and percent error

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Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(3.5 hours)

SLO: C12-4-06
SLO: C12-4-07

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 11 Chemistry (C11-02-05), students performed an experiment to discover Boyle's law, which states that pressure and volume are inversely proportional to one another. In both Grades 11 and 12 Chemistry (C11-3-13, C12-3-04), students have worked with endothermic and exothermic reactions. Students performed a lab activity (C12-3-02) to observe the effects of concentration, temperature, pressure, volume, and the presence of a catalyst on the rate of a reaction.

Assessing Prior Knowledge

Check for students' prior knowledge, and review concepts as necessary.

TEACHER NOTES

Le Châtelier's Principle

In 1884, French chemist Henri Louis Le Châtelier proposed the *law of mobile equilibrium* (commonly referred to as *Le Châtelier's principle*), which states that if a stress is placed on a reversible reaction at chemical equilibrium, the equilibrium will shift to relieve the stress, thereby restoring equilibrium. Le Châtelier's principle describes how a chemical equilibrium shifts in response to a stress or disturbance within an enclosed system, as described in the following table.

General Learning Outcome Connections

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

GLO C8: Evaluate, from a scientific perspective, information and ideas encountered during investigations in daily life.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

Shifts in Equilibrium in Response to Stress		
Stress	**System Response**	**Effect on the Equilibrium Constant**
Increase in temperature	The system shifts to use up the added heat, favouring the endothermic reaction.	The equilibrium constant changes because the equilibrium position shifts without any substances being added or removed. There is no heat-related term in the mass action expression to maintain the ratio.
Decrease in temperature	The system shifts to produce more heat, favouring the exothermic reaction.	It changes because the equilibrium position shifts without any substances being added or removed. There is no heat-related term in the mass action expression to maintain the ratio.
Increase in volume (decrease in pressure)	The system shifts to the side with the most gas particles because solids and liquids are incompressible.	It does not change because all reactant and product concentrations change, resulting in the same ratio.
Decrease in volume (increase in pressure)	The system shifts to the side with the fewest gas particles because solids and liquids are incompressible.	It does not change because all reactant and product concentrations change, resulting in the same ratio.
Increase in concentration	The system shifts to decrease the reactant or product that was added.	It does not change because all reactant and product concentrations change, resulting in the same ratio.
Decrease in concentration	The system shifts to increase the reactant or product that was removed.	It does not change because all reactant and product concentrations change, resulting in the same ratio.
Addition of a catalyst	No change in the system occurs. Catalysts increase the forward and reverse reactions to the same extent, so that they only serve to help bring systems to equilibrium faster.	It does not change.
Addition of an inert gas	No change in the system occurs because it does not take part in the reaction.	It does not change.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(continued)

The following shows how a change in concentration affects the other substances in a chemical reaction (Silberberg 746).

These concentration changes cause a shift to the right:

increase		increase		decrease
PCl_3	+	Cl_2	$\rightleftharpoons$	PCl_5

These concentration changes cause a shift to the left:

decrease		decrease		increase
PCl_3	+	Cl_2	$\rightleftharpoons$	PCl_5

Demonstrations

- **Traffic Light Reaction**

This demonstration shows an oscillating colour reaction starting with yellow-orange, changing to red (after shaking the flask once), and then to green (after shaking the flask again). After the flask stands for awhile, the colour returns to red and then back to yellow-orange. The idea behind this demonstration is that shaking is enough for the first reaction to occur, and then a few more shakes gets the second reaction going. As the solution settles, the kinetic energy (from shaking) drops, and the reactions do not have enough energy to continue.

To prepare for the demonstration, dissolve 32 g of potassium hydroxide in 1200 mL water (solution A), 40 g of glucose in 1200 mL water (solution B), 0.50 g of benzoin in 500 mL water (solution C), and 1.0 g of indigo carmine in 200 mL water (solution D). To a clean, empty flask, add 200 mL of solution A, then 200 mL of B, then 60 mL of C, and then 16 mL of D.

Similar demonstrations can be viewed online.

Sample Websites:

Keusch, Peter. "Belousov-Zhabotinsky Reaction." *Organic Chemistry Demonstration Experiments on Video: Chemistry Visualized.* University of Regensburg. <www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-oscill-e.htm> (22 Feb. 2012).

In this video demonstration, the colour oscillates between red and blue.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

Wyatt, Shawn. "Go-Science Traffic Light Reaction Chemistry Demonstration." *World News.* <http://wn.com/Traffic_Light_Reaction_GO-Science_Demonstration> (22 Feb. 2012).

- **Liquid Crystal Demonstration**

If a sheet of temperature-sensitive liquid crystal is available, wrap the sheet around glasses of cold water, water at room temperature, and hot water to see that warmer temperatures yield darker colours:

$$\underset{\text{(light-coloured liquid crystals)}}{\text{LCLC}} + \text{heat} \rightleftharpoons \underset{\text{(dark-coloured liquid crystals)}}{\text{DCLC}}$$

Mood rings, made of liquid crystals, take advantage of this phenomenon by re-equilibrating as a result of slight changes in body temperature.

Laboratory Activities: Disturbing Equilibrium Systems

Any of the following experiments can be performed to determine how equilibrium systems respond to stresses. It is not intended that students perform all the suggested lab activities. Select lab activities appropriate for the abilities of students in the class and the equipment available at the school.

- **Analogy for an Equilibrium Reaction**

The procedure for this investigation can be found in Appendix 4.6A: An Analogy for an Equilibrium Reaction: Lab Activity. Students use straws of two different diameters to transfer water between two graduated cylinders until equilibrium is achieved. This lab activity demonstrates that systems are not necessarily at equilibrium when the concentrations of reactants and products are identical. Students' results will vary, depending upon the size of straw they place into each graduated cylinder. A lab report checklist for this experiment is given in Appendix 4.6C. Teacher notes are provided in Appendix 4.6B.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(continued)

- **Qualitative Equilibrium**

  The pre-lab exercise provided in Appendix 4.7: Equilibrium and Le Châtelier's Principle (Pre-lab) gives students an opportunity to predict the direction in which the equilibrium will shift with the given stresses. A complete student procedure for this lab activity can be found in Appendix 4.8A: Qualitative Equilibrium: Lab Activity. (See Appendix 4.8B for teacher notes.) Students create an equilibrium system using 0.02 mol/L iron(III) nitrate and 0.002 mol/L potassium thiocyanate. The solutions are mixed, and then "stressed" by adding iron(III) nitrate, solid potassium thiocyante, and sodium hydrogen phosphate to samples of the solution. Shifts in the original equilibrium position may be seen through colour changes.

- **Disrupting Equilibrium Systems**

  The procedure for this lab activity can be found in Appendix 4.9: Disrupting Equilibrium Systems: Lab Activity. The reaction that students study is

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}} + 4Cl^- \rightleftharpoons \underset{\text{blue}}{CoCl_4^{2-}} + 6H_2O$$

  Students dissolve cobalt chloride in ethanol and record the colour of the solution. They add stresses to samples of this prepared solution (distilled water, hydrochloric acid, solid calcium chloride, silver nitrate solution, addition of heat, and removal of heat) and note the resulting colours.

- **MiniLAB 18: Shifts in Equilibrium** (Dingrando, et al., *Glencoe Chemistry: Matter and Change* 573)

  In this experiment, students observe an equilibrium shift in a colourful way. Students add hydrochloric acid to a 0.1 mol/L solution of cobalt chloride. The pink colour changes to a purple colour. To this solution, students then add water, and the colour returns to pink. Then students place a sample of the cobalt chloride-hydrochloric acid solution in hot water, which results in a blue colour being produced. When they place a sample of the cobalt chloride-hydrochloric acid solution in cold water, the pink colour appears.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

- **Lab 15: Observing Equilibrium** (Dingrando, et al., *Glencoe Chemistry: Matter and Change: Small-Scale Laboratory Manual, Teacher Edition* 57)

  In the first part of the lab activity, students record the colours of Fe^{3+} ion, SCN^- ion, and $FeSCN^{2+}$ ion. The direction of shift in equilibrium is measured by the colour change that occurs, which is related to the concentration of reactant. Students pour a dilute solution of iron(III) nitrate and potassium thiocyanate into five separate test tubes. To the first test tube, 0.5 g of $Fe(NO_3)_3$ is added to the solution, and a darker red colour is observed. To the second test tube, 0.5 g NH_4SCN is added to the solution, and a dark red colour results. To the third test tube, 0.5 g KCl is added to the solution, and a light red colour (or orange colour) is observed. To the fourth test tube, a few millilitres of sodium hydroxide solution is added to the original solution, which results in a colourless solution with a white precipitate. To the fifth test tube, a few millilitres of silver nitrate are added, which results in a colourless solution and a white precipitate.

- **Experiment 29: Le Châtelier's Principle and Chemical Equilibrium** (Waterman and Thompson, *Prentice Hall Chemistry: Small-Scale Chemistry Laboratory Manual* 203)

  In this experiment, students "observe and record how a chemical system at equilibrium responds to changes in concentration of reactants or products" (203). They describe these shifts in equilibrium in terms of Le Châtelier's principle. As this is a small-scale lab activity, the quantities required of the following solutions are minimal: bromthymol blue, hydrochloric acid, sodium hydroxide, ammonia, copper(II) sulphate, lead(II) nitrate, potassium iodide, nitric acid, silver nitrate, sodium carbonate, sodium thiosulphate, and sodium phosphate.

- **Investigation 16A: Modelling Equilibrium** (Chastko, et al. 635)

  This investigation is similar to the one outlined in Appendix 4.6A: An Analogy for an Equilibrium Reaction. Using two glass tubes of different diameters, students transfer water from one graduated cylinder to another, and vice versa. In the reactant cylinder, 25 mL of water is present. In the product cylinder, there is no water present initially.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(continued)

- **ExpressLab: Modelling Equilibrium** (Mustoe, et al 491)

  This lab activity is the same as Investigation 16.A: Modelling Equilibrium (Chastko, et al. 635).

- **Investigation 16.B: Disturbing Equilibrium** (Chastko, et al. 652)

  In this three-part investigation, students use Le Châtelier's principle to predict the effect of change on a system at equilibrium. They design an experiment to illustrate and test their prediction by assessing a change of colour or the appearance (or disappearance) of a precipitate. In Part 1, students explore changes to a base equilibrium system. In Part 2, they examine concentration and temperature changes. In Part 3, the teacher performs a demonstration to investigate gaseous equilibria.

- **Investigation 13–B: Perturbing Equilibrium** (Mustoe, et al 521)

  This lab activity is essentially the same as Investigation 16.B: Disturbing Equilibrium (Chastko, et al. 652), except students use different chemicals. Students use Le Châtelier's principle to predict and test the effect of changing one factor in systems at equilibrium. Students complete the first three parts of the investigation, and the teacher demonstrates the last part, dealing with gaseous equilibria.

- **Investigation 7.3.1: Testing Le Châtelier's Principle** (van Kessel, et al 514)

  In this seven-part lab activity, stresses are applied to different chemical equilibrium systems to test Le Châtelier's principle. The lab activity includes an investigation of increasing pressure on a carbon dioxide–bicarbonate mixture.

Whole-Class Learning Activity: Reaction Tendencies

Have students view "Reaction Tendencies," episode 4 of *Chemical Equilibrium* (TVOntario). This episode shows the effects of heat and pressure on an equilibrium system using Le Châtelier's principle. Students can describe these effects on an equilibrium system on both a macroscopic level and a microscopic level.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

Online Demonstrations

Have students view online demonstrations of Le Châtelier's principle.

Sample Website:

The North Carolina School of Science and Mathematics (NCSSM). "Chapter 14: Gas Phase, Solubility, Complex Ion Equilibria." *Chemistry Online Resource Essentials (CORE)*. <www.dlt.ncssm.edu/core/c14.htm> (13 Jan. 2012).

This website provides a variety of video clips that demonstrate shifts in equilibrium using Le Châtelier's principle:

- *$FeSCN^{2+}$ Equilibrium – Le Châtelier's Principle Lab, Part 1* shows the effect of adding stresses to the equilibrium $FeSCN^{2+}$–$Fe(SCN)^{+2}$.
- *Cobalt Complex Ion Equilibrium – Le Châtelier's Principle Lab, Part 3* demonstrates the cobalt chloride complex (pink to blue) equilibrium.
- *NO_2–N_2O_4 Gas Equilibrium – Le Châtelier's Principle Lab, Part 4* shows the effect of temperature on the equilibrium NO_2–N_2O_4. As temperature is decreased, there is an increase in N_2O_4 (colourless).

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. To begin addressing learning outcomes C12-4-06 and C12-4-07 and to review prior knowledge, have students answer the following questions:
   - What are the five factors that affect reaction rate?
   - How do the rates of the forward and reverse reactions compare for a reaction at equilibrium?

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(continued)

2. Have students answer questions related to Le Châtelier's principle.

   Example:

   Much of the brown haze hanging over large cities is nitrogen dioxide ($NO_{2(g)}$). Nitrogen dioxide reacts to form dinitrogen tetraoxide ($N_2O_{4(g)}$), according to the equation

   $$2NO_{2(g)} \rightleftharpoons N_2O_{4(g)} + 57.2\ kJ$$

   brown colourless

   Use this equilibrium to explain why the brownish haze over a large city disappears in the winter, only to reappear again in the spring.

   Answer:

   The stress is a decrease in temperature in the winter. The exothermic reaction (a release of heat) would be favoured to oppose the decrease in temperature. This would favour the production of the colourless dinitrogen tetraoxide gas. In the summer, the stress would be an increase in temperature. The endothermic reaction (absorption of heat) would be favoured to oppose this stress. Nitrogen dioxide would, therefore, be produced, and we would see a brown haze over the city.

Journal Writing

Students can write a fictionalized newspaper article written on the day after Henri Louis Le Châtelier's principle was announced in 1884. Students' articles should highlight this scientific contribution.

Laboratory Reports

Students can use the Lab Report Format to write their lab reports (see *SYSTH* 14.12). Word processing and spreadsheet software could be used to prepare reports. Also refer to the Lab Report Assessment rubric in Appendix 11.

Laboratory Skills

Periodically and randomly review the lab skills of individual students, so that eventually all students are assessed. For sample checklists, refer to *SYSTH* (6.10, 6.11).

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

LEARNING RESOURCES LINKS

Chemistry (Chang 607)

Chemistry (Zumdahl and Zumdahl 640)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 745)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 214)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 569)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 519)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 646)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 450)

Prentice Hall Chemistry (Wilbraham, et al. 552)

Investigations

Glencoe Chemistry: Matter and Change (Dingrando, et al.)
MiniLab 18: Shifts in Equilibrium, 573

Glencoe Chemistry: Matter and Change: Small-Scale Laboratory Manual, Teacher's Edition (Dingrando, et al.)
Lab 15: Observing Equilibrium, 57

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al.)
ExpressLab: Modelling Equilibrium, 491
Investigation 13-B: Perturbing Equilibrium, 521

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al.)
Investigation 16.A: Modelling Equilibrium, 635
Investigation 16.B: Disturbing Equilibrium, 652

Nelson Chemistry 12, Ontario Edition (van Kessel, et al.)
Investigation 7.3.1: Testing Le Châtelier's Principle, 514

Prentice Hall Chemistry: Small-Scale Chemistry Laboratory Manual (Waterman and Thompson)
Experiment 29: Le Châtelier's Principle and Chemical Equilibrium, 203

Video

"Reaction Tendencies." *Chemical Equilibrium*. Concepts in Science series. TVOntario. Toronto, ON. 1984. (60 min)

Topic 4: Chemical Equilibrium

Specific Learning Outcomes

C12-4-06: Use Le Châtelier's principle to predict and explain shifts in equilibrium.

Include: temperature changes, pressure/volume changes, changes in reactant/product concentrations, the addition of a catalyst, the addition of an inert gas, and the effects of the various stresses on the equilibrium constant

C12-4-07: Perform a laboratory activity to demonstrate Le Châtelier's principle.

(continued)

Websites

Keusch, Peter. "Belousov-Zhabotinsky Reaction." *Organic Chemistry Demonstration Experiments on Video: Chemistry Visualized.* University of Regensburg. <www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-oscill-e.htm> (22 Feb. 2012).

The North Carolina School of Science and Mathematics (NCSSM). "Chapter 14: Gas Phase, Solubility, Complex Ion Equilibria." *Chemistry Online Resource Essentials (CORE).* <www.dlt.ncssm.edu/core/c14.htm> (13 Jan. 2012).

Wyatt, Shawn. "Go-Science Traffic Light Reaction Chemistry Demonstration." *World News.* <http://wn.com/Traffic_Light_Reaction_GO-Science_Demonstration> (22 Feb. 2012).

Appendices

Appendix 4.6A: An Analogy for an Equilibrium Reaction: Lab Activity

Appendix 4.6B: An Analogy for an Equilibrium Reaction: Lab Activity (Teacher Notes)

Appendix 4.6C: An Analogy for an Equilibrium Reaction: Lab Report Checklist

Appendix 4.7: Equilibrium and Le Châtelier's Principle (Pre-lab)

Appendix 4.8A: Qualitative Equilibrium: Lab Activity

Appendix 4.8B: Qualitative Equilibrium: Lab Activity (Teacher Notes)

Appendix 4.9: Disrupting Equilibrium Systems: Lab Activity

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S2: State a testable hypothesis or prediction based on background data or on observed events.

C12-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S9: Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

C12-0-A2: Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.

NOTES

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-08: Interpret concentration versus time graphs.

Include: temperature changes, concentration changes, and the addition of a catalyst

(1 hour)

SLO: C12-4-08

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In learning outcome C12-4-01, students were introduced to a qualitative treatment of concentration versus time graphs.

In learning outcome C12-4-06, students saw that a system at equilibrium will shift to minimize a stress and re-establish equilibrium.

TEACHER NOTES

Ask students to recall that equilibrium is shown by a plateau on a concentration versus time graph. If students completed the analogy lab activity in addressing learning outcomes C12-4-06 and C12-4-07, ask them to refer to their results. See Appendix 4.6A: An Analogy for an Equilibrium Reaction: Lab Activity. The plateau in such concentration versus time graphs demonstrates that the concentrations of reactants and products are not changing over time.

Concentration versus Time Graphs: Class Activity

Work through the following sample problem with students to introduce the quantitative analysis of concentration versus time graphs. See the teacher support material in Appendix 4.10: Interpreting Equilibrium Graphs and Appendix 4.11: Interpreting Concentration versus Time Graphs.

Alternatively, provide students with graphical data, such as the following, so that they can generate a graph before its interpretation.

General Learning Outcome Connections

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

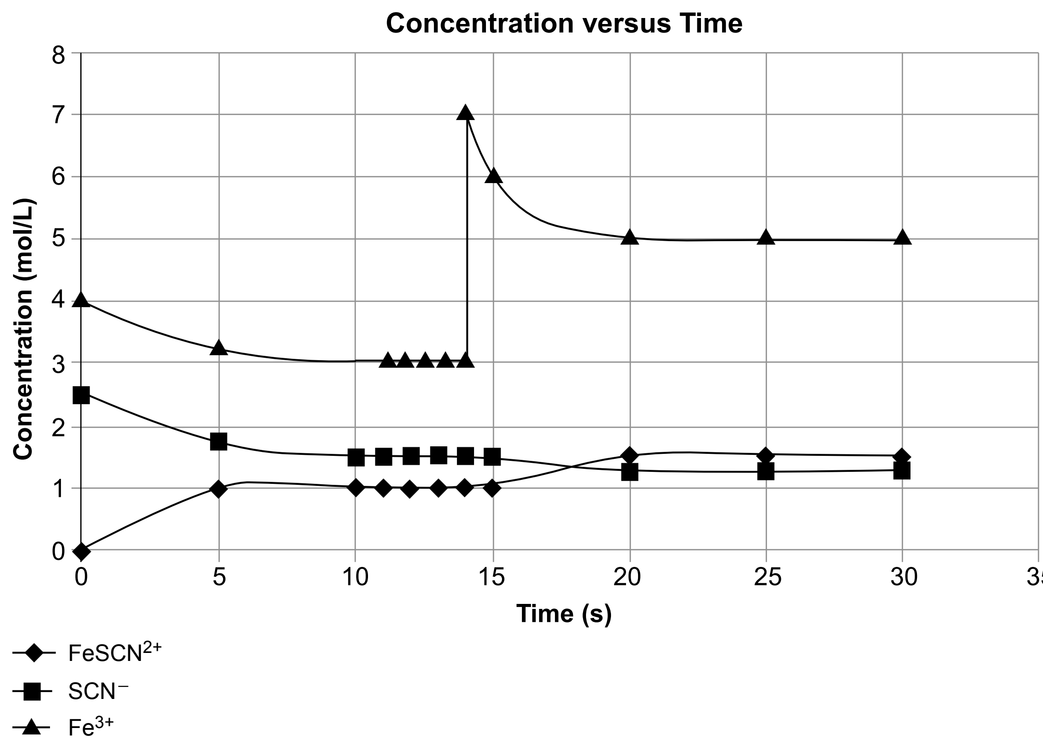
GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

SKILLS AND ATTITUDES OUTCOME

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Data Table

Time	[$FeSCN^{2+}$]	[SCN^-]	[Fe^{3+}]	[Fe^{3+}] (after stress)
0	0	2.5	4	
5	1	1.75	3.25	
10	1	1.5	3	
11	1	1.5	3	
12	1	1.5	3	
13	1	1.5	3	
14	1	1.5	3	7
15	1	1.5		6
20	1.5	1.25		5
25	1.5	1.25		5
30	1.5	1.25		5



Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-08: Interpret concentration versus time graphs.
Include: temperature changes, concentration changes, and the addition of a catalyst

(continued)

Sample Problem: Interpretation of Concentration versus Time Graph

For the reaction, $Fe^{3+} + SCN^{-} \rightleftharpoons FeSCN^{2+}$, the concentrations of the reactants (Fe^{3+} and SCN^{-}) are decreasing as the reaction proceeds and the concentration of the product ($FeSCN^{2+}$) is increasing. It appears that the reaction reaches equilibrium at 10 seconds. At 14 seconds, a stress is added to the equilibrium, as the concentration of Fe^{3+} spikes dramatically upward at that point. There are more molecules of Fe^{3+} in the system, so the number of molecules of SCN^{-} decreases, and more product ($FeSCN^{2+}$) is produced. A new equilibrium is established at 20 seconds.

Questions:

1. Write a balanced equation to represent the reaction.
2. How much time was required for the system to reach equilibrium?
3. Calculate the approximate value of the equilibrium constant from the concentrations at 10 seconds.
4. Calculate the approximate value of the equilibrium constant from the concentrations at 20 seconds.
5. How do the two values from questions 3 and 4 compare? Explain.
6. What stress occurred at 14 seconds?
7. How would the addition of a positive catalyst change the shape of this graph?

Answers:

1. $Fe^{3+} + SCN^{-} \rightleftharpoons FeSCN^{2+}$
2. The system reached equilibrium in 10 seconds.
3. $K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^{-}]} = \frac{(1)}{(3)(1.5)} = 0.22$
4. $K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^{-}]} = \frac{(1.5)}{(5)(1.25)} = 0.24$
5. The two values are approximately the same because the stress imposed on the system was not a change in temperature.
6. The addition of Fe^{3+} occurred at 14 seconds.
7. A catalyst would decrease the time required to reach equilibrium. This would condense ("squish") the graph along the *x*-axis.

SKILLS AND ATTITUDES OUTCOME

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. Students can prepare questions on sketching and interpreting concentration versus time graphs and test their classmates.
2. Have students complete Appendix 4.11: Interpreting Concentration versus Time Graphs.

LEARNING RESOURCES LINKS

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 527)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 647, 648, 650)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 430, 451–455)

Prentice Hall Chemistry (Wilbraham, et al. 550)

Appendices

Appendix 4.10: Interpreting Equilibrium Graphs

Appendix 4.11: Interpreting Concentration versus Time Graphs

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-09: Discuss practical applications of Le Châtelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, carbonated beverages in a hen's diet . . .

(1 hour)

SLO: C12-4-09

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students were introduced to Le Châtelier's principle in learning outcome C12-4-06.

Assessing Prior Knowledge

Check for students' prior knowledge, and review concepts as necessary. Some examples may have been discussed in addressing previous learning outcomes.

TEACHER NOTES

Practical Applications of Le Châtelier's Principle

The following examples of the practical applications of Le Châtelier's principle are provided to indicate the importance of Le Châtelier's principle in our lives. Students are not expected to learn the examples in great detail. Teachers can either have students collect information from their own textbooks or, if information is limited, through additional research. Some information is provided here for teacher reference.

General Learning Outcome Connections

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A3: Distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values.

GLO A5: Recognize that science and technology interact with and advance one another.

GLO B2: Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time.

GLO B4: Demonstrate knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

GLO D1: Understand essential life structures and processes pertaining to a wide variety of organisms, including humans.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO E2: Describe and appreciate how the natural and constructed world is made up of systems and how interactions take place within and among these systems.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-R4: Compare diverse perspectives and interpretations in the media and other information sources.

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

C12-0-A3: Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.

C12-0-A4: Be sensitive and responsible in maintaining a balance between the needs of humans and a sustainable environment.

■ The Haber Process

The Haber process, used to produce ammonia from hydrogen and nitrogen, was discovered in 1909 by German chemist Fritz Haber, Nobel Prize winner and "father of chemical warfare." He is reported to have said, "During peace time a scientist belongs to the world, but during war time he belongs to his country" (Blickenstaff).

Students could research and report on the historical development and importance of Haber's contributions to chemistry. This project can launch into discussions on the ethics of science and scientists, the obligation of scientists to society, the diverse perspectives and interpretations of science in the media, the role of chemistry in agriculture, and so on.

Most chemistry textbooks include a discussion of the Haber process (e.g., Chang, 9th ed. 630; Chastko, et al. 669). Discussions are also available online.

Sample Website:

Clark, Jim. "The Haber Process." *Chemguide*. 2002. <www.chemguide.co.uk/physical/equilibria/haber.html> (13 Jan. 2012).

This website includes a description of the Haber process for manufacturing ammonia.

■ Hemoglobin Production and Altitude

In the body, hemoglobin (Hb) in readily used to transport oxygen to tissues.

$$Hb_{(aq)} + O_{2(g)} \rightleftharpoons HbO_{2(aq)}$$

In a place such as Mexico City, where the elevation is 2.3 km above sea level, atmospheric pressure and oxygen concentration are low. To offset the stress, equilibrium favours the reverse direction. As a result, people who live there may experience hypoxia (a lack of oxygen), which can cause headache, nausea, and extreme fatigue. In serious cases, if victims are not treated quickly, they may slip into a coma and die.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-09: Discuss practical applications of Le Châtelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, carbonated beverages in a hen's diet . . .

(continued)

Individuals living at high altitudes for extended periods of time adapt to reduced oxygen concentrations by producing more hemoglobin. This shifts equilibrium to the right once more, so that the symptoms of hypoxia disappear.

Studies have shown that the Sherpas, long-time residents of the Himalayan mountains, have adapted to high altitude conditions by maintaining high levels of hemoglobin in their blood, sometimes as much as 50 percent more than individuals living at sea level (Chang, 9th ed. 630).

- **Carbonated Beverages**

  Soft drinks are carbonated under high pressure to create the following equilibrium system:

  $$CO_{2(g)} \rightleftharpoons CO_{2(aq)} + \text{heat}$$

  When a bottle of soda pop is opened, the pressure above the carbon dioxide decreases. The system shifts to the left, the solubility of the carbon dioxide drops, and carbon dioxide bubbles out of solution. If the bottle is left open for a long time, the pop will go "flat" due to the reduced pressure.

  Shaking a pop bottle will increase the pressure on the system, which will shift to relieve the stress by favouring the forward reaction. Increasing the temperature of a pop bottle (e.g., leaving it in a warm car on a summer day) will cause equilibrium to shift in the reverse direction, creating more carbon dioxide gas. This will generate a pressure that could potentially cause the pop bottle to burst.

- **Eyes Adjusting to Light**

  Photoreceptors, cells containing the visual pigment rhodopsin, line the inner surface of the eyeball. The rhodopsin is made up of opsin (a protein) and retinene (a pigment). When light strikes a photoreceptor, the energy absorbed changes the shape of the retinene portion of the molecule. This forward reaction takes place very quickly. The shape change signals the optic nerve, which carries information to the brain where it is translated into a visual image.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-R4: Compare diverse perspectives and interpretations in the media and other information sources.

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

C12-0-A3: Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.

C12-0-A4: Be sensitive and responsible in maintaining a balance between the needs of humans and a sustainable environment.

In the absence of light, the retinene is separated from the opsin. It takes time to be able to see in the dark, again because the complex can be recombined with the help of adenosine triphosphate (ATP) molecules in a slower reverse reaction. In a dark room, the photoreceptors in the eyes take a few minutes to re-equilibrate to a lower light intensity, as the reverse reaction is slower. Moving into a brightly lit room, the photoreceptors in the eyes again take a few minutes to adjust to their new equilibrium due to the slower reverse reaction.

$$\text{Ret-Op} \rightleftharpoons \text{Ret} + \text{Op} + \text{light}$$

Signal sent — Signal not sent

- **Blood pH**

  Blood contains dissolved carbonic acid in equilibrium with carbon dioxide and water.

  $$H_2CO_{3(aq)} \rightleftharpoons CO_{2(aq)} + H_2O_{(l)}$$

  To keep carbonic acid at safe concentrations in the blood, the CO_2 product is exhaled. The removal of a product causes the forward reaction to be favoured, reducing the amount of carbonic acid to keep blood pH within a safe range (Chang, 9th ed. 706).

- **Rechargeable Batteries**

  The following types of batteries are recharged through the addition of electrical energy. When energy is added to the system, the reverse reaction is favoured, which produces more reactants. Balanced chemical equations are provided for each of the following types of batteries.

  - lead-acid batteries:

  $$PbO_{2(s)} + Pb_{(s)} + 4H^+_{(aq)} + 2SO_4{}^{2-}{}_{(aq)} \rightleftharpoons 2PbSO_{4(s)} + 2H_2O_{(l)} + \text{energy}$$

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-09: Discuss practical applications of Le Châtelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, carbonated beverages in a hen's diet . . .

(continued)

- nickel-cadmium batteries:

$$Cd_{(s)} + 2NiO(OH)_{(s)} + 2H_2O_{(l)} \rightleftharpoons 2PbSO_{4(s)} + 2H_2O_{(l)} + \text{energy}$$

- fuel cells:

$$2H_{2(g)} + O_{2(g)} \rightleftharpoons 2H_2O_{(l)} + \text{energy}$$

- **Turbocharged/Supercharged Engines**

  In a turbocharged engine, air is compressed and heated. This means that there is a higher concentration (50 percent more) of warmer oxygen reacting with the gasoline. This favours the production of products, which generates more power for the car.

  Turbochargers in normal engines work best at higher altitudes where the air is less dense. The steam created by the reaction of the gasoline and oxygen is used to turn a turbine that runs the air compressor. In a supercharger, a belt runs the compressor.

$$\text{Gasoline} + O_2 \rightleftharpoons CO_2 + H_2O + \text{power}$$

- **Ester Synthesis**

  Reactions producing esters favour the reverse reaction. To favour the forward reaction, scientists must increase the amount of acid present in the system.

$$CH_3OH + CH_3COOH \rightleftharpoons CH_3COOCH_3 + H_2O$$

- **Weather Indicators**

  Students may have seen that weather indicators are blue under normal conditions but turn pink to indicate approaching rain. The colour changes are due to changes in the colour of cobalt(II) chloride:

$$\underset{\text{blue}}{[CoCl_4]^{2-}} + 6H_2O \rightleftharpoons \underset{\text{pink}}{[Co(H_2O)_6]^{2+}} + 4Cl^-$$

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-R4: Compare diverse perspectives and interpretations in the media and other information sources.

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

C12-0-A3: Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.

C12-0-A4: Be sensitive and responsible in maintaining a balance between the needs of humans and a sustainable environment.

Alternatively, use the equilibrium system

$$CoCl_2 + 6H_2O \rightleftharpoons CoCl_2 \cdot 6H_2O$$

blue pink

In periods of low humidity, the colour of the weather indicator is blue. When the humidity is high, the products will be favoured and the colour of the indicator will be pink.

- **Eggs and Soda Pop**

Eggshells are made of calcium carbonate ($CaCO_{3(s)}$), which is made from carbon dioxide (CO_2), a product of cellular respiration.

The net equation is

$$3H_2O_{(l)} + 3CO_{2(g)} + Ca_3{}^{2+}{}_{(aq)} \rightleftharpoons 6H^+{}_{(aq)} + 3CaCO_{3(s)}$$

When chickens become hot, they pant, which decreases the concentration of carbon dioxide in the blood. To offset the stress, the equilibrium will shift in the reverse direction and decrease the amount of calcium carbonate available to make eggshells. This yields eggs with thin shells that break easily. Ted Odom, a graduate student at the University of Illinois, found that giving chickens carbonated water to drink will shift equilibrium in the forward direction and minimize the effects of panting on warm days. This allows farmers to minimize the effects without having to install expensive air conditioning in chicken coops (van Kessel, et al. 457).

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-09: Discuss practical applications of Le Chatelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, carbonated beverages in a hen's diet . . .

(continued)

SUGGESTIONS FOR ASSESSMENT

Class Discussion

To emphasize that the topic of equilibrium is not confined only to the chemistry classroom, have students provide examples of its application in a variety of contexts.

Research and Reports/Presentations

Students can research one or more applications of Le Châtelier's principle, including its use in industry. If students are to use the Internet for their research, provide them with key search words to reduce search time. Students can report on their research findings using a variety of formats:

- written reports
- visual displays (e.g., posters)
- formal class presentations

Sample rubrics for assessing research reports and presentations are provided in Appendix 11.

Collaborative Teamwork

Use collaborative strategies such as Jigsaw (see *SYSTH* 3.20) or Roundtable discussions (see Appendix 7) to have students share their knowledge of specific examples of Le Chatelier's principle with their classmates.

Journal Writing

1. Have students reflect on common examples of Le Châtelier's principle. Students' reflections could be based on examples from their everyday lives or from careers that use the principle.

2. Students can describe how their bodies would relieve the stress placed on them by climbing to a high altitude (Fisher 251).

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-R4: Compare diverse perspectives and interpretations in the media and other information sources.

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

C12-0-A3: Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.

C12-0-A4: Be sensitive and responsible in maintaining a balance between the needs of humans and a sustainable environment.

Quiz/Test

Test students on their understanding of the applications of Le Châtelier's principle, using questions such as the following:

1. When someone takes your photograph, you may see a "ghost" image of the flash for several minutes after the photo is taken. Explain this phenomenon in terms of the rates of the forward and reverse rhodopsin reactions in the eye.

   Answer:

   When the flash occurred, the photoreceptors in the eye responded quickly to the bright burst. However, since the reverse reaction is much slower, and the intensity of the flash was so great, a ghost image can be seen for several minutes while the reactions in the photoreceptors take time to reverse themselves.

2. When isopentyl alcohol and acetic acid react, they form the pleasant-smelling compound isopentyl acetate (the essence of banana oil):

   $$C_5H_{11}OH_{(aq)} + CH_3COOH_{(aq)} \rightleftharpoons CH_3COOC_5H_{11(aq)} + H_2O_{(l)}$$

   A student adds a drying agent to remove water in an attempt to increase the yield of banana oil. Is this approach reasonable? Explain.

   Answer:

   Adding a drying agent will decrease the amount of water present in the system. To minimize the stress and re-establish equilibrium, the system will favour the production of more products. Thus, adding a drying agent is a reasonable course of action to increase the yield of banana oil.

Rubrics/Checklists

See Appendix 11 for a variety of rubrics and checklists that can be used for self-, peer-, and teacher-assessment for any of the research presentations.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-09: Discuss practical applications of Le Chatelier's principle.

Examples: Haber process, hemoglobin production at high altitude, carbonated beverages, eyes adjusting to light, blood pH, recharging of batteries, turbocharged/supercharged engines, ester synthesis, weather indicators, carbonated beverages in a hen's diet . . .

(continued)

LEARNING RESOURCES LINKS

Chemistry, 9th ed. (Chang 630, 706)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 755)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 216)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 574, 588)

Glencoe Chemistry: Matter and Change, Science Notebook (Fisher 251)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 525, 526, 530)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 648, 669)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 457, 461)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, et al. 161)

Websites

Blickenstaff, Jacob Clark. "Haber: Ethics in the Laboratory." 21 Jan. 2011. *National Science Teachers Association*. <www.nsta.org/publications/news/story.aspx?id=58157&print=true> (27 Dec. 2012).

Clark, Jim. "The Haber Process." *Chemguide.* 2002. <www.chemguide.co.uk/physical/equilibria/haber.html> (13 Jan. 2012).

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-R4: Compare diverse perspectives and interpretations in the media and other information sources.

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

C12-0-A3: Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.

C12-0-A4: Be sensitive and responsible in maintaining a balance between the needs of humans and a sustainable environment.

NOTES

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-10: Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11: Solve problems involving K_{sp}.
Include: common ion problems

(3.5 hours)

SLO: C12-4-10
SLO: C12-4-11

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In addressing learning outcomes C12-1-01 and C12-1-02, students saw reactions that produce precipitates.

TEACHER NOTES

Solubility Product Constants

In addressing learning outcomes C12-4-10 and C12-4-11, students should become aware that the precipitates formed by double displacement reactions are not insoluble, but *slightly soluble*. For example, while a solubility table would indicate that silver chloride (AgCl) is insoluble, it does undergo both dissociation and precipitation to set up the equilibrium

$$AgCl_{(s)} \underset{}{\overset{H_2O}{\rightleftharpoons}} Ag^{+}_{(aq)} + Cl^{-}_{(aq)}$$

Earlier in Topic 4, students calculated equilibrium constants using the ratio of product concentrations (raised to the value of their coefficients from the balanced equation) to reactant concentrations (raised to the value of their coefficients from the balanced equation) at equilibrium.

$$K_{eq} = \frac{\left[Ag^{+}_{(aq)}\right]\left[Cl^{-}_{(aq)}\right]}{\left[AgCl_{(s)}\right]}$$

Since solids are not included in equilibrium expressions, as their concentrations are constant, solubility product constants are calculated using only the concentrations of products at equilibrium.

$$K_{sp} = [Ag^{+}][Cl^{-}]$$

Like equilibrium constants, solubility product constants are specific for only one reaction at a particular temperature. The higher the K_{sp} value is, the higher the solubility of the salt will be.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

Examples:

The following K_{sp} values are given for some salts at 25°C (Chang 720):

- calcium phosphate $K_{sp} = 1.2 \times 10^{-26}$
- silver bromide $K_{sp} = 7.7 \times 10^{-13}$
- barium fluoride $K_{sp} = 1.7 \times 10^{-6}$

In these examples, barium fluoride (BaF_2) has a higher solubility than the other two salts, calcium phosphate ($Ca_3(PO_4)_2$) and silver bromide (AgBr) because BaF_2 has the larger K_{sp} value. Calcium phosphate will dissolve very slightly in water due to its very low K_{sp} value.

Be sure to clarify the difference between *solubility* (the number of moles of solute that will dissolve in 1 L of solution, known as concentration) and *solubility product* (the product of the concentrations of ions in solution, raised to the powers of their coefficients in the balanced equation).

In chemistry textbooks, units for K_{sp} are not used because they would vary depending on the powers to which the concentrations are raised, such as mol/L to $(mol/L)^2$ to $(mol/L)^3$.

Visual representations can be viewed online.

Sample Website:

University of Colorado at Boulder. "Salts and Solubility." *PhET Interactive Simulations.* <http://phet.colorado.edu/en/simulation/soluble-salts> (22 Nov. 2012).

In this simulation, students can add different salts to water and watch them dissolve and achieve a dynamic equilibrium with a solid precipitate. They compare the number of ions in solution for highly soluble NaCl to other slightly soluble salts and calculate K_{sp} values.

Solving K_{sp} Problems

When asking students to solve problems involving K_{sp}, limit the problems to

- calculating the K_{sp}, given the molar solubility of a compound
- using an ICE table to solve for the molar solubility of a slightly soluble salt
- identifying the concentration of ions present at equilibrium when the K_{sp} value of the slightly soluble salt has been provided
- determining the molar solubility of a slightly soluble salt in a solution containing a known concentration of a common ion

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-10: Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11: Solve problems involving K_{sp}.

Include: common ion problems

(continued)

Sample problems and solutions follow.

Example 1:

Calculate the K_{sp}, given the molar solubility of a compound.

The solubility of calcium sulphate ($CaSO_4$) is 4.9 × 10^{-3} mol/L. Calculate the K_{sp} for $CaSO_4$.

Solution:

1. Write the dissociation equation for $CaSO_4$.

   $CaSO_{4(s)} \longrightarrow Ca^{2+}{}_{(aq)} + SO_4{}^{2-}{}_{(aq)}$

2. Write the ion-product, or K_{sp}, expression.

   $K_{sp} = [Ca^{2+}][SO_4{}^{2-}]$

3. Substitute the molar concentrations of the ions, Ca^{2+} and $SO_4{}^{2-}$, into the K_{sp} expression and solve the problem.

   $K_{sp} = [4.9 \times 10^{-3}\ \text{mol/L}][4.9 \times 10^{-3}\ \text{mol/L}]$

   $K_{sp} = 2.4 \times 10^{-5}$

Example 2:

Use an ICE table to solve for the molar solubility of a slightly soluble salt.

Calculate the molar solubility of lead chloride ($PbCl_2$) in pure water at 25°C. K_{sp} for $PbCl_2$ is 2 × 10^{-5}.

Solution:

1. Write the dissociation equation for $PbCl_2$.

   $PbCl_{2(s)} \longrightarrow Pb^{2+}{}_{(aq)} + 2Cl^{-}{}_{(aq)}$

2. Set up an ICE table and fill in the values for the unknown ions. Note that for every Pb^{2+} ion there are two Cl^{-} ions, which can be seen from the balanced equation

   $PbCl_{2(s)}) \longrightarrow Pb^{2+}{}_{(aq)} + 2Cl^{-}{}_{(aq)}$

I	?	0	0
C	?	+ x	+ $2x$
E	?	x	$2x$

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

3. Write the ion-product, or K_{sp}, expression and substitute the known values into the expression.

   $K_{sp} = [Pb^{2+}][Cl^-]^2$

   $2 \times 10^{-5} = (x)(2x)^2$

4. Solve for x.

   $2 \times 10^{-5} = 4x^3$

   $x^3 = 5 \times 10^{-6}$

   $x = 1.7 \times 10^{-2}$ mol/L

The molar solubility of $PbCl_2$ in pure water at 25°C is

1.7×10^{-2} mol/L

Example 3:

Identify the concentration of ions present at equilibrium when the K_{sp} value of the slightly soluble salt has been provided.

What is the concentration of silver and chloride ions in a saturated silver chloride (AgCl) solution at 25°C?

$K_{sp} = 1.8 \times 10^{-10}$

Solution:

1. Write the dissociation equation for AgCl.

   $AgCl_{(s)} \longrightarrow Ag^+_{(aq)} + Cl^-_{(aq)}$

2. Set up an ICE table and fill in the table for the unknown values of the ions, x.

	AgCl ⟶	$Ag^+_{(aq)}$ +	$Cl^-_{(aq)}$
I	?	0	0
C	?	+ x	+ x
E	?	x	x

3. Write the ion-product, or K_{sp}, expression and substitute the known values into the expression.

   $K_{sp} = [Ag^+][Cl^-]$

   $1.8 \times 10^{-10} = (x)(x)$

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-10: Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11: Solve problems involving K_{sp}.
Include: common ion problems

(continued)

4. Solve for *x*.

$1.8 \times 10^{-10} = (x)^2$

$x^2 = 1.8 \times 10^{-10}$

$x = 1.3 \times 10^{-5}$ mol/L

The molar solubilities of the ions at equilibrium are equal to

$x = [Ag^+] = [Cl^-] = 1.3 \times 10^{-5}$ mol/L

Example 4:

Determine the molar solubility of a slightly soluble salt in a solution containing a known concentration of a common ion.

Calculate the molar solubility of silver chloride (AgCl) in a 1.5×10^{-3} mol/L silver nitrate ($AgNO_3$) solution.

K_{sp} for AgCl = 1.6×10^{-10}

Solution:

This is a common ion problem. The common ion is Ag^+, which is present in AgCl and $AgNO_3$. Note that the presence of the common ion affects the solubility of AgCl (in mol/L) but not the K_{sp} value because it is an equilibrium constant.

1. $AgNO_3$ dissociates completely, as shown by the equation

$AgNO_{3(s)} \longrightarrow Ag^+_{(aq)} + NO_3^-{}_{(aq)}$

Since the concentration of $AgNO_3$ is given as 1.5×10^{-3} mol/L,

$[Ag^+] = 1.5 \times 10^{-3}$ mol/L

Write the dissociation equation for AgCl.

$AgCl_{(s)} \longrightarrow Ag^+_{(aq)} + Cl^-{}_{(aq)}$

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

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2. Set up an ICE table and fill in the values for the unknown ions. Remember that there are two sources for the Ag+ ion, 1.5×10^{-3} mol/L from $AgNO_3$, and the unknown amount, x, from AgCl.

	$AgCl_{(s)} \longrightarrow$	$Ag^+_{(aq)}$	+	$Cl^-_{(aq)}$
I	?	1.5×10^{-3}		0
C	?	$+ x$		$+ x$
E	?	$1.5 \times 10^{-3} + x$		x

3. Write the ion-product, or K_{sp}, expression and substitute the known values into the expression.

$$K_{sp} = [Ag^+][Cl^-]$$

$$1.6 \times 10^{-10} = (1.5 \times 10^{-3} + x)(x)$$

This x can be ignored because the amount of Ag^+ ion that can dissolve from AgCl is very small compared to the amount of Ag^+ generated from $AgNO_3$.

4. Solve for x.

$$1.6 \times 10^{-10} = (1.5 \times 10^{-3})(x)$$

$$x = 1.1 \times 10^{-7}$$

$$[AgCl] = 1.1 \times 10^{-7} \text{ mol/L}$$

The molar solubility of AgCl in a 1.5×10^{-3} mol/L solution $AgNO_{3(aq)}$ is

1.1×10^{-7} mol/L

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOMES

C12-4-10: Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11: Solve problems involving K_{sp}.
Include: common ion problems

(continued)

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

Have students write K_{sp} expressions from given chemical equations.

1. Write the expression for the solubility product constant for strontium sulphate ($SrSO_4$).

   Answer:

   $$SrSO_{4(s)} \rightleftharpoons Sr^{2+}{}_{(aq)} + SO_4{}^{2-}{}_{(aq)}$$

   $$K_{sp} = \left[Sr^{2+}\right]\left[SO_4{}^{2-}\right]$$

2. Write the expression for the solubility product constant for aluminum sulphate $Al_2(SO_4)_3$.

   Answer:

   $$Al_2\left(SO_4\right)_{3(s)} \rightleftharpoons 2Al^{3+}{}_{(aq)} + 3SO_4{}^{2-}{}_{(aq)}$$

   $$K_{sp} = \left[Al^{3+}\right]\left[SO_4{}^{2-}\right]^3$$

Sample Problems:

1. A sample of barium hydroxide ($Ba(OH)_{2(s)}$) is added to pure water and allowed to come to equilibrium at 25°C. The concentration of Ba^{2+} is found to be 0.108 mol/L and that of OH^- is found to be 0.216 mol/L. What is the value of K_{sp} for $Ba(OH)_{2(s)}$?

   Answer:

   $K_{sp} = 5.04 \times 10^{-3}$

2. What is the molar solubility of a saturated solution of silver chloride (AgCl)? $K_{sp} = 1.6 \times 10^{-10}$.

   Answer:

   $AgCl = 1.26 \times 10^{-5}$ mol/L

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

3. What will be the equilibrium concentrations of Ca^{2+} and OH^- in a saturated solution of calcium hydroxide ($Ca(OH)_2$) if its K_{sp} value is 1.3×10^{-6}?

   Answer:

   $[Ca^{2+}] = 6.9 \times 10^{-3}$ mol/L

   $[OH^-] = 1.4 \times 10^{-2}$ mol/L

4. Calculate the molar solubility of calcium iodate ($Ca(IO_3)_2$) in 0.060 mol/L sodium iodate ($NaIO_3$). The K_{sp} of $Ca(IO_3)_2$ is 7.1×10^{-7}.

   Answer:

   2.0×10^{-4} mol/L

Extension:

5. Will a precipitate form when 1.00 L of 0.150 mol/L iron(II) chloride solution ($FeCl_2$) is mixed with 2.00 L of 0.0333 mol/L sodium hydroxide solution (NaOH)?

   Answer:

   Trial K_{sp} or $Q_{sp} = 2.46 \times 10^{-5}$, $K_{sp} = 4.9 \times 10^{-17}$. $Q_{sp} > K_{sp}$, so a precipitate will form.

Journal Writing

Have students "explain how adding additional sulfate ions to a saturated solution of barium sulfate would affect the concentration of barium ions" (Dingrando, et al., *Glencoe Chemistry: Matter and Change*, *Teacher Wraparound Edition* 577).

LEARNING RESOURCES LINKS

Chemistry, 9th ed. (Chang 720)

Chemistry (Zumdahl and Zumdahl 757)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 833)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 577)

Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition (Dingrando, et al 577)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 483, 490)

Prentice Hall Chemistry (Wilbraham, et al. 560)

Topic 4: Chemical Equilibrium

Specific Learning Outcomes

C12-4-10: Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility.

C12-4-11: Solve problems involving K_{sp}.

Include: common ion problems

(continued)

Website

University of Colorado at Boulder. "Salts and Solubility." *PhET Interactive Simulations*. <http://phet.colorado.edu/en/simulation/soluble-salts> (22 Nov. 2012).

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

NOTES

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-12: Describe examples of the practical applications of salts with low solubility.

Examples: kidney stones, limestone caverns, osteoporosis, tooth decay . . .

(0.5 hour)

SLO: C12-4-12

SUGGESTIONS FOR INSTRUCTION

TEACHER NOTES

Practical Applications of Salts with Low Solubility

The following examples of the practical applications of salts with low solubility are provided to indicate the importance of slightly soluble salts in our lives. Students are not expected to learn the examples in great detail. Teachers can either have students collect information from their own textbooks or, if information is limited, through additional research. Some information is provided here for teacher reference.

- **Limestone Caverns**

  Limestone ($CaCO_3$) is formed through the decay of marine organisms such as snails, clams, corals, and algae. In water, the slightly soluble salt will set up the following equilibrium:

  $$CaCO_{3(s)} \rightleftharpoons Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)}$$

  The chemical erosion of limestone occurs when it is in contact with acidic water:

  $$H^{+}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightleftharpoons HCO_3^{-}{}_{(aq)}$$

  If the limestone deposit is deep enough underground, the dissolution of the limestone produces a cave.

General Learning Outcome Connections

GLO A5: Recognize that science and technology interact with and advance one another.

GLO B2: Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO C7: Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-C1: Collaborate with others to achieve group goals and responsibilities.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

- **Osteoporosis**

Approximately 99 percent of the body's calcium is stored in the bones, where it forms the following equilibrium system:

$$Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}{}_{(aq)} + 2PO_4{}^{3-}{}_{(aq)}$$

When the concentration of calcium in the blood decreases, balance can be restored if the solubility of the calcium phosphate (bone) increases. This leads to the development of porous, brittle bones. We can prevent this from happening by obtaining the minimum daily requirement of calcium (especially between the ages of 10 and 20 when bone growth is most rapid) and through regular weight-bearing exercise. Note, however, that large amounts of calcium in the body may lead to the formation of kidney stones.

- **Tooth Decay**

The major constituent of tooth enamel is hydroxyapatite ($Ca_5(PO_4)_3OH$, $K_{sp} = 6.8 \times 10^{-37}$). In the mouth, the following equilibrium is established:

$$Ca_5(PO_4)_3OH_{(s)} \rightleftharpoons Ca_5(PO_4)^{3+}{}_{(aq)} + OH^-{}_{(aq)}$$

When sugar ferments on the teeth, the hydronium ion is produced. It reacts with the hydroxide ion from the previous reaction, causing the forward reaction to be favoured. An increase in the solubility of the hydroxyapatite leads to the dissolving of tooth enamel. In recent years, fluoride has been added to water and toothpaste. The fluoride ion replaces the hydroxide ion in hydroxyapaptite to create fluorapatite ($Ca_5(PO_4)_3F$, $K_{sp} = 1.0 \times 10^{-60}$). As the fluorapatite is less soluble in water, teeth become more resistant to cavities.

The addition of fluoride to toothpaste has been helpful in preventing tooth decay; however, fluoride is not added to children's toothpaste because an excess of fluoride in the body from swallowing large amounts of paste can lead to fluorosis, damaging teeth and bones.

Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-12: Describe examples of the practical applications of salts with low solubility.

Examples: kidney stones, limestone caverns, osteoporosis, tooth decay . . .

(continued)

SUGGESTIONS FOR ASSESSMENT

Class Discussion

To emphasize that the topic of the solubility of slightly soluble salts is not confined to the chemistry classroom, have students provide examples of its practical application in a variety of contexts.

Research and Reports/Presentations

1. Students can research and report on one or more applications of salts with low solubility. Results can be shared in written, verbal, or electronic format. If students are to use the Internet for their research, provide them with key search words to reduce search time.
2. Using their research, students can describe how the solubility of slightly soluble salts is used in industry. Information may be shared with the entire class through formal presentations.
3. Students could research the insoluble lead compounds that, for many years, were used as paint pigments, which led to people, especially children, being poisoned by exposure to lead-based paints (Dingrando et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 578).

Visual Displays

Students can create visual displays (e.g., posters) to demonstrate practical applications of the solubility of slightly soluble salts. Samples of presentation rubrics are provided in Appendix 11.

Collaborative Teamwork

Collaborative strategies such as Jigsaw (see *SYSTH* 3.20) or Roundtable (see Appendix 7) could be used to have students share their knowledge of specific applications of the solubility of slightly soluble salts with their classmates.

Journal Writing

Have students reflect on common applications of the solubility of slightly soluble salts. Students' reflections could be based on examples from their everyday lives or on career-related applications.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-C1: Collaborate with others to achieve group goals and responsibilities.

C12-0-T3: Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.

LEARNING RESOURCES LINKS

Chemistry (Chang 719)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 840)

Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition (Dingrando, et al 578)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 482)

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Topic 4: Chemical Equilibrium

SPECIFIC LEARNING OUTCOME

C12-4-13: Perform a laboratory activity to determine the K_{sp} of a salt with low solubility.

(1.5 hours)

SLO: C12-4-13

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In addressing learning outcome C12-4-11, students solved problems involving K_{sp}. Learning outcome C12-4-13 provides students with an opportunity to use experimental data to calculate the value of K_{sp} for a slightly soluble salt.

Laboratory Activities

Have students perform a lab activity to determine the K_{sp} of a salt with low solubility. Possible lab activities are suggested below.

- **Experiment 39: A Solubility Product Constant** (Wilbraham, Staley, and Matta 243)

  The purpose of this lab activity is to determine the solubility product constant of lead(II) chloride ($PbCl_2$). Students add 100 mL of saturated $PbCl_2$ to 20 mL of 0.5 mol/L potassium chromate (K_2CrO_4) solution. The mixture is heated to the boiling point and then left to stand and cool for at least five minutes. Students decant the liquid from the beaker, making sure most of the precipitate stays in the beaker. The filter paper is placed in the beaker with the precipitate and then dried. The K_{sp} of $PbCl_2$ is then determined through a series of calculations.

- **Chemlab 18: Comparing Two Solubility Product Constants** (Dingrando, et al. 586)

  The objectives of this lab activity are to compare the values of the K_{sp} for two different compounds and relate them to observations, to explain observations of the two precipitates using Le Châtelier's principle, and to calculate the molar solubilities of the two ionic compounds from their K_{sp} values. As this is a small-scale lab activity, minimal quantities of chemicals are used. Students add 10 drops of silver nitrate ($AgNO_{3(aq)}$) and 10 drops of sodium chloride ($NaCl_{(aq)}$) to two wells of a microplate, and observe that the precipitates that form, silver chloride ($AgCl_{(s)}$), are white. To the second well, students add 10 drops of sodium sulphide (Na_2S) solution. The precipitate that forms, silver sulphide ($Ag_2S_{(s)}$), is black.

General Learning Outcome Connections

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S5: Collect, record, organize, and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S6: Estimate and measure accurately using Système International (SI) and other standard units.
Examples: SI conversions and significant figures

- **Investigation 7.6.1: Determining the K_{sp} of Calcium Oxalate** (van Kessel, et al. 517)

  For this investigation, students determine the K_{sp} of calcium oxalate (CaC_2O_4) by mixing a fixed volume of 0.1 mol/L sodium oxalate ($Na_2C_2O_4$) with a serial dilution of aqueous calcium nitrate ($Ca(NO_3)_2$) in a series of spot-plate wells.

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

Students could use the Laboratory Report Format to write their lab reports (see *SYSTH* 14.12). Word processing and spreadsheet software could be used to prepare reports. Also refer to the Lab Report Assessment rubric in Appendix 11.

Laboratory Skills

Periodically and randomly review the lab skills of individual students, so that eventually all students are assessed. Develop a checklist for the assessment of skills related to measuring and mixing solutions. Sample checklists for assessing lab skills and work habits are available in *SYSTH* (6.10, 6.11).

LEARNING RESOURCES LINKS

Investigations

Glencoe Chemistry: Matter and Change (Dingrando, et al.)
Chemlab 18: Comparing Two Solubility Product Constants, 586

Nelson Chemistry 12, Ontario Edition (van Kessel, et al.)
Investigation 7.6.1: Determining the K_{sp} of Calcium Oxalate, 517

Prentice Hall Chemistry: Laboratory Manual (Wilbraham, Staley, and Matta)
Experiment 39: A Solubility Product Constant, 243

Selecting Learning Resources

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