Manitoba

Education, Citizenship and Youth

Chemistry – Grade 12

Unit 4 - Chemical Equilibrium

DRAFT / Unedited Version

May 2008

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Manitoba

Specific Learning Outcomes

C12-4-01 Relate the concept of equilibrium to physical and chemical systems.
Include: conditions necessary to achieve equilibrium. (1 hour)

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

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…
GLO: D3

Entry-Level Knowledge

In Grade 9 Science students were introduced to the difference between physical and chemical changes (outcome S1-2-12). In Grade 11 Chemistry (outcomes 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

Teachers should check for prior knowledge and review 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).

Activating Demonstration

This topic should be introduced with a demonstration showing the reversibility of chemical reactions. The classic "Blue Bottle" demonstration is very visual in showing a reversible reaction. In a 1000 mL Erlenmeyer flask, dissolve 14 g NaOH in 700 mL distilled water. Add 14 g of dextrose (or glucose) and 1 mL methylene blue to the NaOH solution. Stopper tightly. Shake vigorously and the solution is blue in colour. Allow the solution to sit and then the colour clears. This system involves the oxidation of dextrose (or glucose) by oxygen (caused by shaking the flask) and the methylene blue acts as a catalyst for this reaction. (Smoot 121T). Have students describe the reaction in the flask and speculate why the solution doesn't stay blue.

A video of this demonstration may be seen at
Purdue University: College of Science, Chemical Education Division Groups

19.1 The Blue Bottle Demonstration
http://chemed.chem.purdue.edu/demos/main_pages/19.1.html

Teacher Notes

Up to this point, the curriculum has only addressed reversibility in physical systems (i.e. phase changes and dissociation). Students must now be introduced to the potential for reversibility in chemical systems. Teachers should discuss the conditions that are necessary to achieve equilibrium in physical and chemical systems and stress the differences between the two systems. Physical equilibria require a closed system at constant temperature. Examples of physical equilibria are evaporating and dissolving. In Diagram 1, 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, there is another water vapour molecule, $H_2O(g)$, that condenses to the liquid state. This is an example of a reversible reaction for a physical equilibrium.

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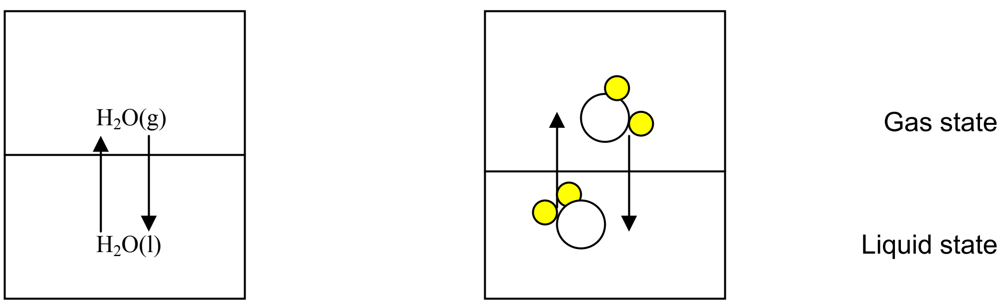
Diagram 1



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 the liquid phase.
Chemistry Experiment Simulations, Tutorials and Conceptual Computer Animations for Introduction to College Chemistry (aka General Chemistry)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/equilvpBr2V8.html
[$Br_{2(l)}$- $Br_{2(g)}$]

Teacher Notes

The conditions required for chemical equilibria include: constant observable macroscopic properties (temperature, pressure, concentration are some examples), a closed system, constant temperature, reversibility and when the rates of opposing changes are equal. [Chastko 637]

An example of a reversible reaction for a chemical equilibrium is
$H_2(g) + Cl_2(g) \leftrightarrows 2\,HCl(g)$

At the molecular 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.
See diagram 2 for a molecular representation of this reversible reaction.

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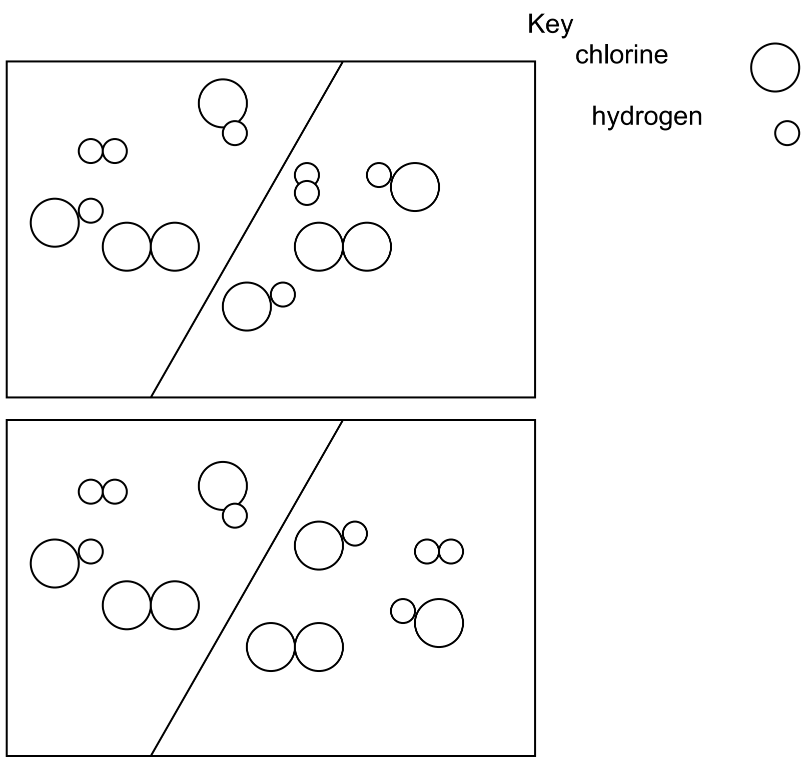
Diagram 2



Notice the right side of the diagram shows $H_2 + Cl_2$ combining to form 2 molecules of HCl. In the bottom diagram, right side, the two molecules of HCl have combined to reform $H_2 + Cl_2$.

Demonstration / Animation
The teacher can demonstrate a chemical equilibrium with a NO_2-N_2O_4 system or a $CoCl_4^{2-}$—$Co(H_2O)_6^{2+}$ system. See Appendix 1: Preparation of Equilibrium Systems for preparation. Also, sealed units of NO_2-N_2O_4 can be purchased from science supply companies rather than preparing the tubes for classroom demonstration.

The animation at this website shows the N_2O_4-NO_2 reaction at the molecular level.
Chemistry Experiment Simulations, Tutorials and Conceptual Computer Animations for Introduction to College Chemistry (aka General Chemistry)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/no2n2o4equilV8.html

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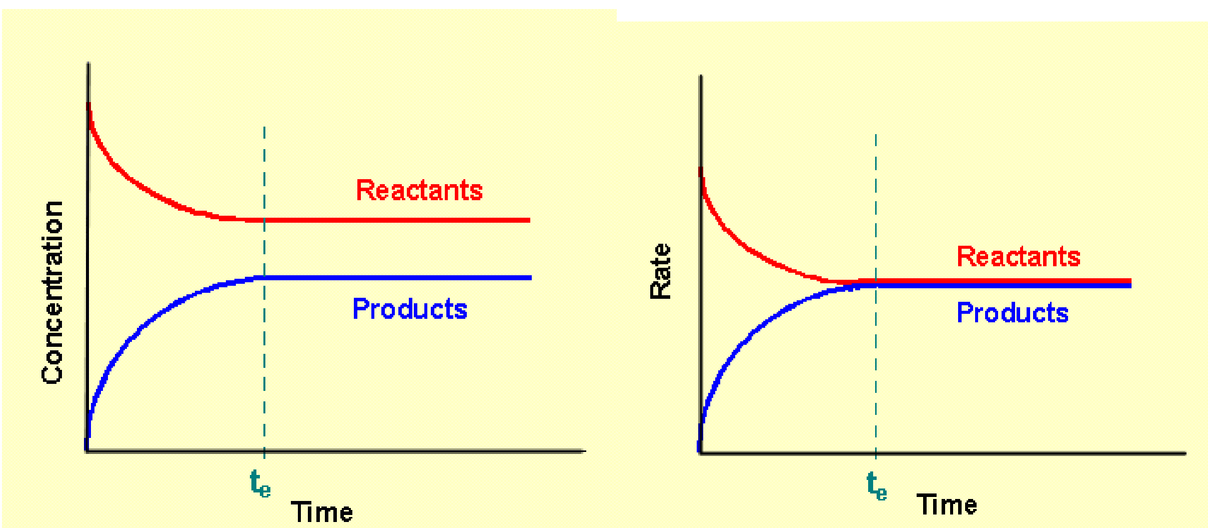
[N_2O_4-NO_2]

The following website shows a macroscopic view of equilibrium, using 2 different sizes of shovels to fill/unfill a well. Section 3 shows the same concept using the NO_2-N_2O_4 chemical equilibrium.
Chemistry: The Science in Context; W.W. Norton & Company
http://www.wwnorton.com/college/chemistry/gilbert/overview/ch15.htm
Equilibrium Tutorial Chapter 15, section 2 (A Macroscopic Equilibrium) and section 3 (Chemical Equilibrium)

Teacher Notes
How systems achieve equilibrium can be demonstrated through rate vs. time and concentration vs. time graphs.



Teachers must point out to the students that equilibrium occurs as soon as the plateau begins to avoid the misconception that equilibrium has been achieved by the end of the plateau.
It must be stressed that a quantitative discussion of these graphs is to be avoided at this point.

Student Activity

Students can be used to represent sodium and chloride ions in the following reaction:
$NaCl_{(s)} + heat \leftrightarrows Na^{+}_{(aq)} + Cl^{-}_{(aq)}$

For example in a class of 20 students, 10 students would represent sodium ions and 10 students would represent chloride ions. Have 4 sodium ions and 4 chloride ions link arms on the left hand side of the room to represent sodium chloride particles. The remaining 12 students would stand on the right hand side of the room. Have 1 student record the number of each particle on the board.

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At this point the teacher would need to explain that in order for sodium chloride to break apart, heat is required. Have 4 pieces of red construction paper on the floor (to represent the heat), that 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 hand side of the room. (The sodium ions in the sodium chloride particle should hold onto the heat).

Students on the right hand side of the room could use the heat to join together to form a sodium chloride particle and move to the left hand side of the room. Teachers can 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 one more time so that students can see that equilibrium has occurred.

It should be stressed at this point that the process of equilibrium is not finished. The forward and reverse processes continue to occur.

Lab Activity
Have students perform the Discovery Lab: What's equal about equilibrium? (from *Dingrando*, 559)
For this activity, students place 20 mL of water in a graduated cylinder and also place 20 mL in a beaker. One glass tube is placed in the graduated cylinder and another glass tube is placed in the beaker. The end of each glass tube is covered with the index fingers and simultaneously water is transferred from the cylinder to the beaker and also 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

<u>Paper and Pencil Tasks</u>
Students can complete a compare and contrast think sheet for the following: physical and chemical systems, open and closed systems.
Students can be presented with examples of situations that show systems which may or may not be at equilibrium. They should identify both types of systems.
Students can be presented with data tables and be asked to identify whether the reaction is at equilibrium or not.

<u>Journal Writing</u>
Students can list reactions that are reversible (dissolving salt in water) and not reversible (burning paper).
Students can 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 won't necessarily be equal.

Learning Resources Links
Appendix 1: Preparation of Equilibrium Systems [From Transitional Chem 40S document]

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GLO: D3

Chemistry (Chang 586)

Chemistry (Zumdahl and Zumdahl 612 5thed)

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

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

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

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

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

Prentice Hall Chemistry (Wilbraham *et al*. 549)

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

Websites
Chemistry Experiment Simulations, Tutorials and Conceptual Computer Animations for Introduction to College Chemistry (aka General Chemistry)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animations/no2n2o4equilV8.html
[N_2O_4-NO_2]

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[$Br_{2(l)}$- $Br_{2(g)}$]

Chemistry: The Science in Context; W.W. Norton & Company
http://www.wwnorton.com/college/chemistry/gilbert/overview/ch15.htm
Equilibrium Tutorial Chapter 15, section 2 (A Macroscopic Equilibrium) and section 3 (Chemical Equilibrium)

Purdue University: College of Science, Chemical Education Division Groups
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Specific Learning Outcomes

C12-4-02 Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems. (1 hour)

C12-4-03 Use the value of the equilibrium constant to identify how far a system at equilibrium has gone towards completion. (0.5 hours)

C12-4-04 Solve problems involving equilibrium constants. (2 hours)

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Entry-Level Knowledge

In Science 7 students were introduced to heterogeneous and homogeneous solutions. Teachers should check for prior knowledge and review as necessary.

Teacher Notes

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 law of mass action (or law of chemical equilibrium). The law of mass action was introduced in 1864 by Cato Maximillian Guldberg and Peter Waage, two Norwegian chemists. Guldberg and Waage 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).

Mass Action Expression (or 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 are 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).

Solids and liquids are not included in the mass action expression because their concentrations are constant. It doesn't matter how much of the solid or liquid is present, the concentration (mol / dm^3) 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}). Students should be made aware 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 towards 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 that the reaction was close to completion when equilibrium was achieved (and vice versa).

Approved 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 should be limited to:

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GLO: D3

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1. Solving for K_{eq} given equilibrium concentrations of all reactants and products.
2. Solving for an equilibrium concentration when K_{eq} and the equilibrium concentrations of all remaining reactants and products are given.
3. Using an ICE table (see **Appendix 2** : ICE and **Appendix 3:** B.I.R/P.E.C. method) to solve for K_{eq} given an initial concentration or an equilibrium concentration of one of the products.

"You may find 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 (X) sign when entering scientific-notation numbers. Point out that the exponent key ([EXP] on most calculators…or [EE] on others) actually represents "X 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*. 579 Teacher's Edition)

Student Activity
Students can determine a mathematical relationship between the equilibrium concentrations of reactants and products in a given data set.

<u>Problem</u>
Your supervisor in the Chem Lab wants you to determine a mathematical relationship for the data that he/she found from studying the following chemical equilibrium:

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

What mathematical formula using equilibrium concentrations of reactants and products gives a constant (K) for the hydrogen iodide reaction system?
Hints:
1. Be sure to analyze all of your data to test your formula.
2. Remember that the rate of the forward reaction is equal to the rate of the reverse reaction at equilibrium.

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

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C12-4-02 Write equilibrium law expressions from balanced chemical equations for heterogeneous and homogeneous systems. (1 hour)

C12-4-03 Use the value of the equilibrium constant to identify how far a system at equilibrium has gone towards completion. (0.5 hours)

C12-4-04 Solve problems involving equilibrium constants. (2 hours)

Skills and Attitudes Outcomes

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GLO: D3

Problem Solution:

$Rate_{forward} = k_f[H_2][I_2]$
$Rate_{reverse} = k_r[HI]^2$
At equilibrium,
$Rate_{forward} = Rate_{reverse}$
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

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

is the value obtained.

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

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

Student groups should obtain answers in the order of 60 or 0.02 when using the concentrations given in the other trials. Let students know that scientists collectively agreed that the equilibrium constants would be reported in texts such as the CRC Handbook (a.k.a. "The Rubber Book") using the ratio of product to reactant concentrations, or

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

Sample Problem for Heterogeneous Equilibrium
Write the mass action expression for the decomposition of solid calcium carbonate.

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

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C12-4-04 Solve problems involving equilibrium constants. (2 hours)

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GLO: D3

Solution:
Applying the standard form of the mass action expression, the equation would be written as follows:

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

But, the concentration 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

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

Suggestions for Assessment

Paper and Pencil Tasks
Students can write equilibrium law expressions from given chemical equations and write chemical equations from equilibrium law expressions.

Have students use process notes to show the derivation of a mass action expression for a reaction that involves solids and/or liquids.

Provide students with various K_{eq} values and have the students identify which reactions were close to completion when equilibrium was achieved and which were not.

Have students solve problems involving equilibrium constants (see Appendix 4 for problems and solutions).

Journal Writing
Students can 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. (Teacher's Edition, Chemistry: Matter and Change, 563)

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Learning Resources Links

Appendix 2: ICE

Appendix 3: B.I.R/P.E.C.

Appendix 4 : BLM Activity Sheet & Solution Set

Chemistry (Chang 587, 588, 600)

Chemistry (Zumdahl and Zumdahl 615 5thed)

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

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

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

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

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

Prentice Hall Chemistry (Wilbraham *et al*. 556)

Specific Learning Outcomes

C12-4-05 Perform a lab to determine the equilibrium constant of an equilibrium system. (1.5 hr)

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), emergency equipment.
GLO: B3, B5, C1, C2

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

C12-0-S8 Evaluate data and data collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error
GLO: C2, C5

Entry-Level Knowledge
In C12-4-04, students solved problems involving equilibrium constants. This outcome provides students with an opportunity to use experimental data to calculate the value of K_{eq} for a reversible reaction.

Teacher Notes
It is not intended that all labs listed in the Learning Resource Links activities be performed by the students. Teachers should select an activity appropriate to student skill level and the equipment available at the school.

Laboratory Activity
Small Scale experiment
Lab 16: Exploring Chemical Equilibrium (Small-Scale Laboratory Manual, Dingrando *et al.,*61). Students will experiment to calculate K_{eq} for a reaction between Fe^{3+} and SCN^-. They will investigate the reaction in which colourless Fe^{3+} and SCN^- ions combine to form red $FeSCN^{2+}$ ion. In this experiment students prepare serial dilutions of $Fe(NO_3)_2$ and they will estimate the colour intensity of solutions at equilibrium. They will then relate colour-intensity values to the concentration of $FeSCN^{2+}$ at equilibrium.

Using a colorimeter or spectrometer
In this experiment, varying concentrations of the SCN^- and Fe^{3+} will be added together in order 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+}, the darker the orange-red colour of the complex. Spectrometers or colorimeters are then used to determine the absorbance of each system, which are then used to determine the equilibrium concentrations of all reactants and products in order to solve for the value of K_{eq}.
See Appendix 5 : Chemical Equilibrium or consult Chemistry with CBL. Dan Holmquist, Jack Randall, Donald L. Volz. Oregon: Vernier Software, 1997. "Chemical Equilibrium – Finding a Constant, Kc" pg. 20-1 to 20-2T.

Activity
Have students use experimental data and apply mathematical relationships to see which gives a constant value. Lab Exercise 7.2.1 Develop an Equilibrium Law (see *Nelson Chemistry 1*2, p. 514)

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Suggestions for Assessment
Laboratory Reports
Students can use Lab Report Format (see SYSTH). Word processing and spreadsheet software could be used to prepare reports.

Laboratory skills
Periodically and randomly review the lab skills of individual students, so that eventually all are assessed (see Appendix for lab skills checklist). Pay particular attention to skills related to serial dilutions from stock solutions.

Learning Resources Links
Appendix 5: Chemical Equilibrium

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

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

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

Investigations
Chemistry with CBL. Dan Holmquist, Jack Randall, Donald L. Volz. Oregon: Vernier Software, 1997. "Chemical Equilibrium – Finding a Constant, Kc" pg. 20-1 to 20-2T.

Small-Scale Laboratory Manual-Teacher's Edition, Glencoe Chemistry, Dingrando et al., McGraw-Hill, 2002 Lab 16 Exploring Chemical Equilibrium 61

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

Specific Learning Outcomes

C12-4-05 Perform a lab to determine the equilibrium constant of an equilibrium system. (1.5 hr)

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), emergency equipment.
GLO: B3, B5, C1, C2

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

C12-0-S8 Evaluate data and data collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error
GLO: C2, C5

Investigation 16.C Using Experimental Data to Determine an Equilibrium Constant, p. 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}.

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

Investigation 13-A Measuring and Equilibrium Constant, p. 501
(Similar to Investigation 16.C Using Experimental Data to Determine an Equilibrium Constant)

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Entry-Level Knowledge
In Grade 11 Chemistry, outcome C11-02-05, students performed an experiment to discover Boyle's Law—that pressure and volume are inversely proportional to one another. In C11-3-13 and C12-3-04, students worked with endothermic and exothermic reactions. In C12-3-02, students performed a lab to observe the effects of concentration, temperature, pressure, volume, and the presence of a catalyst on the rate of a reaction. Teachers should check for prior knowledge, and review concepts as necessary.

Teacher Notes
Le Chatelier's Principle describes how a chemical equilibrium shifts in response to a stress or disturbance within an enclosed system.

Stress	System response	Effect on the equilibrium constant
Increase in temperature	The system shifts to use up the added heat, favouring the endothermic 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.
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.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

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. 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, because it doesn't take part in the reaction.	It does not change.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

The following illustration shows how a change in concentration affects the other substances in a chemical reaction.

Any of these changes causes a shift to the right

increase		increase		decrease
PCl_3	+	Cl_2	$\leftrightarrows$	PCl_5
decrease		decrease		increase

Any of these changes causes a shift to the left

(see *Silberberg,* 746)

Teacher demonstration

Traffic Lights shows an oscillating reaction starting with a yellow-orange colour, through red (after shaking once), and to a green colour (after shaking again). After the flask sits for awhile, the colours reverse order 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, dissolve 32 g of KOH in 1200 mL water (solution A), 40 g of glucose in 1200 mL water (solution B), 0.50 g of benzoine in 500 mL water (solution C), and 1.0 of indigo carmine in 200 mL water (solution D). To a clean, empty flask, add 200 mL of A, then 200 mL of B, then 60 mL of C, and then 16 mL of D.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

An online video of a similar demonstration (different chemicals are used, but the same colours are shown) can be viewed at: Purdue University: College of Science, Chemical Education Division Groups
19.2 Traffic Lights

http://chemed.chem.purdue.edu/demos/main_pages/19.2.html

Internet Video: Belousov-Zhabotinsky Reaction

A video of this demonstration may be seen. The colour oscillates between red and blue.
http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-oscill-e.htm

Liquid crystal demonstration
If teachers have access to a sheet of temperature sensitive liquid crystal, they can wrap the sheet around glasses of cold water, water at room temperature, and hot water to see that warmer temperatures yield darker colours:

LCLC	+	heat	$\leftrightarrows$	DCLC
(light-coloured liquid crystals)				(dark-coloured liquid crystals)

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

Disturbing Equilibrium Systems
Any of the following experiments can be performed to determine how equilibrium systems respond to stresses. It is not intended that all lab activities should be performed by the students. Teachers should select activities appropriate to the abilities of their students and the equipment available at their school.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

- Analogy Lab: A complete student procedure for this lab can be found in Appendix 6: An Analogy for an Equilibrium Reaction. Students will use straws of two different diameters to transfer water between two graduated cylinders until equilibrium is achieved. This activity is beneficial to students, as it demonstrates that systems are not necessarily at equilibrium when the concentrations of reactants and products are identical. Student results will vary, depending upon the size of straw that is placed into each graduated cylinder. A scoring rubric for this analogy lab is given in Appendix 7.

- Qualitative Equilibrium Laboratory :A prelab exercise is provided in Appendix 8: Prelab Equilibrium and Le Chatelier. This exercise gives students an opportunity to predict which direction the equilibrium will shift with the given stresses. A complete student procedure for this lab can be found in Appendix 9: Qualitative Equilibrium Lab (See Appendix 10 for teacher notes). Students will 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: This lab and a scoring rubric are located in Appendix 11: Disrupting Equilibrium Systems.The reaction that is studied in this laboratory is

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

  Cobalt chloride is dissolved in ethanol and the colour of the solution is recorded. Stresses are added to samples of this prepared solution (distilled water, hydrochloric acid, solid calcium chloride, silver nitrate solution, addition of heat, and the removal of heat) and the resulting colours are noted.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

- Minilab 18 Shifts in Equilibrium or MiniLab Shifts in Equilibrium (ChemLab and MiniLab Worksheets, Glencoe Chemistry, 69) or (Dingrando 573): To a 0.1 mol / L solution of cobalt chloride, hydrochloric acid is added. Pink colour changes to a purple colour. To this solution, water is added and the colour returns to pink. Then a sample of the cobalt chloride-hydrochloric acid solution is placed in hot water which results in a blue colour being produced. A sample of the cobalt chloride-hydrochloric acid solution is placed in cold water and the pink colour appears.

- Lab 15: Observing Equilibrium (Small-Scale Laboratory Manual, Teacher's Edition, Glencoe Chemistry, 57): In the first part of the lab, the colours of Fe^{3+} ion, SCN^{-} ion, and $FeSCN^{2+}$ ion are recorded. The direction of shift in equilibrium is measured by the colour change that occurs which is related to the concentration of reactant. A dilute solution of iron(III) nitrate and potassium thiocyanate is poured into 5 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 milliliters of sodium hydroxide solution is added to the original solution. A colourless solution results with a white precipitate. To the fifth test tube, a few milliliters of silver nitrate are added, which results in a colourless solution and a white precipitate.

- Lab 29: Le Chatelier's Principle and Chemical Equilibrium (Small-Scale Chemistry Laboratory Manual, Waterman and Thompson, 203): Students will observe and record how a chemical system at equilibrium responds to changes in concentration of reactants or products. These shifts in equilibrium are to be described in terms of Le Chatelier's principle. As this is a small scale lab activity, the quantities of the following substances are minimal: bromthymol blue,

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

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hydrochloric acid, sodium hydroxide, ammonia, copper(II) sulfate, lead(II) nitrate, potassium iodide, nitric acid, silver nitrate, sodium carbonate, sodium thiosulfate, and sodium phosphate.

- Investigation 16: A Modelling Equilibrium (Chastko 635): This investigation is similar to the Analogy lab given in the Appendix. Water is transferred from one graduated cylinder to another graduated cylinder and vice versa. In the reactant cylinder 25 mL of water is present. In the product cylinder there is no water present initially. Two glass tubes of different diameters are used for the water transfer.

- Investigation 16.B Disturbing Equilibrium (Chastko 652): There are three parts to this investigation. It is suggested that students do the first two parts and that the teacher do the third part as a demonstration. The first part looks at the changes to a base equilibrium system, $NH_3(aq) + H_2O(l) \leftrightarrows NH_4^+(aq) + OH^-(aq)$. Ten milliliters of a 0.10 mol / L NH_3 solution is placed in a small beaker. A few drops of phenolphthalein are added to the beaker. The solution is divided equally into two small beakers. Students are given a list of materials ($NH_4Cl(s)$, 6.0 mol / l HCl, test tubes, test tube rack, scoopula, white paper) and they need to design a procedure to test Le Chatelier's principle. The teacher checks the students' procedures and then the students can test their procedure and record observations.

  The second part of the investigation looks at concentration and temperature changes. The equilibrium system that will be stressed is Heat + $Co(H_2O)_6^{2+}$(aq/et) + $4Cl^-(aq) \leftrightarrows CoCl_4^{2-}(aq) + 6H_2O(l)$
  pink blue or purple
  Students are given a list of materials ($CoCl_2$ dissolved in a solution of water and ethanol, conc HCl, $AgNO_3(aq)$), distilled water, hot water bath, cold water bath, test tubes, test tube rack, test

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

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tube holder). The students design as many procedures as possible to test Le Chatelier's principle. Students test their procedures and record all observations.

The third part of the investigation is to be done by the teacher. This part of the investigation is based on the equilibrium system: Heat + $N_2O_4(g) \leftrightarrows 2NO_2(g)$
colourless brown
Sealed tubes of $NO_2(g)$-$N_2O_4(g)$ are used; one tube is placed in an ice-water bath, another tube is left at room temperature, and the third tube is placed in a hot water bath. Student record their observations using Le Chatelier's principle. The last part of this investigation must take place in a fume hood. $NO_2(g)$ is produced by heating copper with concentrated nitric acid. The gas is collected in a syringe. By increasing the pressure in the syringe the colour changes in the syringe (due to concentration and temperature). After the compressed syringe has stayed in that position for a few seconds, the colour changes as the gas has cooled down to room temperature.

- ExpressLab Modelling Equilibrium (Mustoe 491): This lab is the same as Investigation 16.A Modelling Equilibrium (Chastko 635)

- Investigation 13-B Perturbing Equilibrium (Mustoe 521): This investigation has four parts to it. Part 1 investigates the equilibrium system
$$H^+(aq) + 2CrO_4^{2-}(aq) \leftrightarrows Cr_2O_7^{2-}(aq) + OH^-(aq)$$
yellowish orange
Three test tube contain about 5 mL of 0.1 mol / L $K_2CrO_4(aq)$. Test tube 1 is used as the colour reference. To test tube 2, five drops of HCl(aq) are added. Observations are made. Then five drops of NaOH(aq) are added to this solution. Observations are recorded. Finally to this test tube five drops of $Fe(NO_3)_3(aq)$ are added. A precipitate of $Fe(OH)_3(s)$ should form. To test tube 3, five drops of $BaCl_2(aq)$ are added. The precipitate $BaCrO_4(s)$ should form.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Part 2 looks at the changes to a base equilibrium system, that being,

$$NH_3(aq) + H_2O(l) \leftrightarrows NH_4^+(aq) + OH^-(aq)$$

Ten milliliters of a 0.10 mol / L NH_3 solution is placed in a small beaker. A few drops of phenolphthalein are added to the beaker. The solution is divided equally into two small test tubes. A few crystals of $NH_4Cl(s)$ are added to one test tube and a few drops of HCl(aq) are added to the second test tube until a change is observed.

Part 3 studies the effect of concentration and temperature changes on an equilibrium.

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4Cl^-(aq) + 50\text{ kJ/mol} \leftrightarrows \underset{\text{blue or purple}}{CoCl_4^{2-}(aq)} + 6H_2O(l)$$

Cobalt chloride is added to ethanol (solution should be blue-purple). This solution is divided equally among four test tubes. One test tube is left untouched (serves as the control). Add 3 drops of water to each of the remaining three test tubes and record observations. To one of these test tubes, five drops of concentrated HCl(aq) are added with observations being recorded. To another test tube drops of $AgNO_3(aq)$ are added one at a time until no more precipitate appears. To the remaining test tube immerse this solution in a hot water bath. Record observations. Then place this test tube in a cold water bath and observe the colour change.

Part 4 investigates $N_2O_4(g) + 59\text{ kJ/mol} \leftrightarrows 2NO_2(g)$ as should be performed by the teacher as a demonstration. This part of the investigation is identical to the one noted previously (see Chastko 652)

- Investigation 7.3.1 Testing Le Chatelier's Principle (van Kessel 514) : This investigation contains 7 parts. The first part studies $N_2O_4(g) + \text{energy} \leftrightarrows 2NO_2(g)$ and is meant to be done as a

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

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demonstration by the teacher. Flasks of $NO_2(g)$-$N_2O_4(g)$ are placed in cold water and hot water baths. Part 2 investigates the following equilibrium: $CO_2(g) + H_2O(l) \leftrightarrows H^+(aq) + HCO_3^-(aq)$. A $CO_2(g)$-$HCO_3^-(aq)$ mixture is placed in a syringe and subjected to increased pressure. Part 3 looks at the cobalt(II) complexes: $CoCl_4^{2-}(alcohol) + 6H_2O(l) \leftrightarrows Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq)$ +energy. Water, $AgNO_3(aq)$, the addition of heat and the removal of heat are added to samples of this mixture. Part 4 studies the effect of hydrochloric acid and sodium hydroxide when added to the equilibrium mixture of thymol blue. Part 5 looks at the iron(III)-thiocyanate equilibrium where $Fe(NO_3)_3(aq)$, KSCN(aq), and NaOH(aq) are added to samples of this equilibrium mixture. Part 6 studies the following equilibrium:

$$Cu(H_2O)_4^{2+}(aq) + 4\ NH_3(aq) \leftrightarrows Cu(NH_3)_4^{2+}(aq) + 4\ H_2O(l).$$

$NH_3(aq)$ and HCl(aq) are added separately to samples of this equilibrium. Part 7 investigates chromate-dichromate equilibrium: $2\ CrO_4^{2-}(aq) + 2\ H^+(aq) \leftrightarrows Cr_2O_7^{2-}(aq) + H_2O(l)$
$NH_3(aq)$, HCl(aq), and $Ba(NO_3)_2(aq)$ are added to samples of this equilibrium. Table 2 provides the d diagnostic test colours for all substances that are used in this investigation.

Class Activity

Have students view Program 4, Reaction Tendencies, from TV Ontario series, Chemical Equilibrium. The effects of the heat and pressure are shown on an equilibrium system using Le Chatelier's Principle. Students can describe these effects on an equilibrium system on both a macroscopic and microscopic level.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Demonstration / Internet Resources

This video shows how temperature affects NO_2/N_2O_4 Equilibrium. As temperature is decreased there is an increase in N_2O_4 (colourless).
Purdue University: College of Science, Chemical Education Division Groups
http://chemed.chem.purdue.edu/demos/main_pages/16.3.html
16.3 The Effect of Temperature on the NO_2/N_2O_4 Equilibrium

The $Fe(SCN)^{2+}/Fe(SCN)_2^{+}$ equilibrium is studied by adding stresses ($FeCl_3$, NH_4SCN, NH_4Cl, KNO_3) to this system.
This video is a good visual example of applying Le Chatelier's Principle to a system at equilibrium.
Purdue University: College of Science, Chemical Education Division Groups
http://chemed.chem.purdue.edu/demos/main_pages/18.5.html
18.5 The $Fe(SCN)^{2+}/Fe(SCN)_2^{+}$ Equilibrium

The cobalt chloride complex (pink to blue) equilibrium is explained and demonstrated here.
North Carolina School of Science and Mathematics Distance Learning Technologies
$Co(H_2O)_6^{2+}$ - $CoCl_4^{2-}$ equilibrium-Le Chatelier's Principle
http://www.dlt.ncssm.edu/core/c14.htm

Animation

The following website shows an animation of chemical equilibrium at a macroscopic level. The effects of adding a stress to a chemical equilibrium is displayed graphically and at a particulate level.
Chemistry: The Science in Context; W.W. Norton & Company
http://www.wwnorton.com/college/chemistry/gilbert/overview/ch15.htm

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Le Chatelier's Principle Tutorial chapter 15, section 2 (A Macroscopic Equilibrium), sections 4, 5, 6, and 7 (Shifting Equilibrium)

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Suggestions for Assessment

<u>Pencil and paper tasks</u>
To begin the outcome and review prior knowledge, have the 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?

Have students answer questions related to Le Chatelier's Principle, such as:

1. 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:

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

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

<u>Journal Writing</u>
Students can write a fictionalized newspaper article written on the day after Henri Louis le Chatelier's most important contribution. The student's article should highlight this contribution.

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

<u>Lab Reports</u>
Students use Lab Report Format (see SYSTH). Word processing and spreadsheet software could be used to prepare reports.

<u>Lab skills</u>
Periodically and randomly review the lab skills of individual students, so that eventually all are assessed. See Appendix for lab skills checklist.

Learning Resources Links

Chemistry (Chang 607)

Chemistry (Zumdahl and Zumdahl 640 5thed)

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

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

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

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

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

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

Prentice Hall Chemistry (Wilbraham et al. 552)

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
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Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Video: "Reaction Tendencies" TV Ontario, Chemical Equilibrium (ISBN-0-88944-083-2)

Websites
Purdue University: College of Science, Chemical Education Division Groups
http://chemed.chem.purdue.edu/demos/main_pages/18.5.html
18.5 The $Fe(SCN)^{2+}/Fe(SCN)_2^{+}$ Equilibrium

http://chemed.chem.purdue.edu/demos/main_pages/16.3.html
16.3 The Effect of Temperature on the NO_2/N_2O_4 Equilibrium

Chemistry: The Science in Context; W.W. Norton & Company
http://www.wwnorton.com/college/chemistry/gilbert/overview/ch15.htm
Le Chatelier's Principle Tutorial chapter 15, section 2 (A Macroscopic Equilibrium), sections 4, 5, 6, and 7 (Shifting Equilibrium)

North Carolina School of Science and Mathematics Distance Learning Technologies
$Co(H_2O)_6^{2+}$ - $CoCl_4^{2-}$ equilibrium-Le Chatelier's Principle
http://www.dlt.ncssm.edu/core/c14.htm

Investigations

Appendix 6: An Analogy for an Equilibrium Reaction

Appendix 7: An analogy for an Equilibrium Reaction Rubric

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Appendix 8: Prelab Equilibrium and Le Chatelier

Appendix 9: Qualitative Equilibrium Lab

Appendix 10: Qualitative Equilibrium Lab – Teacher notes

Appendix 11: Disrupting Equilibrium Systems

ChemLab and MiniLab Worksheets, Glencoe Chemistry, McGraw-Hill, 2002
Minilab 18 Shifts in Equilibrium 69

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

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

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

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

Specific Learning Outcome

C12-4-06 Use Le Chatelier's Principle to predict 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 the various stresses on the equilibrium constant. (2 hours)

C12-4-07 Perform a lab to demonstrate le Chatelier's Principle. (1.5 hours)

Skills and Attitudes Outcomes

C12-0-S2 State a testable hypothesis or prediction based on background data or on observed events.
GLO: C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

C12-0-A2 Value scepticism, honesty, accuracy, precision, perseverance, and open-mindedness as scientific and technological habits of mind.
GLO: C2, C3, C4, C5

Small-Scale Laboratory Manual, Teacher's Edition, Glencoe Chemistry, Dingrando et al., McGraw-Hill, 2002
Lab 15 Observing Equilibrium 57

Small-Scale Chemistry Laboratory Manual, Waterman and Thompson, Pearson Education / Prentice-Hall, 2005
Lab 29 Le Chatelier's Principle and Chemical Equilibrium, 203

Specific Learning Outcome

C12-4-08 Interpret concentration versus time graphs.
Include: temperature changes, concentration changes, addition of a catalyst (1 hour)

Skills and Attitudes Outcomes:

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

Entry-Level Knowledge

In C12-4-01 students were introduced to a qualitative treatment of concentration versus time graphs. In C12-4-06 students saw that a system at equilibrium will shift to minimize a stress and re-establish equilibrium.

Teacher Notes

Class Activities

Teachers should ask their students to recall that equilibrium is shown on a concentration versus time graph by a plateau. If students completed the analogy lab in the previous outcome, they can be asked to refer back to their results. The plateau in such concentration versus time graphs demonstrates that the concentrations of reactants and products are not changing over time.
The teacher can work through the following problem with the students to introduce a quantitative analysis of concentration versus time graphs.
See teacher support material in Appendix 12: Interpreting Graphs - Concentration versus Time, Alternatively, teachers can provide students with the graphical data so that they can generate the graph before its interpretation.

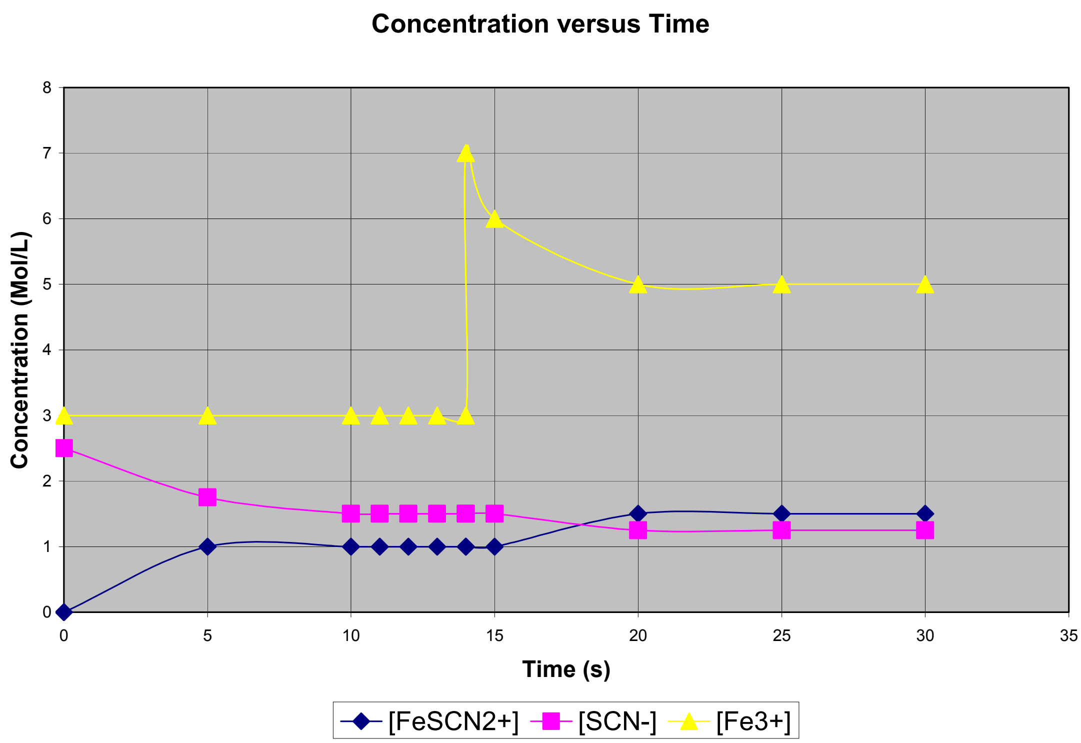
Time	[$FeSCN^{2+}$]	[SCN^-]	[Fe^{3+}]	[Fe^{3+}] after stress
0	0	2.5	4	
5	1	1.75	3.25	
10	1	1.5	3	
11	1	1.5	3	
12	1	1.5	3	
13	1	1.5	3	
14	1	1.5	3	7
15	1	1.5		6
20	1.5	1.25		5
25	1.5	1.25		5
30	1.5	1.25		5

Specific Learning Outcome

C12-4-08 Interpret concentration versus time graphs.
Include: temperature changes, concentration changes, addition of a catalyst (1 hour)

Skills and Attitudes Outcomes:

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5



Interpretation of Concentration versus Time Graph
For the reaction, Fe^{3+} + SCN^{-} ⇆ $FeSCN^{2+}$, 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 15 seconds, a stress is added to the equilibrium, as the concentration of Fe^{3+} spikes dramatically upward at that point in time. 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 3 and 4 compare? Why?

6. What was the stress that occurred at 14 seconds?

Specific Learning Outcome

C12-4-08 Interpret concentration versus time graphs.
Include: temperature changes, concentration changes, addition of a catalyst (1 hour)

Skills and Attitudes Outcomes:

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

---

7. How would the addition of a positive catalyst change the shape of this graph?

Answers:

1. $Fe^{3+} + SCN^{-} \leftrightarrows FeSCN^{2+}$

2. 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. They are approximately the same because the stress imposed on the system was not a change in temperature.

6. Addition of Fe^{3+}.

7. A catalyst would decrease the time required to reach equilibrium. This would condense (“squish”) the graph along the x-axis.

Suggestions for Assessment

<u>Pencil and Paper Tasks</u>

Students can prepare questions on sketching and interpreting concentration versus time graphs and test their classmates.
Students can complete the worksheet provided in Appendix 13, Interpreting Graphs Student Worksheet.

Learning Resources Links

Appendix 12: Interpreting Graphs: Concentration versus Time

Appendix 13: Interpreting Graphs Student Worksheet

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

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

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

Prentice Hall Chemistry (Wilbraham et al. 550)

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

Entry-Level Knowledge
Students were introduced to Le Chatelier's principle in C12-4-06.

Assessing Prior Knowledge
Teachers should check for prior knowledge and review as necessary. Some examples may have been discussed in previous outcomes.

Teacher Notes
It is not intended that students learn the examples in great detail. The examples simply serve as an indicator of the importance of Le Chatelier's principle in our lives. Teachers can either have students collect information from their own textbook or, if information is limited, through additional research. Some information has been provided here for teacher reference.

Haber Process
Most textbooks include a discussion of the Haber process. (Chang 614; Chastko 669) The following websites include a description of the process for manufacturing ammonia for explosives.
http://www.ausetute.com.au/haberpro.html
http://www.fact-index.com/f/fr/fritz_haber.html

Blood pH
Blood contains dissolved carbonic acid in equilibrium with carbon dioxide and water.
$H_2CO_{3(aq)} \leftrightarrows CO_{2(aq)} + H_2O_{(l)}$
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.
(AW, 2002 542??; Chang 688)

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

Chickens' Eggs and Soda Pop

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

$3\ CO_{2(g)} \leftrightarrows 3\ CO_{2(aq)}$
(chicken breath)

$3\ H_2O_{(l)} + 3\ CO_{2(aq)} \leftrightarrows 3\ H_2CO_{3(aq)}$
(in the blood)

$3\ H_2CO_{3(aq)} \leftrightarrow 3\ H^+_{(aq)} + 3\ HCO_3^-{}_{(aq)}$
(in the blood)

$3\ HCO_3^-{}_{(aq)} \leftrightarrow 3\ CO_3^{2-}{}_{(aq)} + 3\ H^+_{(aq)}$

$3\ CO_3^{2-}{}_{(aq)} + Ca_3^{2+}{}_{(aq)} \leftrightarrow 3\ CaCO_{3(s)}$
(in the blood) (eggshell)

Therefore the net equation would be:
$3\ H_2O_{(l)} + 3\ CO_{2(g)} + Ca_3^{2+}{}_{(aq)} \leftrightarrow 6\ H^+_{(aq)} + 3\ CaCO_{3(s)}$

Note – This would be a good opportunity for teachers to review reaction mechanisms, reaction intermediates and net equations with the students.

When chickens get hot, they pant, and decrease 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

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

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. (Chemistry 12, College Preparation Edition, 457??)

Haemoglobin Production and Altitude

In the body haemoglobin in readily used to transport oxygen to tissues.
$Hb_{(aq)} + O_{2(g)} \leftrightarrows HbO_{2(aq)}$
In a place such as Mexico City, where the elevation is 2.3 km, atmospheric pressure and oxygen concentration are low. To offset the stress equilibrium favours the reverse direction. This results in hypoxia, which can cause headache, nausea, and extreme fatigue. In serious cases, if a victim is not treated quickly, they may slip into a coma and die.
Individuals living at high altitudes for extended periods of time adapt to reduced oxygen concentrations by producing more haemoglobin. 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 mountains, have adapted to high altitude conditions by maintaining high levels of haemoglobin in their blood, sometimes as much as 50% more than individuals living at sea level.
(Chemistry, Chang, 613)

Carbonated beverages

Soft drinks are carbonated under high pressure to create the following equilibrium system:
$CO_{2(g)} \leftrightarrows CO_{2(aq)} + \text{heat}$
When a bottle of soda 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 long periods of 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 (i.e. leaving it in a warm car on a summer's day) will cause equilibrium to shift in the reverse direction, creating more carbon dioxide gas. This generates a pressure that could potentially cause the pop bottle to burst.

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

Eyes Adjusting to Light

Photoreceptors, such as 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 that it has 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.
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 ATP molecules in a slower reverse reaction. In a dark room, the photoreceptors in your 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 your eyes again take a few minutes to adjust to their new equilibrium due to the slower reverse reaction.
Ret-Op ⇆ Ret + Op + light
Signal sent   Signal not sent

Supercharged and turbocharged engines

In a turbocharged engine, air is compressed and heated. This means that there is a higher concentration (50% more) of warmer oxygen reacting with the gasoline. This favours the production of products, which generates more power for the car. Note: Turbochargers in normal engines work best at higher altitudes as the air is less dense there. 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.
Gasoline + $O_2 \leftrightharpoons CO_2 + H_2O$ + 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.
i.e. $CH_3OH + CH_3COOH \leftrightharpoons CH_3COOCH_3 + H_2O$

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

Weather indicators

Students may have seen 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:

$[CoCl_4]^{2-} + 6\ H_2O \leftrightarrows [Co(H_2O)_6]^{2+} + 4\ Cl^-$

Blue Pink

Alternately, teachers could use the equilibrium system:

$CoCl_2 + 6\ H_2O \leftrightarrows CoCl_2 \cdot 6H_2O$

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.

Rechargeable batteries

Lead-acid batteries,

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

nickel-cadmium batteries,

$Cd_{(s)} + 2\ NiO(OH)_{(s)} + 2\ H_2O_{(l)} \leftrightarrows 2\ Ni(OH)_{2(s)} + Cd(OH)_{2(s)}$ + energy

and fuel cells

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

are recharged through the addition of electrical energy. When energy is added to the system, the reverse reaction is favoured, which produces more reactants.

Suggestions for Assessment

<u>Class Discussion</u>

To validate equilibrium as a topic that is not only confined to the chemistry classroom, have students provide examples of its applications.

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
GLO: A1, A3, A5, B2

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

Student Research and Report
Students can research and report on one or more applications. Results can be shared in written, verbal, or electronic format. If teachers wish to use the internet for student research, they should provide students with key words to reduce search time.

Visual Display
Students can create a visual display such as a poster to demonstrate an application of Le Chatelier's principle.

Collaborative Teamwork
Instructional strategies such as Jigsaw or Round Table could be used to have students share knowledge of specific examples of Le Chatelier's principle with their classmates.

Journal Writing
Have students reflect on an everyday example of Le Chatelier's principle. The reflection could be based on examples from their everyday lives or on careers that utilize the principle.

Students can describe how their bodies would relieve the stress placed on them by climbing to a high altitude. (Science Notebook: Dingrando 251)

Research/Report – Presentations
From their research, students can describe how Le Chatelier's principle is used in industry. Information may be shared with the entire class through formal presentations.

Quiz / Test
1. When someone takes your photograph, you may see a "Ghost" image of the flash for several minutes after the photo was 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

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

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Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
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C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

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):

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

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

Learning Resources Links

Chemistry (Chang 613, 614, 688)

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

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

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

Science Notebook, Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005

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

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

Specific Learning Outcome

C12-4-09 Discuss practical applications of Le Chatelier's principle.
Examples: Haber Process, haemoglobin 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)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-T1 Describe examples of the relationship between chemical principles and applications of chemistry.
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C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

C12-0-A3 Demonstrate a continuing, increasingly informed interest in chemistry and chemistry-related careers and issues.
GLO: B4

Suggestions for Instruction

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

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

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Entry-Level Knowledge

In C12-1-01 and C12-1-02 students saw that there are reactions that produce precipitates.

Teacher Notes

In this outcome, 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 AgCl is insoluble, it does undergo both dissociation and precipitation to set up the equilibrium:

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

A good visual representation of this reaction at the particulate level is given at the following website North Carolina School of Science and Mathematics Distance Learning Technologies website
http://www.dlt.ncssm.edu/core/Chapter14-Gas_Phase-Solubility-Complex_Ion_Equilibria/Chapter14-Animations/Solubility_of_AgCl.html

Earlier in the unit, 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, the higher the solubility of the salt.
Examples: (Values given for 25°C)

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

[Chang 702]

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

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Teachers must be sure to clarify the difference between solubility (the number of moles of solute that will dissolve in 1 L of solution, a.k.a. 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 textbooks, units for K_{sp} are not used because they would vary depending on the powers to which the concentrations are raised, i.e., mol / L to $(mol / L)^2$ to $(mol / L)^3$.

Problems should be limited to:
1. Calculating the K_{sp} given the molar solubility of a compound.
2. Using an ICE table to solve for the molar solubility of a slightly soluble salt.
3. Identifying the concentration of ions present at equilibrium when the K_{sp} value of the slightly soluble salt has been provided.
4. Determining the molar solubility of a slightly soluble salt in a solution containing a known concentration of a common ion.

Example 1
Calculate the K_{sp} given the molar solubility of a compound.
The solubility of calcium sulfate, $CaSO_4$, is 4.9×10^{-3} mol / L. Calculate the K_{sp} for $CaSO_4$.

Solution:
(1) Write the dissociation equation for $CaSO_4$.

$$CaSO_4(s) \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq)$$

(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.

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

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

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

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Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Example 2

Use an ICE table to solve for the molar solubility of a slightly soluble salt.
Calculate the molar solubility of $PbCl_2$ in pure water at 25°C. K_{sp} for $PbCl_2$ is 2 x 10^{-5}.

Solution:

(1) Write the dissociation equation for $PbCl_2$.

$$PbCl_2(s) \rightarrow Pb^{2+}(aq) + 2\ Cl^{-}(aq)$$

(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.

	$PbCl_2(s)$ →	$Pb^{2+}(aq)$ +	$2\ Cl^{-}(aq)$
I	---	0	0
C	---	+ x	+2x
E	---	x	2x

(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 x 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 solution at 25°C?
K_{sp} = 1.8 x 10^{-10}

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Solution:
(1) Write the dissociation equation for AgCl.

$$AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$$

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

	$AgCl \rightarrow$	$Ag^+(aq)$ +	$Cl^-(aq)$
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.

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

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

(4) Solve for *x*.

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

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

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

The molar solubilities of the ions at equilibrium are equal to $x = [Ag^+] = [Cl^-] = 1.3 \times 10^{-5}$ mol / L.

Example 4
<u>Determine the molar solubility of a slightly soluble salt in a solution containing a known concentration of a common ion</u>.
Calculate the molar solubility of silver chloride in a 1.5×10^{-3} mol / L silver nitrate 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.

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

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(1) $AgNO_3$ dissociates completely as given by the equation, $AgNO_3(s) \rightarrow Ag^+(aq) + NO_3^-(aq)$. Since the concentration of $AgNO_3$ is given as 1.5×10^{-3} mol / L, then $[Ag^+] = 1.5 \times 10^{-3}$ mol / L.

Write the dissociation equation for AgCl.

$$AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$$

(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) →	$Ag^+(aq)$	+	$Cl^-(aq)$
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

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

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 $SrSO_4$.
Answer: $SrSO_{4(s)} \leftrightarrows Sr^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)}$
$K_{sp} = [Sr^{2+}][SO_4^{2-}]$

2. Write the expression for the solubility product constant for $Al_2(SO_4)_3$.
Answer: $Al_2(SO_4)_{3(s)} \leftrightarrows 2\ Al^{3+}_{(aq)} + 3\ SO_4^{2-}{}_{(aq)}$
$K_{sp} = [Al^{3+}]^2[SO_4^{2-}]^3$

Paper and Pencil Tasks

Sample Problems:
(1) A sample of $Ba(OH)_{2(s)}$ 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^- 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 AgCl? $K_{sp} = 1.6 \times 10^{-10}$
Answer: Molar solubility, AgCl = 1.26×10^{-5} mol / L

(3) What will be the equilibrium concentrations of Ca^{2+} and OH^- in a saturated solution of $Ca(OH)_2$, 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 $Ca(IO_3)_2$ in 0.060 mol / L $NaIO_3$. 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 is mixed with 2.00 L of 0.0333 mol / L sodium hydroxide solution?
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

Specific Learning Outcome

C12-4-10 Write solubility product (K_{sp}) expressions from balanced chemical equations for salts with low solubility. (0.5 hours)

C12-4-11 Solve problems involving K_{sp}.
Include: common ion problems (3 hours)

Skills and Attitudes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Ask students to explain how adding additional sulfate ions to a saturated solution of barium sulfate would affect the concentration of barium ions. (Teacher's Edition, Chemistry: Matter and Change, 577)

Learning Resources Links
Chemistry (Chang 701)

Chemistry (Zumdahl and Zumdahl 757 5thed)

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

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

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

Prentice Hall Chemistry (Wilbraham et al. 560)

Websites
North Carolina School of Science and Mathematics Distance Learning Technologies website
http://www.dlt.ncssm.edu/core/Chapter14-Gas_Phase-Solubility-Complex_Ion_Equilibria/Chapter14-Animations/Solubility_of_AgCl.html

Specific Learning Outcome

C12-4-12 Describe practical applications of salts with low solubilities.
Examples: kidney stones, limestone caverns, osteoporosis, tooth decay (0.5 h)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-C1 Collaborate with other to achieve group goals and responsibilities.
GLO: C2, C4, C7

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Suggestions for Instruction

Teacher Notes

It is not intended that students learn the examples in great detail. The examples simply serve as an indicator of the importance of slightly soluble salts in our lives. Teachers can either have students collect information from their own textbook or, if information is limited, through additional research. Some information has been provided here for teacher reference.

Limestone Caverns

Limestone ($CaCO_3$) is formed through the decay of marine organisms like snails, clams, corals, and algae. In water, the slightly soluble salt will set up the following equilibrium:
$CaCO_{3(s)} \leftrightarrows Ca^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)}$
The chemical erosion of limestone occurs when it is in contact with acidic water:
$H^+_{(aq)} + CO_3^{2-}{}_{(aq)}$ v$HCO_3^-{}_{(aq)}$
If the limestone deposit is deep enough underground, the dissolution of the limestone produces a cave.

Osteoporosis

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

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

If the concentration of calcium in the blood decreases, balance can be restored if the solubility of the calcium phosphate (bone) increases. This leads to porous, brittle bones. How can this be prevented? By making sure to obtain 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.
It must be noted, however, that large amounts of calcium in the body may lead to the formation of painful 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:

$$Ca_5(PO_4)_3OH_{(s)} \leftrightarrows Ca_5(PO_4)_3^+{}_{(aq)} + OH^-_{(aq)}$$

Specific Learning Outcome

C12-4-12 Describe practical applications of salts with low solubilities.
Examples: kidney stones, limestone caverns, osteoporosis, tooth decay (0.5 h)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-C1 Collaborate with other to achieve group goals and responsibilities.
GLO: C2, C4, C7

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Suggestions for Instruction

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.
As helpful as the addition of fluoride to toothpaste has been, it is interesting to note to students that fluoride is not an additive to children's toothpastes. Why? Because an excess of fluoride in the body from swallowing large amounts of paste can lead to fluorosis.

Suggestions for Assessment

Class Discussion
To validate the solubility of slightly soluble salts as a topic that is not only confined to the chemistry classroom, have students provide examples of its applications.

Student Research and Report
Students can research and report on one or more applications. Results can be shared in written, verbal, or electronic format. If teachers wish to use the internet for student research, they should provide students with key words to reduce search time.

Visual Display
Students can create a visual display such as a poster to demonstrate an application of the solubility of slightly soluble salts.

Collaborative Teamwork
Instructional strategies such as Jigsaw or Round Table could be used to have students share knowledge of specific examples of the solubility of slightly soluble salts with their classmates.

Journal Writing
Have students reflect on an everyday example of the solubility of slightly soluble salts. The reflection could be based on examples from their everyday lives or on careers that utilize the principle.

Research/Report – Presentations

Specific Learning Outcome

C12-4-12 Describe practical applications of salts with low solubilities.
Examples: kidney stones, limestone caverns, osteoporosis, tooth decay (0.5 h)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-C1 Collaborate with other to achieve group goals and responsibilities.
GLO: C2, C4, C7

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Suggestions for Instruction

From 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.

Students could research the insoluble lead compounds that were used as paint pigments which led to people, especially children, being poisoned by the exposure to these lead-based paints. (Teacher's Edition, Chemistry: Matter and Change, Dingrando *et al*., 578)

Learning Resource Links

Chemistry (Chang 719)

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

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

Specific Learning Outcome

C12-4-13 Perform a lab to determine the Ksp of a salt with low solubility. (1.5 hours)

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…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

Entry Level Knowledge

In C12-4-11, students solved problems involving K_{sp}. This outcome 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 to determine the Ksp of a salt with low solubility. Possible laboratory activities include:

- Lab 39 A Solubility Product Constant (Laboratory Manual, *Dingrando et al.*)
  The purpose of the lab activity is to determine the solubility product constant of lead (II) chloride. 100 mL of saturated $PbCl_2$ is added to 20 mL of 0.5 mol / L K_2CrO_4 solution. The mixture is heated to the boiling point and then left to stand and cool for at least five minutes. The liquid from the beaker is decanted 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.*)
  There are several objectives to this lab: comparing the values of the K_{sp} for two different compounds and relating them to observations, explaining observations of the two precipitates using Le Chatelier's principle, and calculating the molar solubilities of the two ionic compounds from their K_{sp} values. As this is a small scale lab activity the quantities of chemicals used is minimal. Ten drops of $AgNO_3$(aq) and ten drops of NaCl(aq) are added to two wells of a microplate. Observations are made of the precipitates that form (AgCl(s) is a white colour). To the second well 10 drops of Na_2S solution are added. The resulting precipitate that forms is a black colour, which is Ag_2S(s).

- Investigation 7.6.1 Determining the K_{sp} of Calcium Oxalate (*van Kessel, et al.* 517)
  For this investigation the K_{sp} of CaC_2O_4 is determined by mixing a fixed volume of 0.1 mol / L $Na_2C_2O_4$ with a serial dilution of aqueous $Ca(NO_3)_2$ in a series of spotplate wells.

Suggestions for Assessment

<u>Lab Reports</u>
Have students use Lab Report Format (see SYSTH). Word processing and spreadsheet software could be used to prepare reports.

<u>Lab skills</u>
Periodically and randomly review the lab skills of individual students, so that eventually all are assessed. Develop a checklist for the assessment of skills related to the measuring and mixing of solutions. See appendix for lab skills checklist.

Specific Learning Outcome

C12-4-13 Perform a lab to determine the Ksp of a salt with low solubility. (1.5 hours)

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…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

Investigations

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

Laboratory Manual, Chemistry: Matter and Change*, Dingrando et al*., Glencoe-McGraw-Hill, 2005
Lab 39 A Solubility Product Constant 243

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