Unit 1
FROM KINETICS TO EQUILIBRIUM
Specific Curriculum Outcomes
Suggested Time: 30 Hours

Unit Overview

Introduction

Investigation of factors which affect the rates of chemical reactions leads to a deeper understanding of chemical equilibrium and a quantitative treatment of reaction systems. The balance of opposing reactions in chemical equilibrium systems has issues relating to commercial/industrial production.

Focus and Context

Many factors affect the rate of chemical reactions. Understanding that reactions can be described as dynamic equilibrium systems by criteria, equations, calculations, concentrations, and experiments within the context of everyday phenomena are the focus of this unit on solutions and equilibrium. The context might be hemoglobin at high altitudes, ammonia in the Haber process, $CaCO_3$ in caves, acids corroding metals, sodium carbonate in the Solvay process, or any other relevant context.

Problem-solving skills are used throughout this unit. Identifying variables and performing experiments to test equilibrium shifts and reaction rates are valuable to understanding this unit.

Science Curriculum Links

In Science 1206, students will have studied interpreting and balancing chemical equations. Chemistry 2202 introduced ions, ionic compounds, and molecular structure, as well as measuring amounts in moles.

Curriculum Outcomes

STSE	Skills	Knowledge
Students will be expected to	*Students will be expected to*	*Students will be expected to*
Nature of Science and Technology 114-2 explain the roles of evidence, theories, and paradigms in the development of scientific knowledge **Relationships Between Science and Technology** 116-2 analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology 116-4 analyse and describe examples where technologies were developed based on scientific understanding **Social and Environmental Contexts of Science and Technology** 117-7 identify and describe science- and technology-based careers related to the science they are studying	**Initiating and Planning** 212-5 identify the theoretical basis of an investigation and develop a prediction and a hypothesis that are consistent with the theoretical basis **Performing and Recording** 213-1 implement appropriate sampling procedures 213-5 compile and organize data, using appropriate formats and data treatments to facilitate interpretation of the data 213-8 select and use apparatus and materials safely **Analysing and Interpreting** 214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots 214-8 evaluate the relevance, reliability, and adequacy of data and data collection methods 214-10 identify and explain sources of error and uncertainty in measurement and express results in a form that acknowledges the degree of uncertainty	323-3 define the concept of equilibrium as it pertains to solutions 323-4 explain solubility, using the concept of equilibrium 323-5 explain how different factors affect solubility, using the concept of equilibrium **ACC-1** describe collision theory and its connection to factors involved in altering reaction rates **ACC-2** identify and discuss the properties and situations in which the rate of reaction is a factor **ACC-3** describe a reaction mechanism and catalysts' role in a chemical reaction **ACC-4** solve K_{eq} problems involving the initial concentrations, the changes that occur in each substance, and the resulting equilibrium concentrations

Collision Theory, Reaction Mechanisms, and Catalysts

Outcomes

Students will be expected to

- describe collision theory and its connection to factors involved in altering reaction rates (ACC-1)

  – state the Kinetic Molecular Theory (KMT) of matter

  – describe two pieces of evidence that support the KMT

    (i)   pressure
    (ii) diffusion

  – state the collision theory
  – recognize that reaction rate can be measured by monitoring a variety of changing macroproperties including; mass, colour, volume and pH
  – relate the rate of reaction to the number of successful collisions between reacting particles

  – define, draw, and label a potential energy diagram for exothermic and endothermic reactions (overall or one-step mechanism). Include:
    (i)   labelled axis
    (ii)   activation energy
    (iii) activated complex site
   (iv) ΔH
    (v)   reactants and product

Elaborations—Strategies for Learning and Teaching

Students might discuss the fundamentals of collision theory using potential energy diagrams and energy considerations. Controlling reaction rates is important in many commercial and industrial processes. By applying collision theory to the rates of fast and slow reactions, teachers might look for complete and detailed explanations using the correct terminology.

A balloon stays inflated due to the ideas of the KMT (**K**inetic **M**olecular **T**heory). According to the KMT, the gas particles are in constant motion, moving as far apart as possible. The ideas of the KMT also apply to the diffusion of the scent of perfumes through a room. Teachers should note that in Grade 8 science students were introduced to "particle theory", i.e., the fundamentals of the KMT.

When drawing and interpreting potential energy diagrams for various reactions, students' interpretations should include exothermic, endothermic, activation energy for forward and reverse reactions, activated complex, reactants, products, and ΔH. The textbook refers to the activated complex site as transition state and to ΔH, the enthalpy change for the reaction, as ΔE. Teachers should limit the topic of activated complex to its location on the graph and its energy, not its possible structure as described in the textbook.

A typical reaction and potential energy diagram is shown to the right:

Exothermic Chemical Reaction
$$X_{(g)} + Y_{(g)} \rightarrow Z_{(g)}$$
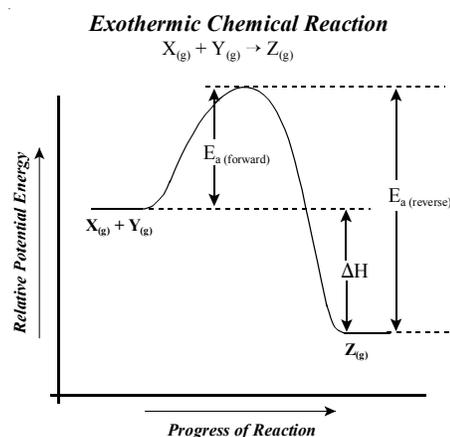
Collision Theory, Reaction Mechanisms, and Catalysts

Tasks for Instruction and/or Assessment	Resources/Notes
Performance	www.gov.nl.ca/edu/science_ref/main.htm
• Students could perform a lab experiment to investigate reaction rates. (ACC-1)	
• Students could role play as moving molecules, a successful collision being a face-to-face one. An unsuccessful collision being any other combination where they would "bounce off" each other. Students observing could record the number of successful versus unsuccessful collisions. (ACC-1)	*MGH Chemistry,* pp. 469-470
	MGH Chemistry, p. 470, p. 466
	MGH Chemistry, pp. 470-473
	MGH Chemistry, pp. 473-476

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Outcomes

Students will be expected to

- identify and discuss the properties and factors which affect reaction rate (ACC-2)

  – explain using collision theory how temperature, concentration/pressure, surface area and nature of reactants affect the rate of reaction

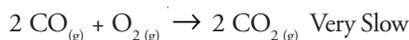 – describe the effect of a catalyst on the rate of reaction

- identify and explain sources of error and uncertainty in measurement (214-10)

- select and use apparatus and materials safely (213-8)

- compile and display evidence and information in charts, tables and graphs (214-3)

- evaluate the relevance, reliability, and adequacy of data and data collection methods (214-8)

- implement appropiate sampling procedures (213-1)

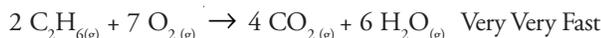## Elaborations—Strategies for Learning and Teaching

Students should describe the role of the following in reaction rate: nature of reactants, surface area, temperature, concentration and catalyst. Students should carry out labs and discussions to determine the factors that affect the rate of a chemical reaction.

Teachers should note that there are many generalizations regarding the affect of nature of reactants on reaction rate. Students should realize that the type of bonding within reactants and products has a profound impact on reaction rate. Include:
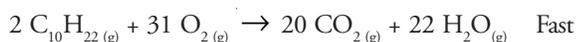
1. Reactions involving ionic compounds are generally faster than those involving molecular compounds. For example, at the same temperature:

$2\ CO_{(g)} + O_{2\ (g)} \rightarrow 2\ CO_{2\ (g)}$ Very Slow

$5\ Fe^{2+}_{(aq)} + MnO_4^-{}_{(aq)} + 8\ H^+{}_{(aq)} \rightarrow 5\ Fe^{3+}_{(aq)} + Mn^{2+}_{(aq)} + 4\ H_2O_{(l)}$ Very Fast

2. Reactions involving breaking weaker bonds are generally faster than those involving stronger bonds. For example, at the same temperature:

$2\ C_2H_{6(g)} + 7\ O_{2\ (g)} \rightarrow 4\ CO_{2\ (g)} + 6\ H_2O_{(g)}$ Very Very Fast

$C_2H_{4(g)} + 3\ O_{2\ (g)} \rightarrow 2\ CO_{2\ (g)} + 2\ H_2O_{(g)}$ Very Fast

3. Reactions involving the breaking of fewer total number of bonds are generally faster than those involving the breaking of larger total number of bonds. For example, at the same temperature:

$C_5H_{12\ (l)} + 8\ O_{2\ (g)} \rightarrow 5\ CO_{2\ (g)} + 6\ H_2O_{(g)}$ Very Fast

$2\ C_{10}H_{22\ (g)} + 31\ O_{2\ (g)} \rightarrow 20\ CO_{2\ (g)} + 22\ H_2O_{(g)}$ Fast

The Laboratory outcomes 214-10, 213-1, 213-8, 214-3, 214-8 and, in part, ACC-2 are addressed by completing *Studying Reaction Rates,* CORE LAB #1.

Students could perform lab experiments to predict which reaction they think would be faster. Using a potassium permanganate solution to react with different ions, such as Fe^{2+} or oxalate, students might demonstrate each and discuss the role the nature of reactants plays in the rates of reactions. Students could investigate the role of surface area, temperature, and concentration by performing lab experiments such as yeast and sugar solution or antacid tablets and water. Discussion in terms of reaction kinetics would be appropriate here. Students could design and carry out experiments to collect data of the rate of a simple reaction. Suggested reactions include a metal with an acid, baking soda with vinegar, or antacid with water. Discussion about slow and fast chemical reactions might give information about why it is important to control the rates of reactions. Society has the need for both slow and fast reactions, for example, an air bag reaction and rust prevention.

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Tasks for Instruction and/or Assessment	Resources/Notes
Journal • Students could answer, "Why is it better to use a catalyst to speed up a reaction rather than increase the temperature?" (ACC-2) *Paper and Pencil* • Students could answer questions such as: - When is it desirable to speed up a chemical reaction? (ACC-2) - When is it desirable to slow down a chemical reaction? (ACC-2) - Why is it easier to light pieces of kindling wood for a fire rather than a log? (ACC-2) *Performance* • Students could act as colliding particles to demonstrate varying reaction conditions. For example; change number of students, in same amount of space, to indicate change in concentration, or, change speed of students, in same amount of space, to indicate change in temperature. (ACC-2)	*MGH Chemistry,* pp. 470-471 *MGH Chemistry,* p. 477 **Core Lab #1**: *"Studying Reaction Rates",* pp. 464-465

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Outcomes

Students will be expected to

- describe a reaction mechanism and a catalyst's role in a chemical reaction (ACC-3)

    – define a reaction mechanism as a series of elementary reactions which determine the reaction rate and when added together result in an overall balanced equation

    – define an elementary process as a single-step reaction in a multi-step reaction mechanism

    – define a reaction intermediate as a substance which is produced by an elementary process, only to be consumed by a later elementary process

    – define rate determining step (RDS) as the slowest elementary process in the reaction mechanism, which is the step that determines the overall reaction rate
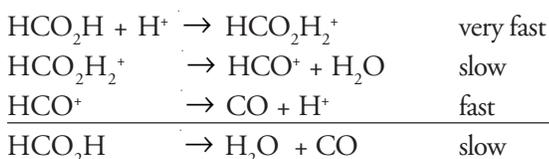
Elaborations—Strategies for Learning and Teaching

Students should define reaction mechanisms and explain how a catalyst affects the rate of a chemical reaction by providing a different reaction mechanism.

An activation energy diagram to show the effect of a catalyst on the rate of reaction allows students the opportunity to understand the role of a catalyst on the rate of reaction. The steps of a reaction mechanism should be given and students asked to identify the rate-determining step, reaction intermediates, and catalysts, and to add the steps of the overall reaction taking place to show that it equals the overall reaction.

When discussing the fundamentals of reaction mechanisms, students might propose balanced equations for multi-step reactions (e.g., the reaction of hydrogen and bromine to form hydrogen bromide). The actual determination of a reaction mechanism is difficult and requires experimentation. Reaction rate, fast or slow, involves many particles that must collide according to the balanced equations of a reaction mechanism step, and not the balanced overall equation for the reaction.

For the following overall balanced exothermic reaction, a three step reaction mechanism is shown:

$$
\begin{array}{lll}
HCO_2H + H^+ \rightarrow HCO_2H_2^+ & \text{very fast} \\
HCO_2H_2^+ \rightarrow HCO^+ + H_2O & \text{slow} \\
HCO^+ \rightarrow CO + H^+ & \text{fast} \\
\hline
HCO_2H \rightarrow H_2O + CO & \text{slow}
\end{array}
$$

For the above:

(i) the reaction intermediates are $HCO_2H_2^+$ and HCO^+ since they are produced in earlier steps and completely consumed in later steps.

(ii) the catalyst is H^+ since it is consumed in an earlier step and produced in equal amounts in a later step.

(iii) step 2 is the rate-determining step

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Tasks for Instruction and/or Assessment	Resources/Notes
Paper and Pencil • Students could draw a potential energy diagram and they should correctly label it for an endothermic and exothermic reaction. Include the shape of the curve, correct labelling for activation energy and energies of reactants, products, and activated complex. (ACC-3) • Students might research and prepare reports on catalysts used in commercial or industrial applications. (ACC-3)	http://www.sparknotes.com/chemistry/kinetics/mechanisms/section1.html *MGH Chemistry,* pp. 477-478 *MGH Chemistry,* pp. 829-830 *MGH Chemistry,* p. 477 *MGH Chemistry,* p. 479

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Outcomes

Students will be expected to

- describe a reaction mechanism and a catalyst's role in a chemical reaction (ACC-3) (**Cont'd**)

  - sketch a potential energy diagram for a given reaction mechanism which shows an energy barrier for each step and the energy barrier of the RDS relative to that of all other elementary processes

  - given a reaction mechanism with the RDS identified, determine all catalysts, intermediates, the overall balanced equation and state the effect of changing a reactant concentration on the overall rate

  - state that a catalyst speeds up a chemical reaction by means of providing an alternate mechanism ("alternate pathway")

  - draw and label a one-step or overall reaction potential energy diagram to show the effect of a catalyst on the reaction

Elaborations — Strategies for Learning and Teaching

For the previous example, $HCO_2H \rightarrow H_2O + CO$ + energy, one possible potential energy diagram would appear as:
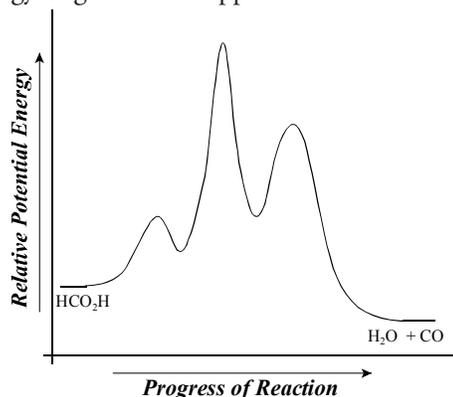

Teachers should note: 1. Each elementary step has its own activation energy barrier and activated complex. Each step could be visualized as three individual, single-step reactions. The step (i.e., the single reaction) with the highest activation energy is the rate-determining step. In this example, step 2 is the rate-determining step since it has the highest "single reaction" activation energy out of the three elementary steps. 2. This reaction profile is consistent with the overall reaction being exothermic (as indicated in the example).

For Chemistry 3202, the rate-determining step will always be the hump that has the highest energy from its reaction intermediate to the peak, **and**, will also be the highest peak in the diagram.

Teachers should use a potential energy diagram to help illustrate a non-catalyzed reaction verses a catalyzed, such as:

Exothermic Chemical Reaction
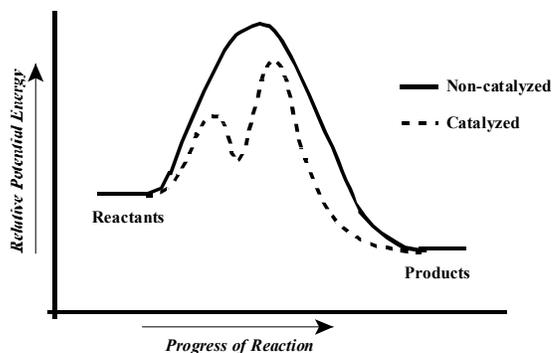
The catalyzed reaction, with different reaction profile (and thus a different reaction mechanism), has a RDS which has lower E_{act} than that of the non-catalyzed route. Students do not need to determine the actual catalyzed reaction mechanism (it may have one or many steps) as long as the largest energy barrier is smaller than the uncatalyzed mechanism.

Collision Theory, Reaction Mechanisms, and Catalysts *(continued)*

Tasks for Instruction and/or Assessment	Resources/Notes
Inquiry • Students could research an industrial process, identify its rate determining step and what is done to increase the overall rate of reaction. (ACC-3)	 *MGH Chemistry,* p. 480 *MGH Chemistry,* p. 830
	MGH Chemistry, pp. 481-482

Applications of Collision Theory

Outcomes

Students will be expected to

- analyze and describe examples where technologies were developed based upon scientific understanding. (116-4)

- analyze and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology. (116-2)

- identify and describe science and technology based careers. (117-7)

Elaborations—Strategies for Learning and Teaching

The CORE STSE component of this unit incorporates a broad range of Chemistry 3202 outcomes. More specifically, it targets (in whole or in part) ACC-1, ACC-2, ACC-3, 116-4, 116-2, and 117-7. The STSE component, *Smog, Catalytic Converters and You,* can be found in Appendix A.

Applications of Collision Theory

Tasks for Instruction and/or Assessment	Resources/Notes
	Core STSE #1: *"Smog, Catalytic Converters and You",* **Appendix A**

Dynamic Equilibrium

Outcomes

Students will be expected to

- define the concept of dynamic equilibrium as it pertains to reversible chemical reactions (323-3)

  – state the criteria that apply to a system at equilibrium: closed system with constant temperature, constancy of macroscopic properties, evidence of reversibility, and equal rates of forward and reverse processes

  – describe the steps in which a chemical system attains dynamic equilibrium

  – write and interpret chemical equations for chemical systems at equilibrium

- explain how different factors affect chemical equilibrium (323-4, 323-5)

  – explain how the forward and reverse reaction rates in a chemical equilibrium are affected by changes in the temperature, pressure/volume, and concentration (of one reactant or product), of a chemical equilibrium

  – state Le Châtelier's Principle

Elaborations—Strategies for Learning and Teaching

Any dynamic equilibrium can be described using a system of reversible rates. In the case of chemical equilibria they are forward and reverse chemical reactions. Any establishment of a dynamic equilibrium involves three steps. In general terms, step one, one reaction is initiated or perturbed; step two, the reverse rate responds; step three, equilibrium is established (or re-established).

From reactants only:

1. The forward rate is initially very high and as concentration of reactants decreases the forward rate decreases.

2. The reverse rate is initially zero and as concentration of products increases, the reverse reaction rate increases.

3. The system reaches equilibrium (the forward and reverse reaction rates become equal)

Teachers should reinforce that, at equilibrium, it is the reaction rates which become equal, not the amounts of products and reactants.

Students must indicate an equilibrium by writing a double arrow ($\rightleftharpoons$) in an equation, as opposed to using a single arrow ($\rightarrow$) for a reaction which goes to completion.

Before starting Le Châtelier's Principle, teachers may choose to first show how changing one of temperature, pressure/volume, or concentration affects the forward and reverse reaction rates. The equilibrium of the Haber Process is used as an example below:

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$
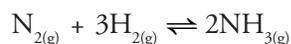
Increasing $[NH_3]$ causes the rate of the reverse reaction to respond to the stress of the added NH_3 to the equilibrium. This shift will result in increased concentration of N_2 and H_2, such that a new set of equilibrium concentrations (i.e., a new equilibrium position) is attained.

Le Châtelier's Principle could be presented as a summary of how equilibria respond to changes in the temperature, pressure and concentration (of one reactant or product). In the next section students will apply this principle.

Dynamic Equilibrium

Tasks for Instruction and/or Assessment	Resources/Notes
Paper and Pencil	*MGH Chemistry,* p. 489
• A chemical equilibrium is a dynamic equilibrium in which opposite processes are occurring at equal rates. Students could discuss this statement. What would help you to infer that the amounts of reactants and products are remaining constant at equilibrium? (323-3)	*MGH Chemistry,* pp. 492-493
• Students could prepare a short, oral presentation from the list of all the things they know about equilibrium generated in class. This is an exploratory exercise. Expectations are that students are questioning, analyzing, describing, and/or evaluating the structure using the scientific principles with which they are familiar. (323-3)	
• Teachers could ask students why does removing a product from an equilibrium system help to produce maximum yield of that product? Teachers could refer to this example: $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} +$ heat (114-2, 323-5)	
Performance	
• Students could examine what happens when carbonated water is made. They could open a bottle of soda pop and explain what they see. Students should write a chemical equation when equilibrium is reached between $CO_{2(aq)}$ and $H_2O_{(l)}$ to form $H_2CO_{3(aq)}$ when the container is open. They should write the equation for the physical equilibrium of $CO_{2(g)}$ and $H_2O_{(l)}$ when the container is closed. (114-2, 323-5)	*MGH Chemistry,* p. 492
Journal	
• Students could name one reversible reaction they may encounter every day. (323-5)	*MGH Chemistry,* pp. 519-528
• Teachers could ask if this instruction is chemically correct: "Add 5 grams of sugar to your tea/coffee/lemonade, and stir until the sugar stops dissolving." Students could explain their answer. (114-2, 323-5)	*MGH Chemistry,* p. 830
• Students could make a list of what they have learned about chemical equilibrium. They should list, for further exploration, any new questions they may have found. (323-5)	
Presentation	
• Students could research the use of solubility principles and equilibrium to remove a pollutant, such as Pb^{2+}, Cl^-, PO_4^{3-}, or SO_4^{2-}, from waste water. They should present their research as a memo to a company. (114-2, 323-5)	*MGH Chemistry,* p. 519

Le Châtelier's Principle

Outcomes

Students will be expected to

- explain how different factors affect chemical equilibrium (323-4, 323-5) (**Cont'd**)

  – use Le Châtelier's Principle to predict, qualitatively, shifts in equilibrium caused by changes in temperature, pressure, volume or concentration

  – use Le Châtelier's Principle to determine how the concentration of a reactant and/or product changes after a change is imposed on an equilibrium (not relative to initial conditions)

  – explain why the addition of a catalyst and varying surface area of a reactant or product do not cause the equilibrium to shift, yet both factors do have an effect on the time it takes for a system to reach equilibrium

Elaborations—Strategies for Learning and Teaching

Students should use Le Châtelier's Principle to determine how the concentrations of reactants and products change after a change is imposed on a system at equilibrium.

Teachers should model, and, students should use Le Châtelier's Principle in a wide variety of problems, given the widespread use of Le Châtelier's Principle in both chemical research and industry.

For example, the esterification reaction (studied in Chemistry 2202) is actually an equilibrium, as shown in the production of methyl ehtanoate below:

$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-OH \ + \ CH_3\text{-}OH \ \rightleftharpoons \ \overset{H^+}{} \ CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_3 \ + \ H_2O$$

Teachers could use the above equilibrium to brainstorm using Le Châtelier's Principle to maximize the yield of ester formed in the lab (i.e., remove H_2O as it is formed, remove ester as it is formed). This is common practice in chemical research.

Various industrial links to Le Châtelier's Principle may be made, the most famous being the Haber Process in the production of ammonia.

Students should explain how a catalyst and the surface area have an effect on the time it takes to reach equilibrium even though these do not cause the equilibrium to shift.

Students should be able to explain that increasing surface area is similar to the effect of a catalyst in that it has no net effect on the equilibrium position. A catalyst, however, does cause the equilibrium position to be reached in a shorter period of time. Increased surface area allows for increased frequency of collisions, resulting in successful collisions occurring more quickly. This effect occurs simultaneously for both forward and reverse reactions, hence no effect on equilibrium position.
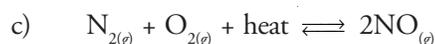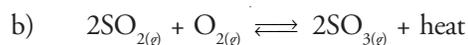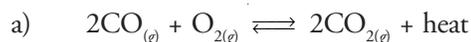
Le Châtelier's Principle

Tasks for Instruction and/or Assessment	Resources/Notes

Paper and Pencil
 	
• Students should determine in which direction equilibrium would shift by an increase in (1) the concentration of O_2, (2) pressure, and (3) temperature in each of the following reactions:
 	
(323-4, 323-5)
 	
    a) $2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)}$ + heat
 	
    b) $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$ + heat
 	
    c) $N_{2(g)} + O_{2(g)}$ + heat $\rightleftharpoons 2NO_{(g)}$
 	
• Students could design a water softener. How would they deal with the problem of hard water? (323-4, 323-5)
 	
• Students could research the development of modern instruments' effect on the purification of drinking water. (323-4, 323-5)
	MGH Chemistry, pp. 526-529
	
	MGH Chemistry, pp. 530-532

Le Châtelier's Principle *(continued)*

Outcomes

Students will be expected to

- explain the roles of evidence and theories, in Le Châtelier's Principle (114-2)

- compile and organize data, using appropriate formats and data treatments to facilitate interpretation of the data (213-5)

- identify the theoretical basis of an investigation and develop a prediction (212-5)

- select and use apparatus and materials safely (213-8)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 114-2, 213-5, 212-5, 213-8 and, in part, 323-5 are addressed by completing *Perturbing Equilibrium,* CORE LAB #2. Note that Part IV of this Core Laboratory is optional. If completed, students may require some background information on gas laws.

Students should do a lab on Le Châtelier's Principle to see how stress does affect equilibrium. Students should apply Le Châtelier's Principle to various changes made to a system at equilibrium. Organizing their observations in a table, as in the example below, might be helpful.

Stress Factors Effect on Equilibrium Reactions

Type of Reaction	Reactant Concentration Increases	Product Removed	Pressure Increases	Temperature Increases
Gaseous				

Le Châtelier's Principle *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- In the early 1900's an endothermic process was demonstrated by Birkeland and Eyde for fixing nitrogen by passing air through a high-temperature electric arc. If a cheap electric power source were available, it could promise to be a rival of the Haber-Borsch process.

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)} \quad \Delta H = +43.2 \text{kJ}$$

Students could apply Le Châtelier's principle, to predict how the yield of $NO_{(g)}$ could be increased? They should explain their answer. (323-4, 323-5, 213-5)

Resources/Notes

Core Lab #2: *"Perturbing Euilibrium"*, pp. 521-524

Equlibrium Constant

Outcomes

*Students will be expected to*

- define the concept of equilibrium constant expression as it pertains to chemical systems (323-3)

  - write equilibrium constant expression, K, for chemical systems

  - recognize that solids and liquids are not included in the equilibrium expression, K

  - recognize that the constant, K will vary with temperature

  - calculate equilibrium constants for simple chemical systems when concentrations at equilibrium are known

  - calculate equilibrium concentrations for chemical systems when K and all other equilibrium concentrations are known

  - predict whether or not reactants or products are favoured in a reversible reaction, on the basis of the magnitude of the equilibrium constant

Elaborations—Strategies for Learning and Teaching

The textbook uses K_c to indicate that K is expressed in terms of molar concentration.

Students could use a table or chart to help with problems involving equilibrium changes. Consider the problem: What is the K value for the following reaction at equilibrium, at 25°C?

$$H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + HCO_3^-_{(aq)}$$
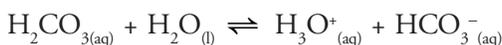
$$\left[H_2CO_3\right] = 3.3 \times 10^{-2}\,M$$

$$\left[HCO_3^-\right] = 1.19 \times 10^{-4}\,M$$

$$\left[H_3O^+\right] = 1.19 \times 10^{-4}\,M$$

When solving this K problem using H_2CO_3, students could list what they know, including the concentrations and what they want to find. Students should write the K expression, substitute values into the expression, and solve it.

$$K = \frac{[H_3O^+][HCO_3^-]}{[H_2CO_3]}$$

$$K = \frac{(1.19 \times 10^{-4})(1.19 \times 10^{-4})}{(3.3 \times 10^{-2})}$$

$$K = 4.3 \times 10^{-6}$$

Teachers can use this sample problem to reinforce that the liquid, water, is not included in the K expression, and that the final value of K has no units.

If K is much greater than 1, products are favored; if K is much less than 1, reactants are favored. Teachers should note that this is a qualitative interpretation of K. In the above example, since K = 4.3 x 10⁻⁶, reactants are favored.

Equlibrium Constant

Tasks for Instruction and/or Assessment	Resources/Notes

Paper and Pencil
 	
• Benzoic acid is used in food preparation. It is slightly soluble. The K for the reaction below is 6.30 × 10^{-5} at 25°C. [C$_6$H$_5$COOH] is 0.020 M. The reaction is C$_5$H$_5$COOH $\rightleftharpoons$ H$_3$O$^+$ + C$_6$H$_5$COO$^-$. Students could calculate the concentrations of [H$_3$O$^+$] and [C$_6$H$_5$COO$^-$].   (325-3)
 	
• Students could be asked, "What does the K value of this reaction tell us about which side is favoured, if any?" (323-3)
 	
• Students could write an equilibrium constant expression for
 	
    CO$_{2(g)}$ + H$_{2(g)}$ $\rightleftharpoons$ H$_2$O$_{(g)}$ + CO$_{(g)}$ K = 1.57
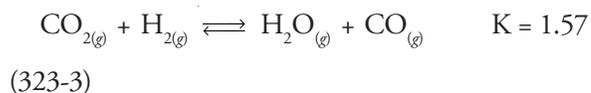 	
  (323-3)
	MGH Chemistry, p. 496
	
	MGH Chemistry, p. 497
	
	MGH Chemistry, p. 498
	MGH Chemistry, p. 830
	
	MGH Chemistry, p. 499
	
	MGH Chemistry, p. 511

Equlibrium Constant *(continued)*

Outcomes

Students will be expected to

- solve K_{eq} problems involving the initial concentrations, the changes that occur in each substance, and the resulting equilibrium concentrations (ACC-4)

  – calculate equilibrium concentrations for simple chemical systems when
    (i) initial concentrations of reactants and one equilibrium concentration are known
    (ii) initial concentrations of reactants and the percent reaction is known

  – calculate equilibrium constants, K, for simple chemical systems when:
    (i) initial concentrations, and one equilibrium concentration are known
    (ii) initial concentrations, and the percent reaction of one of the reactants are known

Elaborations—Strategies for Learning and Teaching

Sample problem: At a particular temperature: $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$
0.40 mol of $SO_{2(g)}$ and 0.40 mol of $O_{2(g)}$ are introduced into a sealed 1.0L reaction vessel. If at equilibrium there is 0.25 mol of $O_{2(g)}$ remaining, what is the equilibrium constant at this temperature?

Equilibrium Table

	$2SO_2 + O_2 \rightleftharpoons 2SO_3$		
Initial Concentration			
Change			
Equilibrium Concentration			

Teachers should reinforce that a "CHANGE' concentration is established for a substance which has the initial concentration [I] and an equilibrium concentration known. The [C] for all other substances can be calculated using molar ratios, and then the table may be completed for [E].

Once the equilibrium concentrations have been obtained from the ICE table, the equilibrium expression may be written and K calculated.

In the above example,

$$K = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(0.30)^2}{(0.10)^2(0.25)} = 36$$

The teacher may wish to revisit the concepts of Le Châtelier's Principle and/or the magnitude of K upon completion of such problems to refine these earlier concepts.

Equlibrium Constant *(continued)*

| Tasks for Instruction and/or Assessment	Resources/Notes

Paper and Pencil
 	
• At 1100 K, 0.777 moles of $SO_{3(g)}$ is introduced into a 1.00 L closed container and allowed to reach the equilibrium stated below. If the equilibrium concentration of $SO_{3(g)}$ is 0.520 M: (i) calculate K, (ii) calculate the percent reaction.
 	
  $2\ SO_{3(g)} \rightleftharpoons 2\ SO_{2(g)} + O_{2(g)}$ (ACC-4)
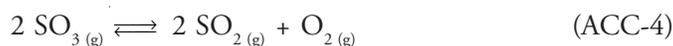 	
• At 298 K, $3\ X_{(g)} + Y_{(g)} \rightleftharpoons 2\ W_{(g)} + Z_{(g)}$, the equilibrium concentrations X, Y, W and Z were found to be 7.0 M, 6.0 M, 5.0 M and 7.0 M respectively. When the temperature was raised to 313 K the new equilibrium concentration of Z was found to be 6.0 M: (i) calculate the new equilibrium concentrations, (ii) calculate the new K. (ACC-4)
 	
• At a constant temperature, 6.0 moles of $SO_{2(g)}$ and 4.0 moles of $O_{2(g)}$ are introduced into a 2.00 L reaction vessel that contains 4.0 moles of $SO_{2(g)}$. If at equilibrium the vessel contains 3.0 moles of $SO_{3(g)}$, calculate the equilibrium constant:
 	
  $2\ SO_{3(g)} \rightleftharpoons 2\ SO_{2(g)} + O_{2(g)}$ (ACC-4)
	MGH Chemistry, pp. 499-500
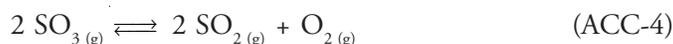	
	MGH Chemistry, pp. 509-510
	
	MGH Chemistry, pp. 499-500
	
	MGH Chemistry, pp. 509-510