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UNIT 4

Quantitative Relationships in Chemical Changes

Chapter 8 *Applications of Stoichiometry*

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

Teaching Unit 4: Quantitative Relationships in Chemical Changes

(32% of course time; approximately 40 hours)

Student Textbook pages 252 to 331

General Outcomes

- Explain how balanced chemical equations show the quantitative relationships among the reactants and products involved in chemical changes.
- Use stoichiometry in quantitative analysis.

Contents

Chapter 7 Stoichiometry

Chapter 8 Applications of Stoichiometry

Content Summary

Quantitative relationships have an impact on every area of chemistry, thus the concepts in this unit have applications in industry, farming, medicine, and the home, as well as in the chemical laboratory. This unit begins with reactions in aqueous solutions and the techniques of qualitative analysis. Quantitative analysis is made possible using chemical equations and mole ratios. These concepts are extended to solution stoichiometry and to gas stoichiometry. The concepts of a limiting reactant and reaction yield are introduced next, and these are extremely important in many industrial reactions. Finally in this unit, quantitative analysis is extended to acid-base titrations.

Chapter 7 begins with ionic and net ionic equations. The net ionic equation for a reaction eliminates spectator ions, leaving a simplified equation showing only the actual chemical change that took place. The techniques of qualitative analysis are described next. These include the colour of the solution of some common ions, flame tests, and the formation of a precipitate. Students apply their knowledge of the solubility guidelines and use flame tests to qualitatively identify unknown ions present in solutions. Students write chemical and net ionic equations and learn how to apply mole ratios to solve stoichiometry problems. Gravimetric stoichiometry naturally follows when the amount of a substance in moles is converted to mass. Students will manipulate between concentrations, volumes, amount in moles, and masses of precipitates. Next, students use gravimetric stoichiometry skills to determine the concentration of a solution. Finally in Chapter 7, gas stoichiometry includes the concepts from Chapter 3 and 4: Exploring Gas Laws, including the law of combining gas volumes and the ideal gas equation.

The focus of Chapter 8 is the applications of stoichiometry in the development of solutions to technological problems. Principles of stoichiometry are used to minimize waste and to maximize the yield of a desired product. Factors that limit experimental yield are discussed, and students predict the theoretical yield and measure the actual yield of a reaction. Students then return to acid-base reactions where they will learn how to perform acid-base titrations using an indicator to determine the equivalence point. Students also determine the molar concentration of hydrochloric acid samples that are to be standardized. Students learn about acid-base titration curves, and plot volumetric data for a strong acid-strong base titration. Finally, students design the procedure and perform a titration using a standard solution of HCl(aq) to determine the concentration of a solution of sodium hydroxide.

Curriculum Fit

Background

- *Science 10,* Unit A: Energy and Matter in Chemical Change.

This unit continues the study of solutions, acids and bases from the previous unit, and includes concepts from gases learned in Unit B. Quantitative relationships may be useful in any area of chemistry but will be essential for success in the following units of *Chemistry 30:* Thermodynamics (found in Unit 5); Electrochemistry (found in Unit 6), and Equilibrium (found in Unit 8).

Core Concepts

Concept	Outcome	Text Reference
Quantitative relationships in chemical reactions are applied by industries and in many technological applications to minimize waste and maximize yield.	20–D2.1sts	Chapter 7: Stoichiometry, p. 260 Section 7.1: Reactions in Aqueous Solution, p. 263 Section 7.2: Stoichiometry and Qualitative Analysis, pp. 275, p. 279 Investigation 7.C: Analyzing Industrial Processes, p. 288 Chapter 8: Applications of Stoichiometry, p. 294 Section 8.2: Predicted and Experimental Yield, p. 307
A total ionic equation shows all the dissociated ions of soluble ionic compounds.	20–D1.4k	Section 7.1: Reactions in Aqueous Solution, pp. 262-263
A net ionic equation shows only the ions involved in a chemical change.	20–D1.4k	Section 7.1: Reactions in Aqueous Solution, pp. 262-263
Spectator ions are present in a solution but are not involved in the chemical reaction.	20–D1.4k	Section 7.1: Reactions in Aqueous Solution, pp. 262-263
Qualitative analysis is the process of separating and identifying substances using a variety of techniques including ion colour in aqueous solution, flame tests, and precipitation reactions.	20–D1.3k	Section 7.1: Reactions in Aqueous Solution, pp. 265-269
Quantitative (or gravimetric) analysis is the process of determining how much of a compound, element, or ion is present in a sample.	20–D1.3k	Section 7.2: Stoichiometry and Qualitative Analysis, p. 271
A mole ratio is the ratio between the molar amounts of any two elements, ions, or compounds in a chemical equation.	20–D1.2k 20–D1.4k 20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 272-274
The amount (mol) of one component in a chemical reaction can be calculated if the amount of another component and the chemical equation for the reaction are known.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 273-274
The mass (m) of a substance may be calculated if its molar mass (M) and amount (n) are known: $m = n \times M$.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 276-279
Stoichiometry is the calculation of the relative quantities of the reactants and products involved in a chemical reaction. Gravimetric stoichiometry involves mass calculations; solution stoichiometry involves the volumes and concentrations of solutions; gas stoichiometry involves volumes, temperatures and pressures of gaseous products or reactants.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 275-287
When gases react, the volumes of reactant and product gases, at the same temperature and pressure, are always in whole number ratios. (Law of combining gas volumes)	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 284-286
The limiting reactant of a chemical reaction is the reactant that is completely consumed in the reaction.	20–D2.2k	Section 8.1: Limiting and Excess Reactants, pp. 296-302

Concept	Outcome	Text Reference
The experimental yield from a reaction is usually reduced by a number of factors. Percentage yield = $\frac{\text{Experimental yield}}{\text{Predicted yield}} \times 100\%$	20–D2.3k 20–D2.4k	Section 8.2: Predicted and Experimental Yield, pp. 305-310
In an acid-base titration, the concentration of one solution is quantitatively determined by observing the reaction with another solution of known concentration. The end of the reaction is often observed using an indicator.	20–D2.6k	Section 8.3: Acid-Base Titration, p. 312
The end point of an acid-base titration occurs when the indictor changes colour. The equivalence point occurs when stoichiometrically equivalent amounts of reactants have been mixed.	20–D2.7k	Section 8.3: Acid-Base Titration, pp. 312-313
An acid-base titration curve is a plot of the pH of the reaction mixture against the volume of titrant added.	20–D2.5k	Section 8.3: Acid-Base Titration, pp. 318-319
The endpoint pH for an indicator must be within the steep change in the titration curve.	20–D2.6k 20–D2.7k	Section 8.3: Acid-Base Titration, pp. 319-320

Related Skills

Skills	Outcome	Text Reference
Students will experimentally determine the mole ratio of reactant to product in a decomposition reaction.	20–D1.3s	Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, p. 261
Given the chemical formula(s) of the reactant(s), students will identify the reaction type, predict the product(s) of the reaction and write a chemical equation describing the change.	20–D1.1k 20–D1.2k	Unit 4 Preparation, pp. 255-258
Students will write ionic and net ionic equations for reactions taking place in aqueous solutions, and identify the spectator ions.	20–D1.1k 20–D1.2k 20–D1.4k	Section 7.1: Reactions in Aqueous Solution, pp. 262-264 Section 7.1, Investigation 7.A: Qualitative Analysis, pp. 268-269
Students will use the techniques of qualitative analysis to identify the ions present in unknown solutions.	20–D1.1k 20–D1.2s 20–D1.4k	Section 7.1, Thought Lab 7.1: Identifying Unknown Aqueous Solutions, p. 267 Section 7.1, Investigation 7.A: Qualitative Analysis, pp. 268-269
Students will write the mole ratio for any two components of a chemical reaction, and determine the amount of one component given the amount of the other.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 273-274
Students will calculate the amount (mol) of one component in a chemical reaction given the amount of another component and the chemical equation for the reaction.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 274, 279
Students will analyze the use of technology to reduce the environmental impact of processing natural gas.	20–D2.2sts	Section 7.2: Stoichiometry and Qualitative Analysis, p. 279

Skills	Outcome	Text Reference
Students will calculate the mass of one component in a chemical reaction given the amount or mass of another component, a table of average atomic mass values, and the chemical equation for the reaction.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 274-279
Students will solve solution stoichiometry problems.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 280-282
Students will determine the concentration of a solution using the techniques of solution stoichiometry.	20–D2.1s 20–D2.1k 20–D2.3s	Section 7.2, Investigation 7.B: Determining the Concentration of a Solution, pp. 282-283
Students will solve gas stoichiometry problems.	20–D1.5k	Section 7.2: Stoichiometry and Qualitative Analysis, pp. 284-287
Students will research how an industry applies principles of stoichiometry to minimize waste and maximize yield, prepare a report, and include a schematic diagram, flowchart, or model of the process.	20–D1.1sts 20–D2.1sts 20–D2.2s 20–D2.4s	Section 7.2, Investigation 7.C: Analyzing Industrial Processes, p. 288
Students will investigate gas stoichiometry by performing an experiment to check their calculations of the theoretical yield of a reaction that generates a gas.	20–D1.1s 20–D1.3s	Chapter 8 Launch Lab: The Model Air Bag, p. 295
Students will calculate the limiting reactant in a chemical reaction.	20–D2.2k	Section 8.1: Limiting and Excess Reactants, pp. 298-303 Section 8.1, Thought Lab 8.1: The Limiting Item, p. 296
Students will predict the limiting and excess reactant in a chemical reaction and test their predictions experimentally.	20–D2.2k	Section 8.1, Investigation 8.A: The Limiting Reactant, p. 300
Students will perform calculations based on the following relationship: $\text{Percentage yield} = \frac{\text{Experimental yield}}{\text{Predicted yield}} \times 100\%$	20–D2.4k	Section 8.2: Predicted and Experimental Yield, pp. 308-309
Students will experimentally determine the percentage yield of a chemical reaction and make suggestions to improve the accuracy of their investigation.	20–D1.1s 20–D1.3s 20–D2.3k 20–D2.4k	Section 8.2, Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, pp. 309-310
Given data for an acid-base titration, students will calculate the molar concentration of one of the solutions.	20–D1.5k	Section 8.3: Acid-Base Titration, pp. 315-316
Students will perform an acid-base titration to determine the concentration of one of the solutions.	20–D1.5k 20–D2.2s 20–D2.4s	Section 8.3, Investigation 8.C: Standardizing a Hydrochloric Acid Solution, pp. 316-317 Section 8.3, Investigation 8.D: Titrating a Strong Base with a Strong Acid, p. 321
Given pH titration data, students will use a spreadsheet program to plot an acid-base titration curve.	20–D1.4s 20–D2.3s 20–D2.4s	Section 8.3, Thought Lab 8.2: Plotting a Titration Curve, p. 320

Activities and Target Skills

Activity	Target Skills
Chapter 7: Stoichiometry	
Launch Lab: The Thermal Decomposition of Baking Soda, p. 261	■ Observing thermal decomposition
Thought Lab 7.1: Identifying Unknown Aqueous Solutions, p. 267	■ Predicting the identity of an ion based on qualitative tests.
Investigation 7.A: Qualitative Analysis, pp. 268-269	■ Predicting the product(s) of a chemical reaction based on the reaction type ■ Writing balanced ionic and net ionic equations
Investigation 7.B: Determining the Concentration of a Solution, pp. 282-283	■ Evaluating an experiment based on a precipitation reaction to determine the concentration of a solution
Investigation 7.C: Analyzing Industrial Processes, p. 288	■ Describing how industries apply principles of stoichiometry to minimize waste and maximize yield ■ Assessing the significance of byproducts from industrial applications of chemical reactions
Chapter 8: Applications of Stoichiometry	
Launch Lab: The Model Air Bag, p. 295	■ Creating a model air bag
Thought Lab 8.1: The Limiting Item, p. 296	■ Identify limiting and excess "reactants"
Investigation 8.A: The Limiting Reactant, p. 300	■ Identifying limiting and excess reactants in chemical reactions
Investigation 8.B Determining the Percentage Yield of a Chemical Reaction, pp. 309-310	■ Calculating percentage yield and explaining the discrepancies between the theoretical and actual yields
Investigation 8.C Standardizing a Hydrochloric Acid Solution, pp. 316-317	■ Standardizing an acid or base solution and comparing group results
Thought Lab 8.2 Plotting a Titration Curve, p. 319	■ Creating and interpreting a titration curve graph for an acid–base experiment
Investigation 8.D: Titrating a Strong Base with a Strong Acid, p. 321	■ Predicting the approximate equivalence point for a strong monoprotic acid–strong monoprotic base titration ■ Performing a titration to determine the concentration of a base

Conceptual Challenges

Section 7.1

- Students beginning their study of chemistry may try to balance a chemical equation by changing the subscript(s) in a chemical formula. Only coefficients can be changed when balancing equations. Changing subscripts changes the nature of the substances, and this can be illustrated by demonstrating what happens when manganese dioxide, MnO_2, is added to water, H_2O, (no change) compared with adding MnO_2 to hydrogen peroxide, H_2O_2, (oxygen gas is formed).

Section 8.1

- The concept of a limiting reactant is sometimes difficult to grasp. Thought Lab 8.1: The Limiting Item (page 296), is a nice reinforcement of the idea of proportionality in a "reaction" and a good introduction to the concept of a limiting reactant.

Section 8.2

- It is very common to mix up the endpoint and equivalence point in a titration, or to believe the terms mean the same thing. With reference to either of the titration curves shown in Figures 8.8 or 8.9 on page 318, ask what would happen if an indicator was used that changed colour in the pH range 0.0–1.6 (methyl violet) or 11.4–13.0 (indigo carmine).

- Students may believe that the volumes of reactant solutions are related by the stoichiometric coefficients. Solution volumes are usually not in the ratio of the moles of reactants, and this can be discussed in the post-lab to either of the titration experiments, Investigation 8.C: Standardizing a Hydrochloric Solution (page 316-317) or Investigation 8.D: Titrating a Strong Base with a Strong Acid (page 321).

Using the Unit 4 Preparation Feature

The unit opener has been designed to establish a social, technical, and environmental context for the science in the unit. Use the unit opener to introduce the general unit topics within that context, and ask the Focussing Questions to guide students' thinking.

The Unit Preparation feature has been included in order to ensure that students are familiar with the science from previous courses that relates specifically to the material they are about to study. Encourage students to take the Unit Prequiz (found at **www.albertachemistry.ca**, Online Learning Centre, Student Edition) to gauge their recall, noting that if they are familiar with the background science, their experience with this unit will be much easier.

The Unit 4 Preparation feature is six pages, and topics reviewed include: conservation of mass, classifying chemical reactions, predicting the products of a reaction, balanced chemical equations (including guidelines), and calculating amounts of substances.

A variety of blackline masters (BLMs) has been prepared to support the material in the Unit Preparation. The BLMs are either for use as overheads (OH); assessment (AST); or to supply answers (ANS) for assessment. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition (password required).

Number (Type) Title
7.0.1 (AST) Identifying Reaction Types Quiz
7.0.1A (ANS) Identifying Reaction Types Quiz Answers
7.0.2 (OH) Guidelines for Balancing Equations
7.0.3 (AST) Balancing Chemical Reactions Quiz
7.0.3A (ANS) Balancing Chemical Reactions Quiz Answers
7.0.4 (AST) Translating Word Equations
7.0.4A (ANS) Translating Word Equations Answers
7.0.5 (AST) Predicting and Balancing Formation, Decomposition, and Hydrocarbon Combustion Reactions
7.0.5A (ANS) Predicting and Balancing Formation, Decomposition, and Hydrocarbon Combustion Reactions Answers
7.0.6 (AST) Predicting and Balancing Single and Double Replacement Reactions
7.0.6A (ANS) Predicting and Balancing Single and Double Replacement Reactions Answers
7.0.7 (OH) Calculating Amounts of Substances
7.0.8 (AST) Determining the Number of Moles in a Sample
7.0.8A (ANS) Determining the Number of Moles in a Sample Answers

Answers to Practice Problems 1-2

Student Textbook page 258

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. (a) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$, this is a hydrocarbon combustion reaction

(b) $P_4(s) + 4I_2(s) \rightarrow 2P_2I_4(s)$, this is a formation reaction

(c) $Cl_2(g) + 2CsBr(aq) \rightarrow Br_2(\ell) + 2CsCl(aq)$, this is a single replacement reaction

(d) $3Ba(ClO_3)_2(aq) + 2Na_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NaClO_3(aq)$, this is a double replacement reaction

(e) $2Li_3N(s) \rightarrow 6Li(s) + N_2(g)$, this is a decomposition reaction.

(f) $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$, this reaction may be classed as a decomposition

2. (a) $2C_4H_{10}(g) + 13O_2(g) \rightarrow 10H_2O(g) + 8CO_2(g)$

(b) $Zn(s) + Pb(NO_3)_2 \rightarrow Pb(s) + Zn(NO_3)_2(aq)$

(c) $8Mg(s) + S_8(s) \rightarrow 8MgS(s)$

(d) $Sr(OH)_2(aq) + H_2SO_4(aq) \rightarrow SrSO_2(aq) + 2H_2O(\ell)$

(e) $2LiN_3(s) \rightarrow 2Li(s) + 3N_2(g)$

UNIT 4: COURSE MATERIALS

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapters 7, 8	safety goggles	40 pairs	Chapter 7 Launch Lab, Ch8 Launch Lab; Investigations: 7.A, 7.B, , 8.A, 8.B, 8.C
Chapters 7, 8	nonlatex disposable gloves	40 pairs × 5 investigations	Investigations: 7.A, 7.B, 8.A, 8.C, 8.D,
Chapters 7, 8	aprons	40	Investigations: 7.B, 8.A, 8.B, 8.C
Chapter 7, Chapter Opener	baking soda crucible iron ring clay triangle Bunsen burner or alcohol burner retort stand electronic balance heat-resistant gloves	2–3 g per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 1 pair per group	Launch Lab: The Thermal Decomposition of Baking Soda, p. 261
Chapter 7, Section 7.1	12- or 24-well plate, or spot plate set of unknown solutions, each set containing the following labelled dropper bottles: A/reactant: 0.10 mol/L $NaNO_3$(aq) B/reactant: 0.10 mol/L $AgNO_3$(aq) C/reactant: 0.10 mol/L $Ca(NO_3)_2$(aq) D/reactabt: 0.10 mol/L $Cu(NO_3)_2$(aq) set of labelled reactants in dropper bottles: 0.10 mol/L HCl (aq) 0.10 mo/L H_2SO_4(aq) cotton swabs laboratory burner heat-resistant pad wash bottle containing de-ionized water waste container	1 per group 1 set per group 50 mL 50 mL 50 mL 50 mL 1 set per group 5 mL per group 5 mL per group 500 1 per group 1 per group 1 per group 1	Investigation 7.A: Qualitative Analysis, p. 268–269
Chapter 7, Section 7.2	$Mg(NO_3)_2$(aq) solution of unknown concentration 0.200 mol/L Na_3PO_4(aq) deionized water 150 mL beaker 50 mL volumetric pipette 250 mL Erlenmeyer flask funnel retort stand wash bottle drying oven (if available) stirring rod ring clamp or funnel rack filter paper large watch glass electronic balance	50 mL per group 50 mL per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 1 per group 1 per group 1 per group 1 per group 1	Investigation 7.B: Determining the Concentration of a Solution, pp. 282–283

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapter 8, Chapter Opener	50.0 mL graduated cylinder 50 mL beaker mercury barometer (or information about latest air pressure, uncorrected) -20°–120°C alcohol (or digital) thermometer resealable plastic sandwich bags (typically 16.9 cm × 14.8 cm) household white vinegar (dilute ethanoic acid, $CH_3COOH(aq)$) baking soda (sodium hydrogencarbonate, $NaHCO_3(s)$) electronic balance	1 per group 1 per group 1 1 per group 1 per group 500 mL 500 g 1	Launch Lab: The Model Air Bag, p. 295
Chapter 8, Section 8.1	heat-resistant gloves CuCl2(s) aluminium foil water 125 mL Erlenmeyer flask stirring rod	1 pair per group 0.51 g per group 0.25 g per group 50 mL per group 1 per group 1 per group	Investigation 8.A: The Limiting Reactant, p. 300
Chapter 8, Section 8.2	distilled water copper chloride dihydrate, CuCl2 • 2H2O(s) 1 mol/L hydrochloric acid, HCl(aq) 250 mL beaker stirring rod electronic balance rust-free, degreased steel wool Erlenmeyer fl ask plastic funnel retort stand wash bottle ring clamp filter paper watch glass drying oven (if available)	100 mL per group 5.00 g per group 20 mL 1 per group 1 per group 1 1.00–1.20 g 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1	Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, pp. 309–310
Chapter 8, Section 8.3	50 mL burette 10 mL volumetric pipette 50 mL beaker 250 mL beaker 125 mL Erlenmeyer flask 100 mL volumetric flask glass stirring rod burette funnel meniscus reader pipette bulb retort stand burette clamp scoopula or spatula electronic balance dropper bottle of phenolphthalein wash bottle containing de-ionized water 0.125 mol/L HCl(aq) sodium carbonate, $Na_2CO_3(s)$	1 per group 1 per group 1 per group 1 per group 2 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 (or as many as available) 1 per group 1 per group 100 mL per group 2.00 g per group	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, pp. 316–317

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapter 8, Section 8.3	50 mL burette 10 mL volumetric pipette 50 mL beaker 250 mL beaker 125 mL Erlenmeyer flask 100 mL volumetric flask glass stirring rod burette funnel meniscus reader pipette bulb retort stand burette clamp scoopula or spatula electronic balance dropper bottle of methyl orange, phenolphthalein, bromothymol blue (or other suitable indicators) wash bottle containing de-ionized water 0.125 mol/L HCl(aq) 0.150 mol/L NaOH(aq)	1 per group 1 per group 1 per group 1 per group 2 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 per group 1 (or as many as available) 1 per group 1 per group 100 mL per group (standardized in Investigation 8.C) 100 mL per group	Investigation 8.D: Titrating a Strong Base with a Strong Acid, p. 321

CHAPTER 7 STOICHIOMETRY

Curriculum Correlation

General Outcome 1: Students will explain how balanced chemical equations indicate the quantitative relationships among reactants and products involved in chemical changes.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
20–D1.1k predict the product(s) of a chemical reaction based upon the reaction type	Classifying Chemical Reactions, Unit 4 Preparation, p. 255 Predicting the Products of a Reaction, Unit 4 Preparation, p. 256 Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, p. 261 Reactions in Aqueous Solution, Section 7.1, pp. 262-263, 264 Thought Lab 7.1: Identifying Unknown Aqueous Solutions, Section 7.1, p. 267 Investigation 7.A: Qualitative Analysis, Section 7.1, p. 268 Connections: Waste Water Treatment, Section 7.2, p. 279	Practice Problems: 1, 2, Unit 4 Preparation, p. 258 Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, Analysis: 1, p. 261 Thought Lab 7.1: Identifying Unknown Aqueous Solutions, Section 7.1, Analysis 4, p. 267 Investigation 7.A: Qualitative Analysis, Analysis: 1-4, Section 7.1, p. 268 Connections: Waste Water Treatment: 1, 2, Section 7.2, p. 279 Chapter 7 Review: 9-11, pp. 292-293 Chapter 7 Test Unit 4 Review: 6–9, 16, 17, 20, 25, 27, 30, 31, pp. 328–331
20–D1.2k recall balancing of chemical equations in terms of atoms, molecules and moles	Guidelines for Balancing Chemical Equations, Unit 4 Preparation, p. 257 Sample Problem: Balancing Chemical Equations, Unit 4 Preparation, p. 258 Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, p. 261 Reactions in Aqueous Solution, Section 7.1, pp. 262-263, 264 Stoichiometry and Qualitative Analysis, Section 7.2, pp. 272-274 Connections: Waste Water Treatment, Section 7.2, p. 279	Practice Problems: 1, 2, Unit 4 Preparation, p. 258 Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, Analysis: 1-3, p. 261 Section 7.1 Review: 8, p. 270 Connections: Waste Water Treatment: 1, 2, Section 7.2, p. 279 Chapter 7 Review: 7, pp. 292-293 Chapter 7 Test Unit 4 Review: 1–4, 6–10, 15, 16, 23, 26, 33, pp. 328–331

	Student Textbook	Assessment Options
20–D1.3k contrast quantitative and qualitative analysis	Qualitative versus Quantitative Analysis, Section 7.1, p. 265 Thought Lab: Identifying Unknown Aqueous Solutions, Section 7.1, p. 267 Stoichiometry and Qualitative Analysis, Section 7.2, p. 271	 Thought Lab: Identifying Unknown Aqueous Solutions: 1-4, Section 7.1, p. 267 Questions for Comprehension: 1, 2, Section 7.1, p. 268 Section 7.1 Review: 6, 7, 11, p. 270 Section 7.2 Review: 1, p. 289 Chapter 7 Review: 2, 6, 10, 19, pp. 292-293 Chapter 7 Test Unit 4 Review: 20, pp. 328–331
20–D1.4k write balanced ionic and net ionic equations, including identification of spectator ions, for reactions taking place in aqueous solutions	Reactions in Aqueous Solution, Section 7.1, pp. 262-263 Guidelines for Balancing Chemical Equations, Unit 4 Preparation, p. 257 Sample Problem: Balancing Chemical Equations, Unit 4 Preparation, p. 258 Sample Problem: Writing a Net Ionic Equation, Section 7.1, p. 264 Thought Lab 7.1: Identifying Unknown Aqueous Solutions, Section 7.1, p. 267 Investigation 7.A: Qualitative Analysis, Section 7.1, pp. 268-269 Stoichiometry and Qualitative Analysis, Section 7.2, pp. 272-274 Investigation 7.B: Determining the Concentration of a Solution, Section 7.2, p. 282	Practice Problems: 1, 2, Unit 4 Preparation, p. 258 Practice Problems: 1, 2, Section 7.1, p. 264 Thought Lab 7.1: Identifying Unknown Aqueous Solutions, Section 7.1, Analysis 4, p. 267 Investigation 7.A: Qualitative Analysis, Analysis: 1, 2, 5, 6, Section 7.1, p. 269 Section 7.1 Review: 1-3, 5, 8-10, p. 270 Investigation 7.B: Determining the Concentration of a Solution: 1-5, Section 7.2, p. 282 Section 7.2 Review: 2-4, p. 289 Chapter 7 Review: 1, 7, 8, pp. 292-293 Chapter 7 Test Unit 4 Review: 1, 6–10, 14, 15, 17, 18, 20, 23, 26–28, 36–42, pp. 328–331

	Student Textbook	Assessment Options
20–D1.5k calculate the quantities of reactants and/or products involved in chemical reactions using gravimetric, solution or gas stoichiometry.	Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, p. 261	Chapter 7 Launch Lab: The Thermal Decomposition of Baking Soda, Analysis: 2, p. 261
	Stoichiometry and Qualitative Analysis, Section 7.2, pp. 274-279, 284-287	Questions for Comprehension: 5, 6, Section 7.2, p. 275
	Sample Problem: Gravimetric Stoichiometry: Reactant to Reactant, Section 7.2, p. 276	Practice Problems: 8-15, Section 7.2, p. 278
	Sample Problem: Gravimetric Stoichiometry: Reactant to Product, Section 7.2, p. 277	
	Connections: Waste Water Treatment, Section 7.2, p. 279	Connections: Waste Water Treatment: 2, Section 7.2, p. 279
	Solution Stoichiometry, Section 7.2, p. 280	Questions for Comprehension: 7, Section 7.2, p. 280
	Sample Problem: Solution Stoichiometry, Section 7.2, p. 280	Practice Problems: 16-19, Section 7.2, p. 282
	Investigation 7.B: Determining the Concentration of a Solution, Section 7.2, p. 282	Investigation 7.B: Determining the Concentration of a Solution: 1, 4, 5, Section 7.2, p. 282
	Sample Problem: Gas Stoichiometry Using the Law of Combining Volumes, Section 7.2, p. 285	Questions for Comprehension: 8, Section 7.2, p. 285
	Sample Problem: Gas Stoichiometry Using the Ideal Gas Law, Section 7.2, p. 286	Practice Problems: 20-23, Section 7.2, p. 286
		Questions for Comprehension: 9, Section 7.2, p. 286
	Acid-Base Titration, Section 8.3, pp. 315-316	Practice Problems: 24-27, Section 7.2, p. 287 Section 7.2 Review: 2-20, p. 289 Chapter 7 Review: 5, 12-22, pp. 292-293 Chapter 7 Test
	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, pp. 316-317	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Analysis 1, p. 317 Unit 4 Review: 16, 23, 24, 26–29, 31, 32–42, pp. 328–331

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on social and environmental contexts)		
20–D1.1sts explain that the focus in technology is on the development of solutions, involving devices and systems that meet a given need within the constraints of a problem by ■ *analyzing the chemical reactions involved in various industrial and commercial processes and products that use stoichiometric and chemical principles, using examples from the following:* *– production of urea* *– fertilizers* *– fuel combustion* *– water treatment* *– air-bag deployment* *– neutralization of excess stomach acid.*	Connections: Waste Water Treatment, Section 7.2, p. 279 Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288	Connections: Waste Water Treatment: 1-4, Section 7.2, p. 279 Investigation 7.C: Analyzing Industrial Processes: 1-3, 1, 2, Section 7.2, p. 288 Chapter 7 Review: 19-22, p. 292-293 Unit 4 Review: 43–45, p. 328–331
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
20–D1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ planning and predicting states, products and theoretical yields for chemical reaction ■ designing an experiment to identify an ion, e.g., *precipitation, flame test* ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information.	Thought Lab: Identifying Unknown Aqueous Solutions, Section 7.1, p. 267 Investigation 7.B: Determining the Concentration of a Solution, Section 7.2, p. 282 Chapter 8, Launch Lab: The Model Air Bag, p. 295 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, pp. 309-310	Thought Lab: Identifying Unknown Aqueous Solutions, Analysis: 1-4, Section 7.1, p. 267 Investigation 7.B: Determining the Concentration of a Solution: 1-5, Section 7.2, p. 282 Chapter 7 Review: 19-21, pp. 292-293 Chapter 8, Launch Lab: The Model Air Bag, Analysis 2, p. 295 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Analysis 1-3, p. 310 Unit 4 Review: 11, 22, 43–45, pp. 328–331
Performing and Recording		
20–D1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ translating word equations for chemical reactions into chemical equations, including states of matter for the products and reactants ■ balancing chemical equations for chemical reactions, using lowest whole-number coefficients.	Thought Lab: Identifying Unknown Aqueous Solutions, Section 7.1, p. 267 Connections: Waste Water Treatment, Section 7.2, p. 279 Investigation 7.A: Qualitative Analysis, pp. 273-274 Investigation 7.B: Determining the Concentration of a Solution, Section 7.2, p. 282	Thought Lab: Identifying Unknown Aqueous Solutions, Analysis: 1-4, Section 7.1, p. 267 Connections: Waste Water Treatment: 1, Section 7.2, p. 279 Investigation 7.A: Qualitative Analysis, Analysis 1, 2, p. 274 Investigation 7.B: Determining the Concentration of a Solution: 1-5, Section 7.2, p. 282

	Student Textbook	Assessment Options
Analyzing and Interpreting		
20–D1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ interpreting stoichiometric ratios from chemical reaction equations ■ performing calculations to determine theoretical yields ■ using appropriate SI notation, fundamental and derived units and significant digits when performing stoichiometric calculations.	Investigation 7.B: Determining the Concentration of a Solution, Section 7.2, p. 282 Throughout Chapter 7 Chapter 8, Launch Lab: The Model Air Bag, p. 295 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, pp. 309-310	Investigation 7.B: Determining the Concentration of a Solution: 1-5, Section 7.2, p. 282 Throughout Chapter 7 Chapter 8, Launch Lab: The Model Air Bag, Analysis 1, p. 295 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Conclusion 4, Extension 5, pp. 309-310 Unit 4 Review: 19, 23–42, pp. 328–331
Communication and Teamwork		
20–D1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ *using integrated software effectively and efficiently to incorporate data and text.*	Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288 Thought Lab 8.2: Plotting a Titration Curve, p. 320	Investigation 7.C: Analyzing Industrial Processes: 1-3, Section 7.2, p. 288 Section 7.2 Review: 8, p. 290 Thought Lab 8.2: Plotting a Titration Curve, Procedure 1, Analysis 5, p. 320

Chapter 7

Stoichiometry

Student Textbook pages 260–293

Chapter Concepts

Section 7.1 Reactions in Aqueous Solution

- Complete balanced, ionic, and net ionic equations are all ways to represent reactions in solution.
- Qualitative tests, such as flame tests and precipitation reactions, test for the presence of dissolved ions.

Section 7.2 Stoichiometry and Quantitative Analysis

- The coefficients of a balanced chemical reaction can be used to predict the masses of products and reactants, given the mass of another product or reactant.
- Stoichiometric techniques can be used to determine the concentration and volume of aqueous solutions.
- Precipitation reactions are useful for determining the concentration of an unknown solution.
- Stoichiometric techniques can be used to determine the volume, temperature, mass, or pressure of gaseous reactants or products.
- Industrial processes use stoichiometric principles to maximize yield and minimize loss.

Common Misconceptions

- When predicting net ionic equations in aqueous solutions, some students may incorrectly dissociate molecular compounds
  $C_6H_{12}O_6(aq) \rightarrow 6C^{2-}(aq) + 12\ H^+(aq) + 6O^{2-}(aq)$.
  Students should be reminded that molecular compounds do not break apart when placed in an aqueous environment. In conjunction, weak acids do not ionize in solutions, and students should be reminded of the distinction between strong and weak acids.
- Some students will believe that flame and solution colours are representative of the element as well as the ion. For example, a piece of sodium will produce a yellow colour when placed in a flame. The flame and solution colours are produced by the ion, not the atom. This point should be reinforced.
- When calculating the molar mass of compounds found in a balanced equation, students will sometimes take the value of the coefficient for a particular compound into consideration. Explain that the units for molar mass are $\frac{g}{mol}$, not $\frac{g}{2\ mol}$ or $\frac{g}{3\ mol}$. The coefficients are part of the balanced chemical equation, not of the molar mass.
- Some students may not be aware that it is the metallic portion of the compound that gives the colour to the flame in a flame test. They may think that the anion is involved as well. It may be helpful to show them that any sodium salt, whether it is a chloride, bromide, iodide, or carbonate, will give the same yellow colour to the flame.
- Students may believe that the colour of ions in solution is the same colour that will be seen from the ion in a flame test. Table 7.2 on page 265 of the student textbook shows the colour of some ions in solution; on the next page, Table 7.3 shows the colour of selected metal ions in a flame test. You could make up one or two of the solutions and show how coloured compounds in solution do not give that same colour in a flame, to show that the two colour charts mean different things.
- The mole is one of the more difficult concepts in an introductory chemistry course. Although this unit is not the first to introduce the mole, it does use the concept extensively. Students need a clear understanding based on making the connection between the amount of substance and a numerical quantity. Students who struggle to manipulate numbers and symbols will find a strictly mathematical approach towards learning the mole very difficult to understand and the chemical meaning of the mole concept should be emphasized.
- Students quite often believe that the number of reactant moles must be the same as the number of product moles in a balanced chemical equation. In other words, they believe that moles are conserved. Point out that mass is conserved in a chemical change, not number of moles.
- It is a quite common misconception that substances always react in a 1:1 ratio. A similar misconception arises when students assume that substances react by equal mass, or that the coefficients in the chemical equation are a ratio of reacting masses. These misconceptions can be dealt with in the post-lab discussion of the Launch lab (page 261), or any of the stoichiometric labs that follow in this unit.
- Students often use the atomic mass for the elements of the diatomic gases (hydrogen, oxygen, chlorine, etc.) as the molar mass. Tell students to be careful of any chemical equation that contains a diatomic gas, and to calculate the molar mass correctly.
- Another fairly common misconception is applied when students use the product of the molar mass and the coefficient as the molar mass. When the coefficient is also used in the mole ratio, the stoichiometry is incorrect. This can be shown with an example the first time this misconception arises in class.

Helpful Resources

Journal Articles

- Ault, A. "How to Say How Much: Amounts and Stoichiometry," *Journal of Chemical Education*, Vol. 79, 2001, p. 1345.
- Haim, L.; Corton, E.; Kocmur, S.; and Galagovsky, L. "Learning Stoichiometry with Hamburger Sandwiches," *Journal of Chemical Education*, Vol. 80, 2003, p. 1021.
  Gabel, D. "Improving Teaching and Learning through Chemistry Education Research: A Look to the Future," *Journal of Chemical Education*, Vol. 76, 1999, p. 548.
- Kashmar, R.J. "The Use of Cut-Out Molecular Models on the Overhead Projector To Illustrate Stoichiometry and

Limiting Reactants," *Journal of Chemical Education*, Vol. 74, 1997, p. 791.
- Krieger, C.R. "Stoogiometry: A Cognitive Approach to Teaching Stoichiometry," *Journal of Chemical Education*, Vol. 74, 1997, p. 306.
- Toth, Z. "Limiting Reactant: An Alternative Analogy," *Journal of Chemical Education*, Vol. 76, 1999, p. 934.
- Witzel, J. E. "Lego Stoichiometry," *Journal of Chemical Education*, Vol. 79, 2002, p. 3528.

Web Sites

Web links related to stoichiometry can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title
7.0.1 (AST) Identifying Reaction Types
7.0.1A (ANS) Identifying Reaction Types Answer Key
7.0.2 (OH) Guidelines for Balancing Equations
7.0.3 (AST) Balancing Chemical Reactions
7.0.3A (ANS) Balancing Chemical Reactions Answer Key
7.0.4 (AST) Translating Word Equations
7.0.4A (ANS) Translating Word Equations Answer Key
7.0.5 (AST) Predicting and Balancing Formation, Decomposition, and Hydrocarbon Combustion Reactions
7.0.5A (ANS) Predicting and Balancing Formation, Decomposition, and Hydrocarbon Combustion Reactions Answer Key
7.0.6 (AST) Predicting and Balancing Single and Double Replacement Reactions
7.0.6A (ANS) Predicting and Balancing Single and Double Replacement Reactions Answer Key
7.0.7 (OH) Calculating Amounts of Substances
7.0.8 (AST) Determining the Number of Moles in a Sample
7.0.8A (ANS) Determining the Number of Moles in a Sample Answer Key
7.0.9 (HAND) Launch Lab: The Thermal Decomposition of Baking Soda
7.0.9A (ANS) Launch Lab: The Thermal Decomposition of Baking Soda Answer Key

7.1.1 (OH) Net Ionic Equations
7.1.2 (AST) Writing Net Ionic Equations
7.1.2A (ANS) Writing Net Ionic Equations Answer Key
7.1.3 (OH) Qualitative Analysis
7.1.4 (OH) Identifying Ions Using Precipitation Reactions
7.1.5 (AST) Qualitative Analysis Questions
7.1.5A (ANS) Qualitative Analysis Questions Answer Key
7.1.6 (HAND) Thought Lab 7.1: Identifying Unknown Aqueous Solutions
7.1.6A (ANS) Thought Lab 7.1: Identifying Unknown Aqueous Solutions Answer Key
7.1.7 (HAND) Investigation 7.A: Qualitative Analysis
7.1.7A (ANS) Investigation 7.A: Qualitative Analysis Answer Key

7.2.1 (OH) Balanced Chemical Equations
7.2.2 (HAND) Gravimetric Stoichiometry Tutorial
7.2.3 (AST) Gravimetric Stoichiometry Problems
7.2.3A (ANS) Gravimetric Stoichiometry Problems Answer Key
7.2.4 (HAND) Solution Stoichiometry Tutorial
7.2.5 (AST) Solution Stoichiometry Problems
7.2.5A (ANS) Solution Stoichiometry Problems Answer Key
7.2.6 (HAND) Investigation 7.B: Determining the Concentration of a Solution
7.2.6A (ANS) Investigation 7.B: Determining the Concentration of a Solution Answer Key
7.2.7 (AST) Gas Stoichiometry Problems
7.2.7A (ANS) Gas Stoichiometry Problems Answer Key
7.2.8 (AST) Law of Combining Volumes
7.2.8A (ANS) Law of Combining Volumes Answer Key
7.2.9 (AST) Mixed Stoichiometry Quiz
7.2.9A (ANS) Mixed Stoichiometry Quiz Answer Key
7.2.10 (HAND) Investigation 7.C: Analyzing Industrial Processes
7.2.10A (ANS) Investigation 7.C: Analyzing Industrial Processes Answer Key

7.3.1 (AST) Chapter 7 Test
7.3.1A (ANS) Chapter 7 Test Answer Key

Using the Chapter 7 Opener

Student Textbook pages 260-261

Teaching Strategies

- Prepare a number of chemical reactions for the class to observe. For example, have a candle burning at the front of the classroom. Ask students to describe what is occurring and how this could be communicated in a simplified manner (the chemical equation). You could discuss the evidence for chemical change. Suggested reactions include: aqueous silver nitrate and copper strips (formation of a precipitate and a colour change if left long enough); household vinegar and baking soda (production of a gas); aqueous sodium iodide and aqueous lead(II) nitrate (formation of a brightly coloured precipitate); and the addition of aqueous sodium hydroxide to a sample of hydrochloric acid containing phenolphthalein (colour change).
- Prepare a number of reactions (reactants only) on separate pieces of paper; fold them and place them into a jar. Divide students into pairs and have one member of each pair select a reaction. Allow the pairs a certain length of time to predict the products, balance the equation, and identify the reaction type. Each team that correctly completes their task receives points. Winning pairs could be given an incentive,

such as a "Get Out of Homework Free" card that can be used during the course of the year.

- Devise a game similar to *Jeopardy*. Categories such as products of reaction, reactants, coefficients of reaction, and evidence of reaction could be used, and appropriate questions could be devised for each category. Form teams and rotate the team members so that each student has the opportunity to respond. Keep track of team points.

Launch Lab — The Thermal Decomposition of Baking Soda

Student Textbook page 261

Purpose

Students observe the thermal decomposition of $NaHCO_3(s)$ and compare the mole relationship between reactant and products in the reaction.

Outcomes

- 20–D1.1k
- 20–D1.2k

Advance Preparation

When to Begin	What to Do
2 to 3 weeks	■ Ensure all materials and chemical are available.
1 day before	■ Set up student stations. ■ Collect materials. ■ Photocopy **BLM 7.0.9 (HAND) Launch Lab: The Thermal Decomposition of Baking Soda.**

Materials
■ baking soda ■ crucible ■ iron ring ■ clay triangle ■ Bunsen burner or alcohol burner ■ retort stand ■ electronic balance

Time Required

45 minutes

Helpful Tips

- A 0.1 g balance is sufficient to determine the difference in mass, but a 0.01 g balance yields more precise data.
- Make sure students understand that the crucibles and other materials must be completely dry before use so that moisture does not affect the change in mass.
- Use **BLM 7.0.9 (HAND) Launch Lab: The Thermal Decomposition of Baking Soda** and **BLM 7.0.9A (ANS) Launch Lab: The Thermal Decomposition of Baking Soda Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** When the sodium hydrogen carbonate is heated, it will decompose according to the equation:

  $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

  The carbon dioxide and water will escape as gases leaving solid sodium carbonate behind. When the students determine the mass of the remaining solid sodium carbonate and calculate the number of moles of the sodium hydrogen carbonate and sodium carbonate, they will find a ratio very close to 2:1. They should notice that the coefficients of sodium hydrogen carbonate and sodium carbonate are 2 and 1 respectively.

Answers to Analysis Questions

1. $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$
2. Using the mass of baking soda suggested in the lab, moles of sodium hydrogen carbonate used = 3.00 g / 84.01 $\frac{g}{mol}$ = 0.0357 mol (to the correct number of significant digits).

   The mass of sodium carbonate obtained ideally would be approximately 2.00 g.

   Moles of sodium carbonate produced =

   2.00 g / 105.99 $\frac{g}{mol}$ = 0.0189 mol
3. The ratio is 1.89:1, or approximately 2:1.
4. The ratio calculated in question 3 is the mole ratio, or the ratio of the whole number coefficients from the balanced chemical equation.

Assessment Options

- Collect and assess students' answers to Analysis questions.
- Use Assessment Checklist 2 Laboratory Reports.

7.1 Reactions in Aqueous Solution

Student Textbook pages 262–270

Section Outcomes

Students will:

- write balanced ionic and net ionic equations, including identification of spectator ions, for reactions taking place in aqueous solutions
- contrast quantitative and qualitative analysis
- perform qualitative analysis to identify unknowns

Key Terms

spectator ions
complete balanced equation
ionic equation

net ionic equation
qualitative analysis
quantitative analysis
flame test
precipitation reaction

Chemistry Background

- Unlike covalent compounds, which can be identified using physical properties like boiling point and refractive index, ionic compounds are more appropriately identified by their chemical properties. In qualitative analysis, the chemical properties of an unknown substance are determined by systematically reacting the unknown with a number of different reactants. By predetermining whether a particular reaction will produce a precipitate if a specific ion is present, the ions that are actually in the solution can be identified. For example, if a reaction is known to produce a precipitate if ion A is present, and a precipitate is formed when the reaction is run, then ion A may be present in solution (there may be, and usually are, other ions that will also precipitate with a particular reactant.) If no precipitate is formed when the reaction is run, then ion A is clearly not present in the unknown solution and a different reaction will have to be run to determine what ions are present. There are two general situations in which qualitative analysis is used—in the identification of a simple salt and the identification of multiple ions in a solution.
- The value of the flame test is limited by interference from other, brighter colours and by ambiguities where certain different metals cause the same flame colour. Sodium, in particular, is present in most compounds and will colour the flame. Sometimes a coloured glass is used to filter out light from one metal. For example, cobalt glass is often used to filter out the yellow of sodium.

Teaching Strategies

- For aqueous solutions, students should review the dissociation of ionic compounds and the ionization of acids. Students must determine which entities are present in aqueous solutions and which entities are reacting in order to predict the net ionic equations.
- The colours of ions can be dramatically shown in class by preparing a sample of each solution for observation. Prepare a dilute (0.10 mol/L) and a concentrated (1.0 mol/L) solution of each and place a sample in a clear glass bottle. Excess solutions can be placed in unlabelled test tubes for identification in class. When discussing solution colour, refer to the prepared samples and point out the difference in intensity of colour between the concentrated and dilute samples. Sets of unlabelled test tubes can be given to groups of students, and the students can be asked to identify them using the reference samples or their colour charts.
- To observe flame colour, prepare solutions of each ion and perform flame tests in class using a Bunsen burner. If Bunsen burners are not available, a small propane torch can be used. Alcohol burners do not produce a hot enough flame to cause the desired flame colour. Students can also be shown that the colour of a solution is not the same as the colour observed in a flame test.
- The general solubility guidelines should be reviewed before discussing selective precipitation. Have students predict which solution to add to precipitate a specific ion before discussing solutions that contain more than one ion. Students should be reminded that they cannot add a single ion [e.g., $Ag^{+}(aq)$] to a solution. They must add a compound [e.g., $AgNO_3(aq)$] so that they add the ion that will cause the precipitation plus a spectator ion (one that will not interfere with the desired reaction).
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 7 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  Number (Type) Title
  7.1.1 (OH) Net Ionic Equations
  7.1.2 (AST) Writing Net Ionic Equations
  7.1.2A (ANS) Writing Net Ionic Equations Answer Key
  7.1.3 (OH) Qualitative Analysis
  7.1.4 (OH) Identifying Ions Using Precipitation Reactions
  7.1.5 (AST) Qualitative Analysis Questions
  7.1.5A (ANS) Qualitative Analysis Questions Answer Key

SUPPORTING DIVERSE STUDENT NEEDS

ESL students can use pencil crayons to show the colours of the solutions and the flame produced by each of the ions listed in their Data Booklet. This will help them associate the colour of the flame with the word for the colour.

Answers to Practice Problems 1-2

Student Textbook page 264

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. **(a)** $Cl_2(g) + 2Br^{-}(aq) \rightarrow Br_2(\ell) + 2Cl^{-}(aq)$
   (b) $Cu(s) + 2Ag^{+}(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$
   (c) $2Al(s) + 3Cu^{2+}(aq) \rightarrow 3Cu(s) + 2Al^{3+}(aq)$
   (d) $Zn(s) + Pb^{2+}(aq) \rightarrow Zn^{2+}(aq) + Pb(s)$
   (e) $H_2(g) + 2Na^{+}(aq) \rightarrow 2Na(s) + 2H^{+}(aq)$
2. **(a)** $3Ba^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Ba_3(PO_4)_2(s)$
   (b) $Sr^{2+}(aq) + SO_4^{2-}(aq) \rightarrow SrSO_4(s)$
   (c) $2Al^{3+}(aq) + 3Cr_2O_7^{2-}(aq) \rightarrow Al_2(Cr_2O_7)_3(s)$
   (d) $H^{+}(aq) + OH^{-}(aq) \rightarrow H_2O(\ell)$
   (e) $Mg^{2+}(aq) + 2OH(aq) \rightarrow Mg(OH)_2(s)$

Chemistry File: Web Link

Student Textbook page 265

Students may report that luminol is a powdery compound made up of nitrogen, hydrogen, oxygen, and carbon ($C_8H_7O_3N_3$).

Investigators mix luminol with liquid containing hydrogen peroxide (H_2O_2), a hydroxide (OH^-) and other chemicals to create a mixture that can be sprayed. Luminol and the hydrogen peroxide are keys to the oxidation reaction, but they need a catalyst to accelerate the process and produce a strong glow. One catalyst is the iron in hemoglobin. The luminol-based spray is interacting with the catalyst when it comes into contact with bloodstains and begins to glow. The chemical reaction produced by the luminol spray can destroy other evidence in the crime scene so it is used as a final step or last resort.

They may also report on other types of chemical tracers such as the HemaTrace test. It is based on the presence of monoclonal antibodies for human hemoglobin. It is called a presumptive test because it isn't perfect. (It also gives a positive for ferret blood.)

Thought Lab 7.1: Identifying Unknown Aqueous Solutions

Student Textbook page 267

Purpose

Students will analyze data from a series of reactions to identify ions in an unknown solution.

Outcomes

- 20–D1.3k
- 20–D1.1s
- 20–D1.2s

Advance Preparation

When to Begin	What to Do
1 day before	■ Photocopy **BLM 7.1.6 (HAND) Thought Lab 7.1: Identifying Unknown Aqueous Solutions**

Time Required

30 minutes

Helpful Tips

- Review concepts learned in Section 7.1 before beginning this Thought Lab.
- Use **BLM 7.1.6 (HAND) Thought Lab 7.1: Identifying Unknown Aqueous Solutions** and **BLM 7.1.6A (ANS) Thought Lab 7.1: Identifying Unknown Aqueous Solutions Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Answers to Analysis Questions

1. $Ca^{2+}(aq)$

2. Ca^{2+} (aq) and Sr^{2+} (aq)

3. The flame will appear yellow, as aqueous sodium ions have been added at Steps 2 and 4.

4.
- Solution 1: a colourless solution that produces a yellow flame and does not produce a precipitate when either HCl(aq) or NaOH(aq) is added.
- Solution 2: a blue solution that produces a blue-green flame and does not produce a precipitate when HCl(aq) is added, but does produce a precipitate when NaOH(aq) is added.
- Solution 3: a colourless solution that produces a yellow flame and produces a precipitate when either HCl(aq) or NaOH(aq) is added.
- Solution 4: a blue solution that produces a blue-green flame, a precipitate when HCl(aq) is added, and a precipitate when NaOH(aq) is added.

Assessment Options

- Collect and assess students' answers to the Analysis questions.

Answers to Questions for Comprehension

Student Textbook page 268

Q1. (a) dichromate ion

(b) copper(II) ion

(c) sodium ion

Q2. (a) SO_4^{2-}(aq), OH^-(aq), PO_4^{3-}(aq), SO_3^{2-}(aq), or CO_3^{2-}(aq).

(b) CH_3COO^-(aq), Cl^- (aq), Br^- (aq), or I^- (aq) will precipitate aqueous silver ions, but not aqueous calcium ions.

(c) Flame colour: the solution containing calcium ions will produce a red flame, while the solution containing silver ions will not.

Investigation 7.A: Qualitative Analysis

Student Textbook pages 268–269

Purpose

Students will use their knowledge of chemical reactions and the general solubility guidelines to identify ions in solution. Qualitative analysis techniques such as selective precipitation and flame colour, in conjunction with solution colour, will be used to identify the ions.

Outcomes

- 20–D1.1k
- 20–D1.4k
- IP–NS2
- IP C6–4.2

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
1 week before	■ Prepare solutions and place the ones that are aliquots in dropper bottles. (Refer to **BLM 5.4.4 (HAND) Preparing Solutions**) ■ Test all reagents to ensure the flame colour and precipitation patterns are as expected.
1 day before	■ Ensure each student station has a set of unknown chemicals and a set of reagent chemicals. ■ Collect apparatus. ■ Provide students with **BLM 7.1.7 (HAND) Investigation 7.A: Qualitative Analysis.** Have students complete the Prediction question.

Materials

- 12- or 24-well plate, or spot plate
- cotton swabs
- laboratory burner
- heat-resistant pad
- wash bottle
- waste container
- sets of unknown solutions; each set will contain the following labelled dropper bottles:
  - A: 0.10 mol/L $NaNO_3(aq)$
  - B: 0.10 mol/L $AgNO_3(aq)$
  - C: 0.10 mol/L $Ca(NO_3)_2(aq)$
  - D: 0.10 mol/L $Cu(NO_3)_2(aq)$
- sets of labelled reactants in dropper bottles:
  - 0.10 mol/L $NaNO_3(aq)$
  - 0.10 mol/L $AgNO_3(aq)$
  - 0.10 mol/L $Ca(NO_3)_2(aq)$
  - 0.10 mol/L $Cu(NO_3)_2(aq)$
  - 0.10 mol/L HCl (aq)
  - 0.10 mo/L $H_2SO_4(aq)$
- de-ionized water

Time Required

60 minutes

Helpful Tips

- It is a good idea for students to predict as much as they can before they start, as a thorough understanding of the concepts introduced in this section is needed in order to understand this lab.
- Clear glass spot plates provide the best results. White, opaque ceramic plates make it difficult to observe white precipitates. If spot plates are not available, clear acetate sheets (overhead transparencies) with spots drawn with a grease pencil make a suitable alternative. Place the acetate sheet on a black piece of construction paper to observe the precipitates more easily.
- The silver ion will discolour skin, so students should wear gloves and be especially careful not to get this chemical on their hands.
- Contamination of chemicals needs to be kept to a minimum. Label both the bottle and the dropper for each bottle with different coloured tapes so that the proper dropper can be placed back into the appropriate bottle. Advise students to take care when replacing the droppers and not to touch any solutions with the ends of their droppers.
- Wooden splints soaked in the unknown solutions can be used instead of cotton swabs. Inoculating loops will also work if cotton swabs are not available. Advise students to hold the cotton swabs with crucible tongs to prevent burning themselves.
- The initial colour seen in the flame appears due to the metallic ion. Once the ion is burned off, a yellow flame will remain. This phenomenon will occur in all trials.
- Use **BLM 7.1.7 (HAND) Investigation 7.A: Qualitative Analysis** and **BLM 7.1.7A (ANS) Investigation 7.A: Qualitative Analysis Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** Part I: Dilute hydrochloric acid will cause a precipitate to form when added to the solution containing the Ag^+ and the Cu^+ ions.

  Dilute sulfuric acid will cause a precipitate to form when added to the solution containing the Ag^+ and the Ca^{2+} ions. Part II: The solutions containing Na^+, Ag^+, and Ca^{2+} will be clear. The solution containing Cu^{2+} will be blue.

  Flame tests will give a yellow colour with Na^+, same as control, i.e., no colour with Ag^+, a yellowish-red colour with Ca^{2+}, and a blue-green colour with Cu^{2+}.

Safety Precautions

Ensure students read and understand “Safety in Your Chemistry Lab and Classroom” in the student textbook (pages xii–xv). Hydrochloric acid and sulfuric acid are corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye-wash station has been tested recently and any eye wash bottles are filled. Ensure all long hair is tied back, as laboratory burners are used in this activity. It is advisable to have a supply of hair ties in the laboratory for student use. Dispose of all materials in a proper waste container.

Answers to Analysis Questions

1. **(a)** The $Ag^+(aq)$ will form a precipitate when hydrochloric acid is added.

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

   (b) Students should be able to predict this reaction using their solubility guidelines.

2. **(a)** Both the $Ag^+(aq)$ and the $Ca^{2+}(aq)$ will form a precipitate when the sulfuric acid is added.

   $2Ag^+(aq) + SO_4^{2-}(aq) \rightarrow Ag_2SO_4(s)$

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

   (b) Students should be able to predict these reactions using their solubility guidelines.

3. Sodium, calcium and copper(II) ions will form soluble chlorides. Sodium and copper(II) ions will form soluble sulfates.

4. $Cu^{2+}(aq)$ is blue.

5. Students' tentative identifications will depend on the letter used to label each unknown solution. Clues to use are: silver ions form a precipitate with both acids; calcium ions form a precipitate with only sulfuric acid; and copper(II) ions make a blue-coloured solution. Sodium ions will need to be confirmed by a flame test, however, because they do not form any precipitates and are colourless in solution.

6. The flame test should easily show the difference between calcium ions (which produce a red-orange colour) and sodium ions (which produce a yellow colour).

Answer to Conclusion Question

7. Given the above clues, students should be able to identify each of the cations and anions and to match them up with the appropriate letter given by the teacher. If the students have correctly identified the ions, they should have confidence in their decisions and no further action will be required. If the students have not correctly identified the ions, they will not have confidence in their decisions and may suggest that they retest some of the solutions or perform the test on a fresh sample of the solution if they feel it may be contaminated, or that they would like to have other solutions to test their unknowns (ones not provided in the investigation).

Assessment Options

- Collect and assess students' responses to the Analysis and Conclusion questions.
- Use Assessment Checklist 3 Performance Task Self-Assessment to assess student participation and parts of Assessment Checklist 5 Learning Skills to assess group interaction.

Section 7.1 Review Answers

Student Textbook page 270

1. Spectator ions are aqueous ions that remain unchanged when the reaction is over. When forming ionic compounds with other ions, spectator ions form compounds with high solubility.

2. **(a)** $3Sn^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Sn_3(PO_4)_2(s)$

   (b) $Ni^{2+}(aq) + CO_3^{2-}(aq) \rightarrow NiCO_3(s)$

   (c) $2Cr^{3+}(aq) + 3S^{2-}(aq) \rightarrow Cr_2S_3(s)$

3. **(a)** The spectator ions are $Cl^-(aq)$ and $K^+(aq)$.

   (b) The spectator ions are $Cl^-(aq)$ and $Na^+(aq)$.

   (c) The spectator ions are $SO_4^{2-}(aq)$ and $NH_4^+(aq)$.

4. The precipitate that will form is copper(II) carbonate, $CuCO_3(s)$. The net ionic equation is $Cu^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CuCO_3(s)$. The spectator ions are $SO_4^{2-}(aq)$ and $Na^+(aq)$.

5. **(a)** $Ba(NO_3)_2(aq)$* + $Na_3PO_4(aq)$**

   (b) $Mg(NO_3)_2(aq)$* + $NaOH(aq)$**

   (c) $Al(NO_3)_3(aq)$* + $Na_2Cr_2O_7(aq)$**

   *the cation can also combine with ClO_4^- or ClO_3^-

   **the anion can combine with any group 1 ion, H^+ or NH_4^+

6. Qualitative analysis only determines whether or not a particular substance is present. Quantitative analysis allows the determination of the amount of a particular substance.

7. No. Qualitative analysis will only provide the identity of ions present. Qualitative analysis such as solution colour, flame colour, and selective precipitation will only tell you if an ion is present or not. More complicated gravimetric procedures (that will be described in the remaining part of this chapter, as well as in Chapter 8) are needed to determine the amount of each ion present.

8. **(a)** $CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$

   $H_2CO_3(aq) + Ca(OH)_2(aq) \rightarrow 2HOH(\ell) + CaCO_3(s)$

   (b) The first reaction can be classified as a formation reaction, while the second is classified as a double-replacement reaction.

   (c) This is a qualitative test, as it only tells you if carbon dioxide is present, not how much is present.

9. **(a)** $Pb^{2+}(aq)$, $PbCl_2(s)$

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

10. **(a)** $Na_2SO_4(aq)$ (any group 1 sulfate)

    (b) $NaCl(aq)$, $NaBr(aq)$, $NaI(aq)$ (any group 1 halide)

    (c) To the solution, add $Na_2SO_4(aq)$ until no more precipitate forms.
    Remove the $PbSO_4(s)$ precipitate by filtration and dispose of the precipitate appropriately.

    To the filtrate, add $NaCl(aq)$ until no more precipitate forms. Remove the $CuCl(s)$ precipitate by filtration and dispose of the precipitate appropriately.

    To the filtrate, add $NaOH(aq)$ until no more precipitate forms. Remove the $Eu(OH)_3(s)$ precipitate by filtration and dispose of the precipitate appropriately.

(d) To test for Pb^{2+}(aq), add Na_2SO_4(aq). If a precipitate forms, lead(II) ions are present; if no precipitate forms, lead(II) ions are not present. To remove all of the lead(II) ions, continue to add Na_2SO_4(aq) until no more precipitate forms. (If a precipitate forms, filter the solution before continuing to test for the presence of other ions.)

To test for the presence of Cu^{+}(aq), observe the solution colour. If the solution appears blue-green, copper(I) ions are present; if the solution is colourless, copper(I) ions are not present. To remove all of the copper(I) ions, add NaCl(aq) until no more precipitate forms before continuing to test for europium(III) ions. (If a precipitate forms, filter the solution before continuing to test for the presence of other ions.)

To test for Eu^{3+}(aq), add NaOH(aq). If a precipitate forms, europium(III) ions are present; if no precipitate forms, europium(III) ions are not present.

Dispose of all wastes appropriately.

11. From left to right – purple: permanganate; orange: dichromate; green: chromium, copper(I), iron(II), or nickel(III); yellow: chromate; pink: cobalt(II) or manganese(II). To increase confidence in predictions about the composition of solutions, react them with a variety of cations and/or anions in order to produce precipitate according to the solubility guidelines.

7.2 Stoichiometry and Quantitative Analysis

Student Textbook pages 271-290

Section Outcomes

In this section, students will:

- analyze data and apply mathematical and conceptual models to develop and assess possible solutions to problems by using stoichiometric ratios from chemical equations
- write balanced ionic and net ionic equations, including identification of spectator ions for reactions taking place in aqueous solution
- calculate the quantities of reactants and products involved in chemical reactions using gravimetric solution and gas stoichiometry
- use appropriate SI notation, fundamental and derived units, and significant digit rules when performing stoichiometry calculations
- explain that the focus of technology is on the development of answers to problems, involving devices and systems that meet a given need within the constraints of a problem

Key Terms

mole ratio
stoichiometry
gravimetric stoichiometry
solution stoichiometry
gas stoichiometry

Chemistry Background

- Stoichiometry is a process that allows us to solve problems based on balanced chemical equations. The purpose of stoichiometry is to quantitatively predict amounts of reactants or products involved in chemical processes, and this allows us to work with masses of reactants and products.
- Although students were introduced to the concept of net ionic equations, the use in the previous section, the use of nonionic equations to solve solution stoichiometry problems should be stressed. In order to solve these problems using net ionic equations, an understanding of dissociation and how this process affects the concentration of ions in solutions must be well developed.
- Students should review the relationship between pressure, temperature, and volume of gaseous substances to the amount of gas present. When the reaction conditions remain constant (temperature and pressure) for homogeneous gaseous reactions, Gay-Lussac's law of combining volumes can be used when predicting volumes of gaseous substances produced or consumed. However, when the conditions of the reaction change (a change in temperature, pressure, or both), the ideal gas law should be used to predict amounts of gaseous substances.

Teaching Strategies

- Most students have used recipes, and introducing this subject using a recipe metaphor allows them to work with familiar ideas. Write a recipe on the board, as it is found in a standard cookbook, and have the students convert it into a balanced "chemical equation." For example,

  Cream Puffs

2 cups water	1 cup butter
8 eggs	2 cups flour

  Yield: 20 cream puffs

  This recipe would translate into the following balanced equation: 1 cup butter + 2 cups water + 2 cups flour + 8 eggs → 20 cream puffs

  Students will be introduced to the concept of ratios when asked to predict the number of cream puffs that would be produced with various amounts of reactants. Once students are comfortable working with this ratio, you can introduce mass by measuring the mass of each reactant and using these conversion factors to predict the number of cream puffs that could be made when a certain mass of reactant (i.e., 10.0 g of eggs) reacts.
- An excellent classroom activity, "Lego Stoichiometry," is available from the *Journal of Chemical Education,* Vol. 79, No. 3 (2002). The object of the activity is to determine the relationship between number and mass for each required component (the pieces of the kit) and the final product (the car).

- Consistent use of symbols and units for all quantities is crucial to building an understanding of the process of stoichiometry. The symbols *n* (number of moles, unit is the mol); *m* (mass, unit is g); and *M* (molar mass, unit is $\frac{g}{mol}$) should be used for solving all problems.
- Students should develop a consistent method for solving problems involving balanced chemical equations.
- Mass to mass stoichiometric problems can be difficult for some students to master. It is a good idea to work with them through as many problems as possible. Have students put their work on the chalkboard, and go over the problems with the class to provide feedback. Remind students that balanced chemical equations show a molar relationship. Therefore, the ratio of moles (not the mass) is established.
- Consistent use of significant digits should be encouraged when performing stoichiometric calculations. Students should keep all digits in their calculators while performing sequential calculations. Intermediate answers may contain more significant digits than required, but the final answer should be reported to the correct number of significant digits.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 7 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  Number (Type) Title
  7.2.1 (OH) Balanced Chemical Equations
  7.2.2 (HAND) Gravimetric Stoichiometry Tutorial
  7.2.3 (AST) Gravimetric Stoichiometry Problems
  7.2.3A (ANS) Gravimetric Stoichiometry Problems Answer Key
  7.2.4 (HAND) Solution Stoichiometry Tutorial
  7.2.5 (AST) Solution Stoichiometry Problems
  7.2.5A (ANS) Solution Stoichiometry Problems Answer Key
  7.2.7 (AST) Gas Stoichiometry Problems
  7.2.7A (ANS) Gas Stoichiometry Problems Answer Key
  7.2.8 (AST) Law of Combining Volumes
  7.2.8A (ANS) Law of Combining Volumes Answer Key
  7.2.9 (AST) Mixed Stoichiometry Quiz
  7.2.9A (ANS) Mixed Stoichiometry Quiz Answer Key

SUPPORTING DIVERSE STUDENT NEEDS

- Have students highlight important information in the problem with specific colours, labelling the quantity with the previously described symbols. This will allow weak readers to focus only on the relevant material in each question.
- Organization of data will assist some students with solving stoichiometric problems. Have the students highlight important information in the problem, labelling the quantity with the previously described symbols. Then, have them organize this information underneath the appropriate formula in the balanced equation.
- As is always the case with stoichiometry, it is a good idea to go over some examples of stoichiometric calculations step by step on the chalkboard.
- Gifted Students: Ask them to solve solution stoichiometry problems with units other than mol/L. For example, instead of having a 0.100 mol/L solution of sodium chloride, provide an initial concentration of a specific mass of solute dissolved in specific volume of solute, the concentration expressed in ppm or in percentage mass/volume. Alternatively, ask for the final answer in any of the previously described units rather than mol/L.

Chemistry File: Web Link

Student Textbook page 272

The major industrial use of ammonia is in the production of fertilizers. Ammonia is also used to produce explosives and polymers, including dyes, drugs, and plastics.

Answers to Questions for Comprehension

Student Textbook page 272

Q3. (a) 2 mol $H_2(g)$: 1 mol $O_2(g)$: 2 mol $H_2O(\ell)$
(b) 1 mol $O_2(g)$: 2 mol $H_2O(\ell)$
(c) 2 mol $H_2(g)$: 1 mol $O_2(g)$

Q4. (a) 2 mol $C_2H_6(g)$: 7 mol $O_2(g)$: 4 mol $CO_2(g)$: 6 mol $H_2O(g)$
(b) 1 mol $C_2H_6(g)$: 2 mol $CO_2(g)$
(c) 2 mol $C_2H_6(g)$: 7 mol $O_2(g)$

Answers to Practice Problems 3-7

Student Textbook page 274

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

3. (a) 2 mol $AgNO_3(aq)$: 1 mol $Na_2CrO_4(aq)$: 1 mol $Ag_2CrO_4(s)$: 2 mol $NaNO_3(aq)$
(b) 2 mol $AgNO_3(aq)$: 1 mol $Ag_2CrO_4(s)$
(c) 0.25 mol

4. (a) 2 mol $NH_3(g)$:1 mol $CO_2(g)$:1 mol $NH_2CONH_2(s)$: 1 mol $H_2O(g)$
(b) 2.60 mol
(c) 6.0 mol

5. (a) 2 mol $NH_3(g)$:1 mol $H_2SO_4(aq)$: 1 mol $(NH_4)_2SO_4(s)$
(b) 40 000 mol or 40 kmol
(c) 1.64 mol

6. (a) 1 mol $Xe(g)$:2 mol $F_2(g)$:1 mol $XeF_4(s)$
(b) 4.70 mol
(c) 24.4 mmol or 0.0244 mol

7. (a) 2 mol $N_2(g)$: 1 mol $O_2(g)$: 2 mol $N_2O(g)$ and 1 mol $N_2(g)$: 2 mol $O_2(g)$: 2 mol $NO_2(g)$

(b) 0.0468 mol

(c) 187 mmol or 0.187 mol

Answers to Questions for Comprehension

Student Textbook page 275

Q5. The equation used is $n = \frac{m}{M}$, where n is the number of moles of reactant or product, m is the mass and M is the molar mass.

Q6. 0.72 g CuO(s) is produced

Complete Solution

Using equations:
$n = 0.0090$ mol CuO(s)
$M = 79.55$ g/mol CuO(s)
$m = ?$

$$n = \frac{m}{M}$$
$$m = nM$$
$$= (0.0090 \text{ mol CuO(s)})(79.55 \frac{\text{g}}{\text{mol}} \text{ CuO(s)})$$
$$= 0.72 \text{ g CuO(s)}$$

Using dimensional analysis:

$$m_{CuO(s)} = 0.0090 \text{ mol CuO(s)} \times \frac{79.55 \text{ g}}{\text{mol CuO(s)}}$$
$$= 0.72 \text{ g CuO(s)}$$

Answers to Practice Problems 8-15

Student Textbook page 278

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

8. 1.3×10^5 g

9. 5.84×10^5 g or 5.84×10^2 kg

10. **(a)** $Cu(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Cu(NO_3)_2(aq)$
(b) 3.39 g

11. 112 g

12. 8.06 g

13. 20.1 g

14. 40.3 g

15. 417 g

Connections (Science and Technology): Waste Water Treatment

Student Textbook page 279

Teaching Strategies

- Have students research the methods used to remove phosphate and nitrogen from waste water in their area.
- Use question 4 to stimulate a class discussion. Create an overhead chart and ask students to list possible benefits and drawbacks of the two different waste water treatment methods.

Answers to Questions

1. $FeCl_3(aq) + PO_4^{3-}(aq) \rightarrow FePO_4(s) + 3Cl^-(aq)$

2. $Al_2(SO_4)_3{\bullet}14H_2O(s) + 2PO_4^{3-}(aq) \rightarrow 2AlPO_4(s) + 3SO_4^{2-}(aq) + 14H_2O(l)$

$m = ?$ g $\qquad m = 2$ mg
$M = 594.45$ g/mol $\qquad M = 94.97$ g/mol

$$m_{alum} = 2 \text{ mg } PO_4^{3-} \times \frac{1 \text{ mol } PO_4^{3-}}{94.97 \text{ g } PO_4^{3-}} \times \frac{1 \text{ mol alum}}{2 \text{ mol } PO_4^{3-}} \times \frac{594.45 \text{ g alum}}{1 \text{ mol alum}}$$
$$= 6 \text{ mg}$$

3. The sludge contains bacteria (and other forms of micro-organisms) from human waste, some of which may be pathogenic. The sludge can be used for grain crops, as the grain is processed prior to human consumption. Vegetables can be eaten raw (unprocessed or only slightly processed) and if contaminated with pathogenic bacteria, can cause disease. Washing the vegetables would not be sufficient to remove all contaminants.

4. Sample of possible answer:

(a) Benefits: produces ammonia that can be used for fertilizer production; removal of the substances prevents eutrophification.

Drawbacks: produces a precipitate that must be removed and disposed of, adding chemicals to the water that may be harmful (aluminium ions have been linked to Alzheimer's disease).

(b) Benefits: removal prevents eutrophification; no addition of harmful chemicals to the environment; produces a fertilizer that can be used in crops; produces nitrogen gas; a naturally occurring substance.

Drawbacks: harmful organisms can be introduced into crops in the field (and ultimately the water table).

Chemistry File: Web Link

Student Textbook page 280

The chemical reaction that occurs when alcohol reacts with an acidic aqueous solution of potassium dichromate is:

$$2K_2Cr_2O_7 + 3CH_3CH_2OH + H_2SO_4 \rightarrow 2Cr_2(SO_4)_3 + 2K_2SO_4 + 3CH_3COOH + 11H_2O$$

The legal limit for driving in Alberta is a blood alcohol concentration of 0.08 g/100 mL of blood.

Answer to Question for Comprehension

Student Textbook page 280

Q7. 0.03 mol NaCl(aq)

Complete Solution

$$n_{NaCl(aq)} = c_{NaCl(aq)} \times V_{NaCl(aq)}$$

$$= \frac{1 \text{ mol NaCl(aq)}}{\text{L}} \times 0.025 \text{ L}$$

$$= 0.3 \text{ mol NaCl(aq)}$$

Answers to Practice Problems 16-19

Student Textbook page 282

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

16. 18 mL

17. 12.9 mL

18. **(a)** $Pb(NO_3)_2(aq) + 2NaI(aq) \rightarrow PbI_2(s) + 2NaNO_3(aq)$

(b) 40.0 mL

(c) 1.15 g

19. **(a)** 0.33 L

(b) 0.13 L

(c) 0.46 L

Investigation 7.B: Determining the Concentration of a Solution

Student Textbook page 282-283

Purpose

Students determine the concentration of a solution based on a precipitation reaction.

Outcomes

- 20-D2.1s
- 20-D2.3s

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
1 week before	■ Prepare solutions. (Refer to **BLM 5.4.4 (HAND) Preparing Solutions)** ■ Test all reagents to ensure the reaction takes place as expected.
1 day before	■ Collect materials. ■ Photocopy **BLM 7.2.6 (HAND) Investigation 7.B: Determining the Concentration of a Solution.**

Materials
■ 150 mL beaker ■ 50 mL volumetric pipette ■ 250 mL Erlenmeyer flask ■ funnel ■ retort stand ■ wash bottle ■ drying oven (if available) ■ stirring rod ■ ring clamp or funnel rack ■ filter paper ■ electronic balance ■ large watch glass ■ 0.150 mol/L $Mg(NO_3)_2(aq)$ or $Ca(NO_3)_2(aq)$ (concentration unknown to student) ■ 0.200 mol/ L $Na_3PO_4(aq)$ ■ deionized water

Time Required

- 60 minutes to carry out procedure

Helpful Tips

- Ensure students are confident with the concepts involved in solution stoichiometry before beginning this investigation.
- Use **BLM 7.2.6 (HAND) Investigation 7.B: Determining the Concentration of a Solution** and **BLM 7.2.6A (ANS) Investigation 7.B: Determining the Concentration of a Solution Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** A small amount of the magnesium nitrate will be soluble and therefore lost in the solution. Some of the magnesium nitrate will be lost in the transfer process. The calculated concentration will be less than the actual concentration.

Safety Precautions

- Ensure students read and understand "Safety in Your Chemistry Laboratory and Classroom" in the student textbook.
- Dispose of all material in a proper waste container.
- Flush skin with plenty of water if it comes in contact solutions.

Answers to Analysis Questions

1. Students' responses should show all calculations clearly.

(a) Suppose students were given a volume of 50.0 mL of 0.150 mol/L $Mg(NO_3)_2(aq)$, and decide to use sodium phosphate, $Na_3PO_4(aq)$, to precipitate the magnesium from solution. The equation is:

$3Mg(NO_3)_2(aq) + 2Na_3PO_4(aq) \rightarrow Mg_3(PO_4)_2(s) + 6NaNO_3(aq)$

If a student obtains 0.62 g of $Mg_3(PO_4)_2(s)$ by filtration. The calculation is as follows:

$$m = 0.62\ \cancel{g\ Mg_3(PO_4)_2(s)} \times \frac{1\ \cancel{mol\ Mg_3(PO_4)_2(s)}}{262.87\ \cancel{g\ Mg_3(PO_4)_2(s)}} \times \frac{3\ \cancel{mol\ Mg(NO_3)_2(aq)}}{1\ \cancel{mol\ Mg_3(PO_4)_2(s)}} \times \frac{148.31\ g\ Mg(NO_3)_2(aq)}{1\ \cancel{mol\ Mg(NO_3)_2(aq)}}$$

$$= 1.0\ g\ Mg(NO_3)_2(aq)$$

This represents the mass of solute dissolved in 50.0 mL of the original solution.

(b) Continuing with the same data as above, the mass of solute per 100 mL of solution is $2 \times 1.0\ g = 2.0\ g$.

(c) Using the same data as above, student should calculate the molar concentration in the following way:

$$c = 0.62\ \cancel{g\ Mg_3(PO_4)_2(s)} \times \frac{1\ \cancel{mol\ Mg_3(PO_4)_2(s)}}{262.87\ \cancel{g\ Mg_3(PO_4)_2(s)}} \times \frac{3\ mol\ Mg(NO_3)_2(aq)}{1\ \cancel{mol\ Mg_3(PO_4)_2(s)}} \times \frac{1000\ \cancel{mL}/L}{50.0\ \cancel{mL}}$$

$$= 0.14\ mol/L\ Mg(NO_3)_2(aq)$$

If the expected concentration is 0.150 mol/L this is a reasonable result considering that some of the magnesium phosphate will remain dissolved in solution.

2. Errors could include:

- The solubility of expected precipitate is close to the 0.1 mol/L limit and less precipitate is obtained than expected, because the combined volume of the filtrate and washings dissolved precipitate significantly. This is especially true for the $CaSO_4(s)$ which has the highest Ks_p of the salts suggested—students need to consider this qualitatively, not quantitatively.
- The sample is insufficiently dry and the mass obtained exceeds what should be expected, resulting in a higher than expected concentration for the original solution concentration.
- Milky filtrate or damaged filter paper could give a low result.
- Not adding sufficient reactant to produce maximum precipitate would give a low result.

3. Improvements could include drying for a longer period of time, refiltering the filtrate if it is milky, using a smaller-pore filter paper, or adding more reactant to ensure maximum precipitation.

4. A milky filtrate is an example of evidence that not all of the precipitate was collected on the filter paper. Students could suggest that a different reactant could have been used, that a different filter paper could have been used, or that the solution could have been cooled to reduce solubility.

Answer to Conclusion Question

5. Students should report their data with the appropriate number of significant digits. Using the data in the answer to Analysis question 1, the concentration of the solution is 0.14 mol/L $Mg(NO_3)_2(aq)$.

Assessment Options

When assessing procedures, note that a sound procedure should include or demonstrate:

- between 5 and 10 steps
- steps that are sufficient to obtain the kind of data/information needed to answer the problem
- good control of variables
- clean materials
- knowledge of what to observe (how do you know the reaction is complete?)
- suitable sample size (e.g., 50 mL)
- thorough drying of the sample
- clean-up/disposal considerations

A good example would be:

1. Set up the filtration apparatus as demonstrated by your teacher. Rinse the funnel with deionized water.
2. Fold a suitable-sized filter paper in preparation for the procedure before measuring and recording its mass.
3. Use a clean 100 mL measuring cylinder (or volumetric pipette) to obtain 50 mL of the aqueous solution of the $Mg(NO_3)_2(aq)$ and deliver it to a clean 100 mL beaker.
4. Add $Na_3PO_4(aq)$ to the solution in the beaker until no trace of additional precipitate formation is evident when the solution is added in small amounts.
5. Filter the mixture through filter paper, record the precipitate colour, and wash the precipitate with small amounts of deionized water.
6. When the filtration/washing step is complete, remove the filter paper with its precipitate and place it on a watch glass.
7. Leave the sample to dry (one hour in an oven at 70 °C, or overnight on the countertop).
8. Clean up your laboratory station and dispose of all waste as instructed by your teacher.
9. Measure and record the mass of the filter paper and precipitate and dispose of the waste as instructed by your teacher.

- Students are prone to neglect cleaning materials, volume measurements, colour recordings, mass recordings, and disposal requirements.
- Use Assessment Checklist 3 for self evaluation by each student. (This rubric could be given to each student before they design their experiment.)
- Use Assessment Checklist 2 to assess each students' laboratory reports.

Answers to Question for Comprehension

Student Textbook page 285

Q8. (a) 2 mol $O_2(g)$:1 mol $N_2O_4(g)$

(b) 2 L $O_2(g)$:1 L $N_2O_4(g)$

(c) If 1 L of $N_2O_4(g)$ is produced, then 2 L of $O_2(g)$ would have been consumed if temperature and pressure remain constant.

(d) 2 L of oxygen will be consumed.

Answers to Practice Problems 20-23

Student Textbook page 286

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

20. (a) 1 mol $O_2(g)$: 2 mol $H_2O(g)$

(b) 1 mol $H_2(g)$: 1 mol $H_2O(g)$

(c) 20 L

21. 24.0 L

22. 30 L

23. (a) $2A(g) + B(g) \rightarrow C(g)$

(b) $A_4B_2(g)$

Answer to Question for Comprehension

Student Textbook page 286

Q9. 74 L

Complete Solution

$P = 100$ kPa
$n = 3.0$ mol $H_2(g)$
$T = 25°C = 298.15$ K
$V = ?$

$$PV = nRT$$

$$V = \frac{nRT}{P}$$

$$= \frac{(3.0\ \cancel{mol}\ H_2(g))\left(\dfrac{8.314\ L \bullet \cancel{kPa}}{\cancel{mol} \bullet \cancel{K}}\right)(298.15\ \cancel{K})}{100\ \cancel{kPa}}$$

$= 74$ L

Answers to Practice Problems 24-27

Student Textbook page 287

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

24. (a) 67 L

(b) 0.016 mol

(c) 4.8×10^{-4} mol

25. 0.787 L

26. 5.7×10^{6} L

27. 2.73×10^{-3} g

Investigation 7.C: Analyzing Industrial Processes

Student Textbook page 288

Purpose

Students will investigate an industrial process used by an Alberta industry. The purpose of this exercise is to describe how industries apply principles of stoichiometry to minimize waste and maximize yield, and to assess the significance of by-products from industrial applications of chemical reactions.

Outcomes

- 20–D2.1sts
- 20–D2.2sts
- 20–D2.4sts
- 20–D1.4s
- ICT P4-4.3

Advance Preparation

When to Begin	What to Do
2 to 3 months before	■ Search the Internet for links to the industries listed in the text. Contact the companies and ask them to provide print information regarding their company. You may want to contact environmental protection agencies and ask them for additional materials as well. ■ Book the computer lab (if necessary).
2 to 3 days before	■ Provide **BLM 7.2.10 (HAND) Investigation 7.C: Analyzing Industrial Processes** to each student. ■ Develop an assessment rubric with the class using Assessment Checklist 7.
1 day before	■ Divide the class into groups and have each group select an industry. Each group should have time to go over the assignment and divide the work appropriately.

Materials
■ computers with Internet access ■ industry pamphlets (if available) ■ environmental pamphlets (if available) ■ Newspapers (if available) ■ **BLM 7.2.10 (HAND) Investigation 7.C: Analyzing Industrial Processes** ■ paper and pencil

Time Required

120 minutes (over two periods) for computer work

Helpful Tips

- Make sure adequate resources are available. Students find it frustrating to search for materials when none are available. Also, if students find alternative industries to study, encourage them to develop these potential resources.
- Instead of a report, students could prepare a computer slide presentation (if the appropriate technology is available). Have students point out similarities between the different industrial processes. These presentations could be shown at the beginning of classes (perhaps 2 or 3 per day).
- Developing an assessment rubric with your class will help students become more thoughtful judges of their own work.
- Suggested criteria for grading include:
  - Does the student explain how the process maximizes yield?
  - Does the student explain how the process minimizes waste?
  - Does the student explain how the process minimizes environmental impact?
  - Is the process described from raw materials to finished product?
  - Are all relevant chemical equations included, along with details of reaction conditions?
  - Are the by-products identified and their uses described?
  - Is a list of references included?
  - Does the author state an opinion about the process and does he or she support this opinion with scientific facts?
  - Does the author include a plan for improvement of the process and does he or she support this plan with specific examples?

An example of a worked criterion:

Criterion	Level 4	Level 3	Level 2	Level 1	Insufficient
Details of process	■ Clear, detailed description of the chemical process including all reactants and products involved is included. ■ Clearly labelled flowchart of the process is present. ■ All chemical equations are present, are balanced, and use scientific conventions.	■ Description of process is complete, but lacks details such as temperature. Some reactants or products may be missing. ■ Flowchart is labelled but may contain minor errors or omissions. ■ Chemical equations are balanced but do not use scientific conventions.	■ Description of the process is incomplete, some reactants or products are missing. ■ Flowchart is partially labelled and contains major errors or omissions, such as missing products. ■ Chemical equations are not balanced and do not use scientific conventions.	■ Description of process is incomplete, no clear finished product is evident, or the student is unsure of starting materials. ■ Flowchart is minimal, major steps are omitted, products or reactants are not evident. ■ Chemical equations are not balanced and chemical formulas used are incorrect.	■ No process is evident. ■ Flowchart is incomprehensible. ■ No evidence of a balanced chemical equation is present.

  - If you have it in your school library, the following resource is extremely useful for finding details of standard industrial chemical processes:
    Austin, G.T., *Shreve's Chemical Process Industries, 5th edition*, McGraw-Hill, New York, 1984.
- Use **BLM 7.2.10 (HAND) Investigation 7.C: Analyzing Industrial Processes** and **BLM 7.2.10A (ANS) Investigation 7.C: Analyzing Industrial Processes Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Assessment Options

- Assessment Checklists 3, 4, and/or 7.

Section 7.2 Review Answers

Student Textbook page 289

1. Qualitative analysis only determines whether or not a particular substance is present. Quantitative analysis allows the determination of the amount of a particular substance.
2. $2KOH(aq) + Cu(NO_3)_2(aq) \rightarrow Cu(OH)_2(s) + 2KNO_3(aq)$

   $m = 3.66$ g $\qquad m = ?$ g

   $M = 56.11$ g/mol $\qquad M = 97.57$ g/mol

$$m\,Cu(OH)_2 = 3.66\text{ g KOH} \times \frac{1\text{ mol KOH}}{56.11\text{ g KOH}} \times \frac{1\text{ mol } Cu(OH)_2}{2\text{ mol KOH}} \times \frac{97.57\text{ g } Cu(OH)_2}{1\text{ mol } Cu(OH)_2}$$
$$= 3.18\text{ g}$$

3. $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

$m = 1.00$ kg $m = ?$ kg

$m = ?$ kg $M = 16.05$ g/mol

$M = 44.01$ g/mol $M = 18.02$ g/mol

$$mCO_2 = 1.00\text{ kg } CH_4 \times \frac{1\text{ mol } CH_4}{16.05\text{ g } CH_4} \times \frac{1\text{ mol } CO_2}{1\text{ mol } CH_4} \times \frac{44.01\text{ g } CO_2}{1\text{ mol } CO_2}$$
$$= 2.74\text{ kg}$$
$$mH_2O = 1.00\text{ kg } CH_4 \times \frac{1\text{ mol } CH_4}{16.05\text{ g } CH_4} \times \frac{2\text{ mol } H_2O}{1\text{ mol } CH_4} \times \frac{18.02\text{ g } H_2O}{1\text{ mol } H_2O}$$
$$= 2.25\text{ kg}$$

4. $Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(\ell)$

$m = 28$ kg $m = ?$ g

$M = 159.70$ g/mol $M = 55.85$ g/mol

$$mAl = 28\text{ kg } Fe_2O_3 \times \frac{1\text{ mol } Fe_2O_3}{159.70\text{ g } Fe_2O_3} \times \frac{2\text{ mol Al}}{1\text{ mol } Fe_2O_3} \times \frac{97.57\text{ g Al}}{1\text{ mol Al}}$$
$$= 20\text{ kg}$$

5. $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

$m = 16.8$ g $m = ?$ g

$M = 84.01$ g/mol $M = 105.99$ g/mol

$$mNa_2CO_3 = 16.8\text{ g } NaHCO_3 \times \frac{1\text{ mol } NaHCO_3}{84.01\text{ g } NaHCO_3} \times \frac{1\text{ mol } Na_2CO_3}{2\text{ mol } NaHCO_3} \times \frac{105.99\text{ g } Na_2CO_3}{1\text{ mol } Na_2CO_3}$$
$$= 10.6\text{ g}$$

6. $Zn(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Zn(NO_3)_2(aq)$

$m = 1.6$ g $m = ?$ g

$M = 65.39$ g/mol $M = 169.88$ g/mol

$$mAg\,NO_3 = 1.6\text{ g Zn} \times \frac{1\text{ mol Zn}}{65.41\text{ g Zn}} \times \frac{2\text{ mol } AgNO_3}{1\text{ mol Zn}} \times \frac{169.88\text{ g AgNO}}{1\text{ mol } AgNO_3}$$
$$= 8.3\text{ g } AgNO_3$$

7. To the solution that contains $Pb(NO_3)_2(aq)$, add NaI(aq) until no more precipitate forms. Weigh a piece of filter paper, remove the $PbI_2(s)$ by filtration, and allow the precipitate and filter paper to dry overnight. Determine the mass of the filter paper and precipitate, and then subtract the mass of the filter paper to obtain the mass of the precipitate. Use stoichiometry to determine the mass of the $Pb(NO_3)_2(aq)$ in the original solution.

8. There are many different types of spreadsheets students can prepare. Have students e-mail their spreadsheet to you so you can assess each design individually. Have some students present their spreadsheet designs to the class.

9. $Ba(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow BaCO_3(s) + 2NaNO_3(aq)$

$V = 60.0$ mL $m = ?$ g

$c = 0.100$ mol/L $M = 105.99$ g/mol

$$m\,Na_2CO_3 = 0.0600\text{ L} \times \frac{0.100\text{ mol } Ba(NO_3)_2}{\text{L}} \times \frac{1\text{ mol } Na_2CO_3}{1\text{ mol } Ba(NO_3)_2} \times \frac{105.99\text{ g } Na_2CO_3}{1\text{ mol } Na_2CO_3}$$
$$= 636\text{ mg or } 0.636\text{ g } Na_2CO_3$$

10. $MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(\ell) + CO_2(g)$

$m = 1.62$ g $V = ?$ L

$M = 84.32$ g/mol $c = 0.383$ mol/L

$$V\,HCl = 1.62\text{ g } MgCO_3 \times \frac{1\text{ mol } MgCO_3}{84.32\text{ g } MgCO_3} \times \frac{2\text{ mol HCl}}{1\text{ mol } MgCO_3} \times \frac{1\text{ L}}{0.383\text{ mol HCl}}$$
$$= 0.100\text{ L}$$

11. $2Na_2S_2O_3(aq) + Cl_2(aq) \rightarrow 2NaCl(aq) + Na_2S_4O_6(aq)$

$V = ?$ L $V = 54$ L

$c = 0.170$ mol/L $c = 2.8 \times 10^{-5}$ mol/L

$$V\,Na_2S_2O_3 = 54\text{ L} \times \frac{2.8 \times 10^{-5}\text{ mol } Cl_2}{1\text{ L}} \times \frac{2\text{ mol } Na_2S_2O_3}{1\text{ mol } Cl_2} \times \frac{1\text{ L}}{0.170\text{ mol } Na_2S_2O_3}$$
$$= 18\text{ mL or } 0.018\text{ L}$$

12. $Na_2SO_4(aq) + Pb(NO_3)_2(aq) \rightarrow PbSO_4(s) + 2NaNO_3(aq)$

$V = ?$ L $V = 100$ mL

$c = 0.150$ mol/L $c = 0.100$ mol/L

$$V\,Na_2SO_4 = 100\text{ mL} \times \frac{0.100\text{ mol } Pb(NO_3)_2}{1\text{ mL}} \times \frac{1\text{ mol } Na_2SO_4}{1\text{ mol } Pb(NO_3)_2} \times \frac{1\text{ mL}}{0.150\text{ mol } Na_2SO_4}$$
$$= 66.7\text{ mL or } 0.0667\text{ L}$$

13. $Sr(OH)_2(aq) + 2CH_3COOH(aq) \rightarrow Sr(CH_3COO)_2(aq) + 2\,H_2O(l)$

$V = ?$ L $V = 5.00$ mL

$c = 0.100$ mol/L $c = 0.833$ mol/L

$$V\,Sr(OH)_2 = 5.00 \text{ mL} \times \frac{0.100 \text{ mol } CH_3COOH}{1 \text{ L}} \times \frac{1 \text{ mol } Sr(OH)_2}{2 \text{ mol } CH_3COOH} \times \frac{1 \text{ L}}{0.150 \text{ mol } Sr(OH)_2}$$
$$= 20.8 \text{ mL}$$

14. $3NO_2(g) + H_2O(\ell) \rightarrow 2HNO_3(aq) + NO(g)$

$n = 2.31 \times 10^4$ mol $V = ?$ L

$c = 15.4$ mol/L

$$V\,HNO_3 = 2.31 \times 10^4 \text{ mol } NO_2 \times \frac{2 \text{ mol } HNO_3}{3 \text{ mol } NO_2} \times \frac{1 \text{ L}}{15.4 \text{ mol } HNO_3}$$
$$= 1.00 \times 10^3 \text{ L}$$

15. $C_2H_5OH(aq) + O_2(g) \rightarrow CH_3COOH(aq) + H_2O(\ell)$

$m = 6.00$ g $V = 1.00$L

$M = 46.08$ g/mol $c = ?$ mol/L

$$c\,CH_3COOH = 6.00 \text{ g } C_2H_5OH \times \frac{1 \text{ mol } C_2H_5OH}{46.08 \text{ g } C_2H_5OH} \times \frac{1 \text{ mol } CH_3COOH}{1 \text{ mol } C_2H_5OH} \times \frac{1}{1.00 \text{ L}}$$
$$= 0.130 \text{ mol/L}$$

16. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

$V = 2.00$ L $V = ?$ L

$$V\,HCl = 2.00 \text{ L } H_2 \times \frac{2 \text{ L HCl}}{1 \text{ L } H_2} = 4.00 \text{ L HCl}$$

17. $$v_{\text{Total}} = 4.00 \text{ mol } C_3H_5(NO_3)_2 \times \frac{29 \text{ mol gas}}{4 \text{ mol } C_3H_5(NO_3)_2} \times \frac{24.8 \text{ L}}{1 \text{ mol gas}}$$
$$= 719 \text{ L}$$

18. $2NI_3(s) \rightarrow N_2(g) + 3I_2(g)$

$m = 395$ mg $V = ?$ L $V = ?$ L

$M = 394.71$ g/mol

$$V\,N_2 = 395 \text{ mg } NI_3 \times \frac{1 \text{ mol } NI_3}{394.71 \text{ g } NI_3} \times \frac{1 \text{ mol } N_2}{2 \text{ mol } NI_3} \times \frac{22.4 \text{ L}}{1 \text{ mol } N_2}$$
$$= 10.1 \text{ mL}$$

$$V\,I_2 = 395 \text{ mg } NI_3 \times \frac{1 \text{ mol } NI_3}{394.71 \text{ g } NI_3} \times \frac{3 \text{ mol } I_2}{2 \text{ mol } NI_3} \times \frac{22.4 \text{ L}}{1 \text{ mol } I_2}$$
$$= 44.8 \text{ mL}$$

19. $MnO_2(s) + 4HCl(aq) \rightarrow MnCl_2(aq) + 2H_2O(\ell) + Cl_2(g)$

$m = 0.250$ g $V = 100$ mL $V = ?$ L

$M = 86.94$ g/mol $c = 0.104$ mol/L

If the MnO_2 is limiting

$$m\,Cl_2 = 0.250 \text{ g } MnO_2 \times \frac{1 \text{ mol } MnO_2}{86.94 \text{ g } MnO_2} \times \frac{1 \text{ mol } Cl_2}{1 \text{ mol } MnO_2} \times \frac{24.8 \text{ L}}{1 \text{ mol } Cl_2}$$
$$= 0.0713 \text{ L}$$

If the HCl is limiting

$$m\,Cl_2 = 0.100 \text{ L} \times \frac{0.104 \text{ mol HCl}}{1 \text{ L}} \times \frac{1 \text{ mol } Cl_2}{4 \text{ mol HCl}} \times \frac{24.8 \text{ L}}{1 \text{ mol } Cl_2}$$
$$= 0.0645 \text{ L}$$

Since the HCl(aq) would produce the least amount of product, it is the limiting reactant and the volume of gas to be collected will be 0.0645 L.

20. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(\ell)$

If the C_2H_6 is limiting

$$V\,CO_2 = 2.00 \text{ L } C_2H_6 \times \frac{4 \text{ L } CO_2}{2 \text{ L } C_2H_6} = 4.00 \text{ L}$$

If the O_2 is limiting

$$V\,CO_2 = 2.00 \text{ L } O_2 \times \frac{4 \text{ L } CO_2}{7 \text{ L } O_2} = 1.14 \text{ L}$$

Since the $O_2(g)$ produces the least amount of product, it is the limiting reactant and the volume of gas to be collected will be 1.14 L.

Chapter 7 Review Answers

Student Textbook pages 292-293

Answers to Understanding Concepts Questions

1. A complete balanced equation shows all the reactants and products as if they were intact compounds that do not dissociate in solution. An ionic equation is a more accurate representation of a reaction in solution, because it shows all the high-solubility ionic compounds dissociated into ions. A net ionic equation shows only the actual chemical change that occurs.
2. A specific colour is emitted when thermally excited electrons from a heated metal ion emit energy as visible light as they move back down to lower energy levels within the ion.
3. To determine the mole ratio of two compounds in a reaction, use the coefficients in the balanced chemical equation.
4. A stoichiometric calculation would be important to chemical engineers trying to determine the masses of liquid hydrogen, liquid oxygen, and solid fuel needed for launching a space shuttle.
5. Gravimetric stoichiometry calculations determine the mass of one component based on the mass of another component in a reaction equation. Solution stoichiometry

calculations determine the concentration, volume, or mass of one component based on the concentration or volume of another component in the solution. Gas stoichiometry calculations use the volumes, temperatures, and pressures of gaseous reactants or products to determine the amount of other reactants or products in a reaction equation.

Answers to Applying Concepts Questions

6. **(a)** $MnO_4^-(aq)$

(b) $Ni^{2+}(aq)$

(c) $Na^+(aq)$

(d) $Cu^{2+}(aq)$

7. **(a)** $3Ba^{2+}(aq) + 2BO_3^{2-}(aq) \rightarrow Ba_3(BO_3)_2(s)$

(b) $Cr(s) + 2Ag^+(aq) \rightarrow Cr^{2+}(aq) + 2Ag(s)$

(c) $2Al(s) + 3Zn^{2+}(aq) \rightarrow 3Zn(s) + 2Al^{3+}(aq)$

(d) $Br_2(\ell) + 2I^-(aq) \rightarrow I_2(s) + 2Br^-(aq)$

(e) $H^+(aq) + HSO_4^-(aq) + Sr^{2+}(aq) + 2OH^-(aq) \rightarrow SrSO_4(s) + 2H_2O(\ell)$

8. $Cu(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow 2NaNO_3(aq) + CuSO_4(s)$

The spectator ions are $Na^+(aq)$ and $NO_3^-(aq)$. They are identified as the two ions that are present in aqueous form on both sides of the reaction. Or, a total ionic equation may be written. When this equation is written, the spectator ions are in the same form on both the reactant and product sides of the equation (their states do not change), as shown below:

Net ionic equation: $Cu^{2+}(aq) + SO_4^{2-} \rightarrow CuSO_4(s)$

9. The only ions that produce a pink solution are $Co^{2+}(aq)$ and $Mn^{2+}(aq)$, while the ions that produce a green solution are $Cr^{3+}(aq)$, $Cu^+(aq)$, $Fe^{2+}(aq)$ and $Ni^{2+}(aq)$. To produce a precipitate that leaves a pink solution, the anion must be insoluble with the cation producing the green solution, while being soluble with the cation that produces the pink solution. Using the data available in the solubility chart, one such combination would be $CoCl_2(aq)$ or $MnCl_2(aq)$ (or $CoBr_2(aq)$, $MnBr_2(aq)$, $CoI_2(aq)$ or $MnI_2(aq)$ mixed with $CuNO_3(aq)$). An example of the reaction that takes place is shown below:

$CoCl_2(aq) + 2CuNO_3(aq) \rightarrow Co(NO_3)_2(aq) + 2CuCl(s)$

pink green pink precipitate

10. Once the solid is dissolved, use a flame test to attempt to identify the cation. If the flame is red, it could be strontium ion. Add a few drops of aqueous sodium sulfate to the solution. Strontium ions and sulfate ions will form insoluble strontium sulfate. As well, a solution of strontium ions will be colourless.

11. To solve a gas stoichiometry problem, you would need the pressure and the temperature at which the reaction takes place in addition to the mass of the beryllium that reacts.

Answers to Solving Problems Questions

12. **(a)** $2 \text{ mol } H_2(g):1 \text{ mol } CO(g):1 \text{ mol } CH_3OH(g)$

(b) $$nH_2 = 130 \text{ kmol } CH_3OH \times \frac{2 \text{ mol } H_2}{1 \text{ mol } CH_3OH} = 260 \text{ kmol } H_2$$

260 kmol of hydrogen is required.

(c) $$nH_2 = 6.00 \text{ mol } CO \times \frac{2 \text{ mol } H_2}{1 \text{ mol } CO} = 12.0 \text{ mol } H_2$$

12.0 mol of hydrogen is required.

13. **(a)** $2 \text{ mol } C_4H_{10}(g) : 13 \text{ mol } O_2(g) : 8 \text{ mol } CO_2(g) : 10 \text{ mol } H_2O(g)$

(b) $$nO_2 = 8.0 \text{ mol } C_4H_{10} \times \frac{13 \text{ mol } O_2}{2 \text{ mol } C_4H_{10}} = 52 \text{ mol } O_2$$

52 mol of oxygen is required.

(c) $$nH_2O = 3.50 \text{ mol } C_4H_{10} \times \frac{10 \text{ mol } H_2O}{2 \text{ mol } C_4H_{10}} = 17.5 \text{ mol } H_2O$$

17.5 mol of water vapour is produced.

14. $2 Mg(s) + O_2(g) \rightarrow 2MgO(s)$

$m = 50$ g $\quad m = ?$ g

$M = 24.31$ g/mol $\quad M = 40.31$ g/mol

$$mMgO = 50 \cancel{\text{ g Mg}} \times \frac{1 \cancel{\text{ mol Mg}}}{24.31 \cancel{\text{ g Mg}}} \times \frac{1 \cancel{\text{ mol MgO}}}{1 \cancel{\text{ mol Mg}}} \times \frac{40.31 \text{ g MgO}}{1 \cancel{\text{ mol MgO}}} = 83 \text{ g}$$

83 g of metal oxide is formed.

15. $Cl_2(g) + Na(s) \rightarrow 2NaCl(s)$

$m = 4.6$ g $\quad m = ?$ g

$M = 22.99$ g/mol $\quad M = 58.44$ g/mol

$$mNaCl = 4.6 \cancel{\text{ g Na}} \times \frac{1 \cancel{\text{ mol Na}}}{22.99 \cancel{\text{ g Na}}} \times \frac{2 \cancel{\text{ mol NaCl}}}{1 \cancel{\text{ mol Na}}} \times \frac{58.44 \text{ g NaCl}}{1 \cancel{\text{ mol NaCl}}} = 12 \text{ g}$$

12 g of white solid is expected.

16. $2C_8H_{18}(\ell) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$

$m = 72.1$ g $\quad m = ?$ g

$M = 114.26$ g/mol $\quad M = 44.01$ g/mol

$$mCO_2 = 72.1 \cancel{\text{ g } C_8H_{18}} \times \frac{1 \cancel{\text{ mol } C_8H_{18}}}{114.26 \cancel{\text{ g } C_8H_{18}}} \times \frac{16 \cancel{\text{ mol } CO_2}}{2 \cancel{\text{ mol } C_8H_{18}}} \times \frac{44.01 \text{ g } CO_2}{1 \cancel{\text{ mol } CO_2}} = 222 \text{ g}$$

222 g of carbon dioxide is expected.

17. $TiCl_4(\ell) + 2H_2O(\ell) \rightarrow TiO_2(s) + 4HCl(g)$

$m = 85.6$ g $\quad m = ?$ g

$M = 189.67$ g/mol $\quad M = 79.87$ g/mol

$$m\text{TiO}_2 = 85.6\ \cancel{\text{g TiCl}_4} \times \frac{1\ \cancel{\text{mol TiCl}_4}}{189.67\ \cancel{\text{g TiCl}_4}} \times \frac{1\ \cancel{\text{mol TiO}_2}}{1\ \cancel{\text{mol TiCl}_4}} \times \frac{79.87\text{ g TiO}_2}{1\ \cancel{\text{mol TiO}_2}} = 36.0\text{ g}$$

36.0 g of titanium(IV) oxide is expected.

18. $3Ag_2S(s) + 2Al(s) \rightarrow 6Ag(s) + Al_2S_3(aq)$

$m = ?$ g $\quad m = 6.4$ g

$M = 247.81$ g/mol $\quad M = 107.87$ g/mol

$$m\text{Ag}_2\text{S} = 6.4\ \cancel{\text{g Ag}} \times \frac{1\ \cancel{\text{mol Ag}}}{107.87\ \cancel{\text{g Ag}}} \times \frac{3\ \cancel{\text{mol Ag}_2\text{S}}}{6\ \cancel{\text{mol Ag}}} \times \frac{247.81\text{ g Ag}_2\text{S}}{1\ \cancel{\text{mol Ag}_2\text{S}}} = 7.4\text{ g}$$

7.4 g of tarnish is removed.

Answers to Making Connections Questions

19. (a) $Hg(NO_3)_2(aq) + Na_2S(aq) \rightarrow HgS(s) + 2NaNO_3(aq)$

$Hg^{2+}(aq) + S^{2-}(aq) \rightarrow HgS(s)$

(b) The reaction of mercury(II) nitrate with sodium sulfide can be used to remove mercury(II) ions from the waste water because of the formation of solid mercury(II) sulfide. The solid precipitate can then be filtered to separate the mercury from the waste water.

(c) Mercury(II) nitrate is more of an environmental concern because it is soluble in water and can be ingested by marine species and carried up through the food chain (biomagnification) more easily than solid mercury(II) sulfide.

(d) We are making the assumption that both sodium sulfide and sodium nitrate are less toxic to the environment than either mercury(II) nitrate or mercury(II) sulfide.

(e) $Hg(NO_3)_2(aq) + Na_2S(aq) \rightarrow HgS(s) + 2NaNO_3(aq)$

$m = 300$ g $\quad m = ?$ g

$M = 324.61$ g/mol $\quad M = 78.05$ g/mol

$$m\text{Na}_2\text{S} = 300\ \cancel{\text{g Hg(NO}_3)_2} \times \frac{1\ \cancel{\text{mol Hg(NO}_3)_2}}{324.61\ \cancel{\text{g Hg(NO}_3)_2}} \times \frac{1\ \cancel{\text{mol Na}_2\text{S}}}{1\ \cancel{\text{mol Hg(NO}_3)_2}} \times \frac{78.05\text{ g Na}_2\text{S}}{1\ \cancel{\text{mol Na}_2\text{S}}} = 72.1\text{ g}$$

72.1 g sodium sulfide will be required.

20. Sample Procedure:

1. Observe the solution colour. The solution that appears blue-green will be the $NiSO_4(aq)$, and the remaining four will be colourless.
2. To an aliquot of each of the four colourless solutions, add one drop of NaCl(aq). The solution that forms a precipitate will be $AgNO_3(aq)$.
3. To an aliquot of each of the remaining three solutions, add one drop of Na_2SO_4. The solution that forms a precipitate will be $CaCl_2(aq)$.
4. Perform a flame test on an aliquot of the remaining two solutions. The solution that produces a red flame is LiOH(aq).
5. The remaining solution is $NH_4Cl(aq)$.

Sample Evidence Table

Solution identity	Solution colour	Addition of NaCl(aq)	Addition of $Na_2SO_4(aq)$	Flame colour
$CaCl_2(aq)$	colourless	no precipitate	precipitate	N/A
$NiSO_4(aq)$	blue-green	N/A	N/A	N/A
$AgNO_3(aq)$	colourless	precipitate	N/A	N/A
LiOH(aq)	colourless	no precipitate	no precipitate	red
$NH_4Cl(aq)$	colourless	no precipitate	no precipitate	colour

Students' may select other chemicals for the selective precipitation. Check the solubility table (Appendix G: Chemistry Data Tables in the student textbook: Table G.9 p. 782) to ensure the correct precipitation patterns. Students may also try to use litmus paper to differentiate the LiOH(aq) (a base) from $NH_4Cl(aq)$ (they will predict neutral). They will not be able to predict that ammonium chloride is an acid until *Chemistry 30*.

21. (a) $10NaN_3(s) + 2KNO_3(s) + 6SiO_2(s) \rightarrow K_2SiO_3(s) + 5Na_2SiO_3(s) + 16N_2(g)$

$m = ?$ g $\quad V = 60.0$L

$M = 65.02$ g/mol $\quad T = 303$ K

$P = 115$ kPa

$$m\text{ NaN}_3 = \frac{115\ \cancel{\text{kPa}} \times 60.0\ \cancel{\text{L}}}{8.314\ \cancel{\text{kPa}}\bullet\cancel{\text{L}}/\cancel{\text{mol}}\bullet\ \cancel{\text{K}} \times 303\ \cancel{\text{K}}} \times \frac{10\ \cancel{\text{mol NaN}_3}}{16\ \cancel{\text{mol N}_2}} \times \frac{65.02\text{ g }\cancel{\text{NaN}_3}}{1\ \cancel{\text{mol NaN}_3}} = 111\text{ g}$$

(b) If there was not an excess amount of potassium nitrate and silicon dioxide, the $NaN_3(s)$ would react to form sodium metal.

(c) Testing the safety of reactions is important because it ensures that they are safe and people who use the final product will be unharmed. Safety testing can also help predict where reactions can go wrong if the system needs to be redesigned.

22. (a) $4KO_2(s) + 2CO_2(g) \rightarrow 2K_2CO_3(s) + 3O_2(g)$

$m = ?\ g \qquad v = 50.0\ L$

$M = 71.10\ \frac{g}{mol} \qquad T = 295\ K$

$P = 101.3\ kPa$

$$mKO = \frac{101.3\ \cancel{kPa} \times 50.0\ \cancel{L}}{8.314\ \cancel{kPa} \bullet \cancel{L}/\cancel{mol} \bullet} \times \frac{4\ \cancel{mol\ KO_2}}{\cancel{K} \times 295\ \cancel{K}} \times \frac{71.10\ g\ \cancel{KO_2}}{2\ \cancel{mol\ CO_2}\ 1\ \cancel{mol\ KO_2}}$$

$$= 294\ g$$

(b) The potassium superoxide reaction also produces oxygen that is required by the astronauts in the space vehicle.

CHAPTER 8 APPLICATIONS OF STOICHIOMETRY

Curriculum Correlation

General Outcome 2: Students will use stoichiometry in quantitative analysis.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
20–D2.1k explain chemical principles, i.e., conservation of mass in a chemical change, using quantitative analysis	Limiting and Excess Reactants, Section 8.1, p. 296 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Section 8.2, p. 309	Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Extension: 5, Section 8.2, p. 309 Section 8.1 Review: 1, p. 304 Chapter 8 Review: 2, 3, pp. 324-325 Chapter 8 Test Unit 4 Review: 1, 2, pp. 328-331
20–D2.2k identify limiting and excess reagents in chemical reactions	Thought Lab 8.1: The Limiting Item, Section 8.1, p. 296 Limiting and Excess Reactants, Section 8.1, pp. 296, 298-303 Limiting and Excess Reactants in Chemical Reactions, Section 8.1, p. 297 Sample Problem: Gravimetric Stoichiometry with a Limiting Reactant, Section 8.1, p. 298 Investigation 8.A: The Limiting Reactant, Section 8.1, p. 300 Sample Problem: Precipitating Mercury: A Limiting Reactant Problem, Section 8.1, p. 301 Sample Problem: Precipitating Silver Chromate, Section 8.1, p. 302 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Section 8.2, pp. 309-310	Thought Lab 8.1: The Limiting Item: Analysis: 1-3, Section 8.1, p. 296 Questions for Comprehension: 1, Section 8.1, p. 297 Practice Problems: 1-6, Section 8.1, p. 299 Investigation 8.A: The Limiting Reactant, Analysis: 1, 2, Conclusion: 4, Extension: 5, Section 8.1, p. 300 Practice Problems: 7-12, Section 8.1, p. 302 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Analysis: 1, Section 8.2, pp. 309-310 Section 8.1 Review: 1-8, p. 304 Chapter 8 Review: 1, 3, 11-15, pp. 324-325 Chapter 8 Test Unit 4 Review: 23-42, pp. 328-331

	Student Textbook	Assessment Options
20–D2.3k calculate theoretical yields and determine actual yields	Chapter 8 Launch Lab: The Model Air Bag, Analysis, p. 295 Sample Problem: Gravimetric Stoichiometry with a Limiting Reactant, Section 8.1, p. 298 Sample Problem: Precipitating Mercury: A Limiting Reactant Problem, Section 8.1, p. 301 Sample Problem: Precipitating Silver Chromate, Section 8.1, p. 302 Predicted and Exerpmental Yield, Section 8.2, pp. 305-310 Sample Problem: Calculating the Percentage Yield, Section 8.2, p. 307 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Section 8.2, p. 309 Connections: Sulfur from Sour Gas, Section 8.3, p. 320	Chapter 8 Launch Lab: The Model Air Bag, Analysis: 1, 2, p. 295 Practice Problems: 1-6, Section 8.1, p. 299 Practice Problems: 7-12, Section 8.1, p. 302 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Analysis: 3, Extension: 4, 5, Section 8.2, p. 309 Connections: Sulfur from Sour Gas: 1, 2, Section 8.3, p. 320 Section 8.1 Review: 3-8, p. 304 Questions for Comprehension: 3, Section 8.2, p. 307 Practice Problems: 13-19, Section 8.2, p. 308 Section 8.2 Review: 1-8, p. 311 Chapter 8 Review: 15-17, pp. 324-325 Chapter 8 Test Unit 4 Review: 35, 40-42, pp. 328-331
20–D2.4k explain the discrepancy between theoretical and actual yields and calculate percent yield	Predicted and Experimental Yield, Section 8.2, pp. 305, 308-309 Calculating the Percentage Yield of a Reaction, Section 8.2, p. 307 Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Section 8.2, p. 309 Acid-Base Titration, Section 8.3, p. 312	Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction, Analysis: 2, 3, Conclusion: 4, Extension: 5, Section 8.2, p. 309 Section 8.1 Review: 6, 7, p. 304 Questions for Comprehension: 2, 3, Section 8.2, p. 307 Practice Problems: 13-19, Section 8.2, p. 308 Section 8.2 Review: 1, 2, 7, 8, p. 311 Chapter 8 Review: 3-5, pp. 324-325 Chapter 8 Test

	Student Textbook	Assessment Options
20–D2.5k draw and interpret titration curve graphs, using data from titration experiments involving strong monoprotic acids and strong monoprotic bases	Sample Problem: Determining Acid Concentration by Titration, Section 8.3, p. 314 Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Acid-Base Titration Curves, Section 8.3, p. 317 Acid-Base Titration, Section 8.3, pp. 318-319 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319	Practice Problems: 20-25, Section 8.3, p. 315 Investigation 8.C: Standardizing a Hydrochloric Acid Solution: 1-8, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve: 1-6, Section 8.3, p. 319 Questions for Comprehension: 8-10, Section 8.3, p. 319 Section 8.3 Review: 4, 6, p. 322 Chapter 8 Review: 10, 19, pp. 324-325 Chapter 8 Test
20–D2.6k describe the function and choice of indicators in titrations	Acid-Base Titration, Section 8.3, p. 312 Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Choosing an Indicator, Section 8.3, p. 318 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid, Section 8.3, p. 321	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, 1-8, p. 317 Thought Lab 8.2: Plotting a Titration Curve, Extension: 6, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid: 7, Section 8.3, p. 321 Section 8.3 Review: 2, 6, p. 322 Chapter 8 Review: 6, 10, 19, pp. 324-325 Chapter 8 Test Unit 4 Review: 12, 35, pp. 328-331
20–D2.7k identify equivalence points on strong monoprotic acid-strong monoprotic base titration curves and differentiate between the indicator endpoint and the equivalence point.	Acid-Base Titration, Section 8.3, pp. 312, 319-320 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid, Section 8.3, p. 321	Questions for Comprehension: 9, 10, Section 8.3, p. 319 Thought Lab 8.2: Plotting a Titration Curve, Extension: 6, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid: 6, 7, Section 8.3, p. 321 Section 8.3 Review: 2, 6, p. 322 Chapter 8 Review: 6, 8, 21, pp. 324-325 Chapter 8 Test Unit 4 Review: 12, pp. 328-331

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
20–D2.1sts explain that scientific knowledge may lead to the development of new technologies and that new technologies may lead to scientific discovery by ■ *describing how industries apply principles of stoichiometry to minimize waste and maximize yield*	Stoichiometry, Chapter 7 opener, p. 260 Reactions in Aqueous Solution, Section 7.1, p. 263 Stoiciometry and qualitative Analysis, Section 7.2, pp, 275, 279 Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288 Applications of Stoichiometry, Chapter 8 opener, p. 294 Chapter 8 Launch Lab: The Model Air Bag, p. 295 Predicted and Experimental Yield, Section 8.2, p. 307 Connections: Sulfur from Sour Gas, Section 8.3, p. 320	Investigation 7.C: Analyzing Industrial Processes: 1-3, 1, 2 Section 7.2, p. 288 Chapter 8 Launch Lab: The Model Air Bag, Analysis: 1, 2, p. 295 Connections: Sulfur from Sour Gas: 1-3, Section 8.3, p. 320 Chapter 8 Review: 3, 5, 21, pp. 324-325 Unit 4 Review: 43-45, pp. 328-331
20–D2.2sts explain how the appropriateness and the risks and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability by ■ *assessing the significance of specific by-products from industrial, commercial and household applications of chemical reactions* ■ *analyzing the use of technology to reduce environmental impact in $SO_2(g)$ removal from smokestacks, catalytic converters in automobiles and reducing greenhouse gas emissions.*	Stoichiometry and Qualitative Analysis, Section 7.2, p. 279 Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288 Chapter 8 Launch Lab: The Model Air Bag, Analysis, p. 295 Connections: Sulfur from Sour Gas, Section 8.3, p. 320	Investigation 7.C: Analyzing Industrial Processes: 1-3, 1, 2 Section 7.2, p. 288 Chapter 8 Launch Lab: The Model Air Bag, Analysis: 1, 2, p. 295 Chapter 8 Review: 3, 5, 21, pp. 324-325 Unit 4 Review: 43-45, pp. 328-331 Connections: Sulfur from Sour Gas: 1-3, Section 8.3, p. 320
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
20–D2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ designing a method using crystallization, filtration or titration to determine theconcentration of a solution ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ predicting the approximate equivalence point for a strong monoprotic acid-strong monoprotic base titration and selecting an appropriate indicator.	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid, Section 8.3, p. 321	Section 8.1 Review: 8, p. 304 Investigation 8.C: Standardizing a Hydrochloric Acid Solution: 1-8, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve, Extension: 6, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid: 1-7, Section 8.3, p. 321 Chapter 8 Review: 10, 24, pp. 324-325 Unit 4 Review: 22, 45, pp. 328-331

	Student Textbook	Assessment Options
Performing and Recording		
20–D2.2s conduct investigations into relationships between and among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing a titration to determine the concentration of an acid or base restricted to strong monoprotic acid-strong monoprotic base combinations ■ *using probes and software to collect titration data* ■ *researching methods used by industry to reduce emissions* ■ *designing a prototype of a chemical industrial plant.*	Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288 Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid, Section 8.3, p. 321	Assessment Checklist 1: Designing an Experiment Investigation 8.C: Standardizing a Hydrochloric Acid Solution: 1-8, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve: 1-6, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid: 1-8, Section 8.3, p. 321 Unit 4 Review: 22, 45, pp. 328-331
Analyzing and Interpreting		
20–D2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ evaluating an experiment based on a precipitation reaction, to determine the concentration of a solution ■ creating and interpreting titration curve graphs for acid-base experiments restricted to strong monoprotic acid-strong monoprotic base combinations ■ calculating percent yield and explaining the discrepancies between the theoretical and actual yields ■ using appropriate SI notation, fundamental and derived units and significant digits when performing stoichiometric calculations	Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319 Investigation 8.D: Titrating a Strong Base with a Strong Acid, Section 8.3, p. 321	Investigation 8.C: Standardizing a Hydrochloric Acid Solution: 1-8, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve: 1-6, Section 8.3, p. 319 Assessment Checklist 1: Designing an Experiment
Communication and Teamwork		
20–D2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ standardizing an acid or base solution and comparing group results ■ *drawing a flowchart for an industrial chemical process* ■ *using integrated software effectively and efficiently to produce work that incorporates data, graphics and text.*	Investigation 7.C: Analyzing Industrial Processes, Section 7.2, p. 288 Investigation 8.C: Standardizing a Hydrochloric Acid Solution, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve, Section 8.3, p. 319	Assessment Checklist 4: Performance Task Group Assessment Investigation 8.C: Standardizing a Hydrochloric Acid Solution: 1-8, Section 8.3, p. 316 Thought Lab 8.2: Plotting a Titration Curve: 1-6, Section 8.3, p. 319

Chapter 8

Applications of Stoichiometry

Student Textbook pages 294-325

Chapter Concepts

Section 8.1 Limiting and Excess Reactants

- Reactants are not usually present in the exact amounts required by the reaction.
- One reactant limits the reaction, while the other reactants are left over after the reaction is complete.

Section 8.2 Predicted and Experimental Yield

- Chemical reactions rarely produce the predicted amount of product.
- Percentage yield compares the experimental yield with the predicted yield.

Section 8.3 Acid-Base Titration

- You can determine the concentration of a strong acid by adding a strong base or the concentration of strong base by adding a strong acid.
- Indicators and pH meters allow you to determine when neutralization is near.

Common Misconceptions

- Students may designate the limiting reactant as the reactant present in the lowest mass, or in the lowest number of moles, without looking at the balanced chemical equation. Remind students that the ratio of reactants must be taken into consideration when determining the limiting reactant.
- Some students will confuse the endpoint and equivalence point or treat them as the same thing. The point in the titration at which the chosen indicator changes colour is the endpoint. The equivalence point, or stoichiometric point, is the point at which the number of moles of acid equals the number of moles of base that have been added. A good choice of indicator for a titration is one that will produce an endpoint that occurs at the equivalence point or very close to it (in the steep portion of the pH curve).

Helpful Resources

Journal Articles

- Arasasingham, R.D., Taagepera, M., Potter, F., and Lonjers, S. "Using Knowledge Space Theory to Assess Student Understanding of Stoichiometry," *Journal of Chemical Education*, Vol. 81, No. 10, October 2004, p. 1517.
- Ault, A. "How to Say How Much: Amounts and Stoichiometry," *Journal of Chemical Education*, Vol. 78, No. 10, October 2001, p. 1345.
- Cook, E. and Cook, R.L. "Cross-Proportions: A Conceptual Method for Developing Quantitative Problem-Solving Skills," *Journal of Chemical Education*, Vol. 82, No. 8, August 2005, p. 1187.
- Gabel, D. "Improving Teaching and Learning through Chemistry Education Research: A Look to the Future," *Journal of Chemical Education*, Vol. 76, No. 4, April 1999, p. 548.
- Krieger, C.R. "Stoogiometry: A Cognitive Approach to Teaching Stoichiometry," *Journal of Chemical Education*, Vol. 74, No. 3, March 1997, p. 306.
- Lin, H. and Cheng, H. "The Assessment of Students and Teachers' Understanding of Gas Laws," *Journal of Chemical Education*, Vol. 77, No. 2, February 2000, p. 235.
- Rohrig, B, "Fizzy Drinks: Stoichiometry You Can Taste," *Journal of Chemical Education*, Vol. 77, No. 12, December 2000, p. 1608B.

Web Sites

Web links related to applications of stoichiometry can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title

8.0.1 (HAND) Launch Lab: The Model Airbag
8.0.1A (ANS) Launch Lab: The Model Airbag Answer Key

8.1.1 (HAND) Thought Lab 8.1: The Limiting Item
8.1.1A (ANS) Thought Lab 8.1: The Limiting Item Answer Key
8.1.2 (AST) Limiting Reactant Problems
8.1.2A (ANS) Limiting Reactant Problems Answer Key
8.1.3 (AST) Expected Quantity of Product Problems
8.1.3A (ANS) Expected Quantity of Product Problems Answer Key
8.1.4 (OH) Process for Solving Limited Reactant Solution Stoichiometry Problems
8.1.5 (AST) Limiting Reactant in Solution and Gas Stoichiometry
8.1.5A (ANS) Limiting Reactant in Solution and Gas Stoichiometry Answer Key
8.1.6 (HAND) Investigation 8.A: The Limiting Reactant
8.1.6A (ANS) Investigation 8.A: The Limiting Reactant Answer Key

8.2.1 (AST) Percentage Yield Problems
8.2.1A (ANS) Percentage Yield Problems Answer Key
8.2.2 (HAND) Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction
8.2.2A (ANS) Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction Answer Key

8.3.1 (AST) Acid-Base Titration
8.3.1A (ANS) Acid-Base Titration Answer Key
8.3.2 (OH) Titration Step-by-Step
8.3.3 (AST) Titration Problems
8.3.3A (ANS) Titration Problems Answer Key
8.3.4 (HAND) Investigation 8.C: Standardizing a Hydrochloric Acid Solution
8.3.4A (ANS) Investigation 8.C: Standardizing a Hydrochloric Acid Solution Answer Key
8.3.5 (OH) pH Titration Curves and Indicators
8.3.6 (AST) Selecting an Indicator
8.3.6A (ANS) Selecting an Indicator Answer Key
8.3.7 (HAND) Thought Lab 8.2: Plotting a Titration Curve
8.3.7A (ANS) Thought Lab 8.2: Plotting a Titration Curve Answer Key
8.3.8 (HAND) Investigation 8.D: Titrating a Strong Base with a Strong Acid
8.3.8A (ANS) Investigation 8.D: Titrating a Strong Base with a Strong Acid Answer Key

8.4.1 (AST) Chapter 8 Test
8.4.1A (ANS) Chapter 8 Test Answer Key

Using the Chapter 8 Opener

Student Textbook pages 294-295

Teaching Strategies

- Read the Chapter Opener with students. Ask them what engineers need to predict when they want to fill an air bag with gas (answer: the volume of the gas). Ask students how they would determine the volume of a gaseous product based on the mass of a solid reactant (answer: convert mass of reactant to moles, convert moles of product to volume). Have students discuss how to determine the volume of a gas based on molar amount (answer: molecular volume, Gay-Lussac's law of combining volumes, and the ideal gas law). This discussion will prepare students nicely for the Launch Lab: The Model Airbag.

Launch Lab The Model Airbag

Student Textbook page 295

Purpose

Students try to fill a bag by producing a gas from the reaction of household vinegar (ethanoic acid) and baking soda (sodium hydrogen carbonate). In this way, students gain an appreciation of how stoichiometry can be used to solve real problems.

Outcomes

- 20-D1.1sts
- 20-D1.3s

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available
1 day before	■ Set up student stations ■ Collect materials ■ Test the reaction and materials to ensure that the desired effect is achieved ■ Provide each student with **BLM 8.0.1 (HAND) Launch Lab: The Model Airbag** and have students complete the prediction
The day of the lab	■ Check the weather office for the barometric pressure (uncorrected) if a mercury barometer is unavailable

Materials
■ 50 mL graduated cylinder ■ 50 mL beaker ■ barometer or the latest air pressure (uncorrected) ■ –20 to 120 °C alcohol or digital thermometer ■ resealable plastic sandwich bags (typically 16.9 cm x 14.8 cm) ■ household white vinegar ($CH_3COOH(aq)$) ■ baking soda ($NaHCO_3(s)$)

Time Required

30 minutes

Helpful Tips

- Typically, sandwich bags have a capacity of 500 to 700 mL in volume before the plastic bag stretches.
- If possible, try the procedure yourself using one of the sandwich bags you will provide for the students. This way you can test the capacity and stretchiness of the bags and will also have some idea how quickly the reaction will proceed.
- Measure the barometric pressure and the room temperature and provide to students the day before the laboratory exercise to allow them to make a prediction. The mass of baking soda should be approximately 1.6 to 2.3 g assuming a pressure of 94 kPa and a temperature of 22 °C.
- The concentration of vinegar is typically 5% by volume, which corresponds to a molar concentration of 0.833 mol/L ethanoic acid. The volume of ethanoic acid that should be

added should exceed 23 to 33 mL. This ensures all the baking soda will react.

- Have the students place the bags in a sink while the reaction is taking place. Should the bag open or break, cleanup will be much easier if the spill is contained.
- Use **BLM 8.0.1 (HAND) Launch Lab: The Model Airbag** and **BLM 8.0.1A (ANS) Launch Lab: The Model Airbag Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** A small sandwich bag holds roughly 800 mL of liquid or gas. At SATP, 800 mL of carbon dioxide has just over 0.030 mol. The temperature and atmospheric pressure in classrooms will vary but, if you use 0.030 mol as a rough estimate, the student would need about 2.5 g of baking soda and about 36 mL of household vinegar to make enough carbon dioxide to fill the sandwich bag. Discuss the rate at which the reaction produces carbon dioxide with the rate of gas production needed in an air bag.

Safety Precautions

- Ensure students read and understand "Safety in Your Chemistry Lab and Classroom" in the front matter of the student textbook (pages xii-xv).
- Ethanoic acid is corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials down the drain.

Answers to Analysis Questions

1. Successful students will have used gas, solution, and stoichiometry calculations to figure out:

(a) how many moles of carbon dioxide correspond to a large enough volume to fill the bag (using $n = \frac{PV}{RT}$);

(b) how many moles of baking soda and acetic acid are needed to react (using mole ratios); and

(c) what mass of baking soda and what volume of acetic acid correspond to those calculated amounts (using $m = nM$ and $V = \frac{n}{c}$) .

Successful students will probably have used an excess of vinegar to ensure a complete reaction. Generally students will err in measurement (temperature, mass, pressure), in calculations, or in not adding excess vinegar to ensure complete reaction of the baking soda.

2. The reaction between vinegar and baking soda is not used to fill air bags because it is too slow. Air bags need to fill immediately on impact to be effective. Also, a trigger mechanism that would instantly mix the solid and liquid reactants on impact would be difficult to design. Finally, the mass of the gas produced by the reaction is small compared to the mass of the reactants (31%). By contrast, the mass of the product gas compared to the reactant for the decomposition of sodium azide (see the Chapter 8 Opener in the textbook) is large (65%). Especially in space travel, it is important to minimize mass and waste.

Assessment Options

- Collect and assess the students' predictions, observations, and/or answers to Analysis questions.
- Use Assessment Checklist 2 Laboratory Report

8.1 Limiting Excess Reactants

Student Textbook pages 296-304

Section Outcomes

Students will:

- calculate the quantities of reactants and products involved in chemical reactions using gravimetric and solution stoichiometry
- interpret stoichiometric ratios from chemical reaction equations
- perform stoichiometry calculations to determine predicted yields
- identify limiting and excess reactants in chemical reactions

Key Terms

stoichiometric coefficients
stoichiometric amounts
limiting reactant
excess reactant

Chemistry Background

- Significant digits are obtained through measurement—the greater the certainty of measurement, the greater the number significant digits. Students have encountered the use of significant digits in calculations in *Science 10.* Guidelines for use of significant digits in calculations are provided in Appendix E: Math and Chemistry.

Teaching Strategies

- Introduce the concept of the limiting reactant by relating it to concrete examples, such as those found in Thought Lab 8.1: The Limiting Item (student textbook, page 296). If you used recipes to introduce stoichiometry, you can build on this idea by providing students with a list of reactants and asking them to predict how many products can be formed (for example, how many cream puffs could be produced if you used 5 cups of butter, flour, and water and one dozen eggs?). The process used to answer this question is very similar to the process students will use to solve limiting reactant problems.
- A quick and easy demonstration is to add a measured quantity of sodium metal to 1.00 L of water. Because a

large volume of water is left after the reaction is complete, it will be quite obvious to the students that the limiting reactant is sodium.

- Provide students with clues on how to recognize a limiting reactant problem. The question, *"How much product will form from x g of reactant?"* represents a stoichiometric problem that can be solved using the simple method learned in the previous section. When the problem states fixed amounts of two or more reactants, it is a limiting reactant problem, and students must identify the limiting reactant in order to predict the amount of the desired product.
- Consistent use of the strategies developed in Chapter 7 should be reinforced. Students should continue to use the organizational skills learned in the previous section to solve limiting reactant problems.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 8 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  Number (Type) Title
  8.1.2 (AST) Limiting Reactant Problems
  8.1.2A (ANS) Limiting Reactant Problems Answer Key
  8.1.3 (AST) Expected Quantity of Product Problems
  8.1.3A (ANS) Expected Quantity of Product Problems Answer Key
  8.1.4 (OH) Process for Solving Limited Reactant Solution Stoichiometry Problems
  8.1.5 (AST) Limiting Reactant in Solution and Gas Stoichiometry
  8.1.5A (ANS) Limiting Reactant in Solution and Gas Stoichiometry Answer Key

SUPPORTING DIVERSE STUDENT NEEDS

Molecular model kits can enable students to make models of the reactants in the equation, and students can use the number of models to represent the number of moles of each reactant present. Students will physically construct the products from the reactants and have a concrete representation of the limiting reactant and the reactant in excess.

Thought Lab 8.1: The Limiting Item

Student Textbook page 296

Purpose

The purpose of this exercise is to identify limiting and excess reactants in a representation of a chemical reaction.

Outcome

- 20–D2.2k

Advance Preparation

When to Begin	What to Do
1 day before	■ Photocopy **BLM 8.1.1 (HAND) Thought Lab 8.1: The Limiting Item**

Time Required

40 minutes

Helpful Tips

- Prepare a number of different "kits" that contain various numbers of bolts, washers, and nuts for student use. Using **BLM 8.1.1 (HAND) Thought Lab 8.1: The Limiting Item** as an overhead, show the students a widget and have them produce the "balanced equation" for the formation of the widget. Have students produce as many widgets as possible with their kits. This activity may help some of the tactile learners to understand the concept of limiting and excess reactants.
- Use **BLM 8.1.1 (HAND) Thought Lab 8.1: The Limiting Item** and **BLM 8.1.1A (ANS) Thought Lab 8.1: The Limiting Item Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Answers to Analysis Questions

1. According to the balanced equation, 75 bolts will produce 75 widgets, 100 washers will produce 100 widgets, and 100 nuts will produce 50 widgets.

(a) The nuts are the limiting reactant.

(b) The bolts and the washers were present in excess.

(c) Since we can only produce 50 widgets, 25 bolts and 50 washers will remain.

(d) 2 Nu:1 Bt

(e) 2 Nu:1 Wa

2. The amount of a reactant does not affect the quantity of the product obtained. Only the limiting reactant can affect the quantity of product. Only the stoichiometric amount of this reactant will be consumed.

3. Despite being present in the least amount, the bolts were not the limiting reactant due to the ratio of the bolts to the final product. In the reaction, only one bolt was consumed to produce one widget (a 1:1 ratio). Another reactant, the washers, was consumed in a greater ratio (2 washers to one widget), and this fact, in conjunction to the initial amount, determined the maximum number of widgets that could be produced.

Answers to Question for Comprehension

Student Textbook page 297

Q1. (a) The limiting reactant is the reactant that is completely consumed in a chemical reaction.

(b) The limiting reactant is not always the chemical present in the fewest number of moles. It is the reactant that will form fewer moles of product.

Answers to Practice Problems 1-6

Student Textbook page 299

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. $Fe(NO_3)_2(aq)$
2. 1.9 g
3. 22 g
4. 7.7 g
5. The zinc would react completely.
6. $NH_3(g)$ is the limiting reagent.

Investigation 8.A: The Limiting Reactant

Student Textbook page 300

Purpose

Students will predict the limiting reactant in a chemical reaction between a strip of aluminium foil and a solution containing copper(II) chloride. Students will test their predictions by performing the reaction and observing which reactant was present at the conclusion of the reaction. Students will have an opportunity in the Extension to determine the excess reactant by observation when the quantities of reactants are unknown.

Outcomes

- 20–D2.2k
- 20–D1.4s
- 20–D2.1s

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
2 to 3 days before	■ Measure the mass of aluminium and copper(II) chloride (and Mg(s) and volumes of HCl(aq) if you are planning to do the Extension). ■ Test all reagents to ensure the reaction goes to completion as expected and to determine the approximate length of time that the reaction will need.
1 day before	■ Set up student stations. ■ Collect apparatus. ■ Provide each student with **BLM 8.1.6 (HAND) Investigation 8.A: The Limiting Reactant** and have students complete the Prediction.

Materials
■ 125 mL Erlenmeyer flask ■ stirring rod ■ 500 mL wash bottle ■ waste container ■ electronic balance ■ $CuCl_2(s)$ ■ aluminium foil ■ de-ionized water ■ Mg(s) ribbon ■ 0.125 mol/L HCl(aq)

Time Required

60 minutes

Helpful Tips

- Prepare a sample mass of aluminium foil and $CuCl_2(s)$ for students to see before they perform the investigation.
- Pre-weighed samples of $CuCl_2(s)$ can be stored in film canisters. Students who finish the experiment quickly can prepare these samples for the next class. $CuCl_2$ frequently comes as a dihydrate, $CuCl_2{\bullet}2H_2O(s)$. If this is the case, you need to give each group 0.65 g of the dihydrate. Do not tell the students; talking about hydrated ionic compounds is an unnecessary complication at this point.
- All solids should be filtered out upon completion of this lab. The solid copper can be kept for later use, and the $AlCl_3(aq)$ can be stored in a sealed container labelled "organic waste."
- Students should have completed the prediction for this laboratory exercise and prepared an evidence table. The prediction should include the formation of a precipitate, colour changes, and a decrease in mass of the aluminium foil. Students who have completed this section will be better prepared to make all the necessary observations to complete this exercise.
- If you wish to do the Extension to the investigation, measure 15 strips of magnesium ribbon with a mass of 0.3 g, and prepare the following volumes of HCl(aq) prior to the laboratory date.
  - Unknown A: 10 mL 0.125 mol/L HCl(aq) + 40 mL de-ionized water (4 flasks).
  - Unknown B: 15 mL 0.125 mol/L HCl(aq) + 35 mL de-ionized water (4 flasks).

- Unknown C: 25 mL 0.125 mol/L HCl(aq) + 25 mL de-ionized water (4 flasks).
- Unknown D: 30 mL 0.125 mol/L HCl(aq) + 20 mL de-ionized water (4 flasks).

In Unknowns A and B, the HCl(aq) is limiting, and in Unknowns C and D, the magnesium is limiting. If you wish to simplify this portion of the lab, prepare all the flasks with the same amounts of HCl(aq).

- This lab can be performed as a demonstration in front of the class to reduce chemicals and clean up. The flask when placed on a white sheet of paper will be visible at the back of a regular-sized classroom. Model making observations and lead a discussion while the reaction proceeds to completion.
- Use **BLM 8.1.6 (HAND) Investigation 8.A: The Limiting Reactant** and **BLM 8.1.6A (ANS) Investigation 8.A: The Limiting Reactant Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** Copper (II) chloride is the limiting reactant. When the reaction is complete and the aluminium is no longer visible, the solution will remain blue because there is still some Cu^{2+} in the solution.

Safety Precautions

Ensure students read and understand "Safety in Your Chemistry Lab and Classroom" in the student textbook (pages xii-xv). The reaction mixture may get very hot. Instruct the students not to hold the flask as the reaction proceeds. They can gently swirl the flask while on the laboratory bench. Make sure you have the necessary equipment available to clean up glass, should a flask break during the reaction. Dispose of all materials in a proper waste container.

Answers to Analysis Questions

1. The $CuCl_2$(aq) was the limiting reactant because the blue colour of the original solution completely disappeared.
2. The Al(s) was present in excess because small pieces of Al(s) remained in the flask at the end of the reaction.
3. If the students correctly calculated the prediction, their observations should match. $CuCl_2$(aq) was the limiting reactant and should be completely consumed in the reaction.

Answer to Conclusion Question

4. In the reaction between 0.25 g of Al(s) and 0.51 g of $CuCl_2$(aq), $CuCl_2$(aq) was determined to be the limiting reactant because the blue colour caused by the Cu^{2+}(aq) completely disappeared during the course of the reaction, while small pieces of Al(s) remained. These observations were supported by the stoichiometric calculations performed in the prediction. Based on the results of this exercise, stoichiometric calculations appear to be an effective way to predict limiting and excess reactants.

Answer to Extension Question

5. **(a)** The solid magnesium ribbon would be completely consumed (the metal would disappear) in the reaction if the magnesium were the limiting reactant. If the hydrochloric acid were limiting, small pieces of the magnesium would remain at the end of the reaction.

   (b) Place the Mg(s) in the HCl(aq) and observe the reaction. If the bubbling, due to production of H_2(g), stops and there is Mg(s) remaining, then the HCl(aq) is the limiting reactant. If the Mg(s) is used up completely, then it is likely the limiting reactant, although the possibility exists that there may be stoichiometric quantities of both. A second test can be carried out to ensure that Mg(s) is the limiting reactant by adding a second piece of Mg(s) to the solution. If bubbles are produced, this confirms that there is HCl(aq) left from the previous reaction and Mg(s) is definitely the limiting reactant.

Assessment Options

- Collect and assess students' predictions.
- Collect and assess students' responses to the Analysis, Conclusion, and Extension questions.
- Use Assessment Checklist 3 Performance Task Self-Assessment to assess student participation.
- You could also use parts of Assessment Checklist 5 Learning Skills and Assessment Checklist 6 Using Math in Science.

Answers to Practice Problems 7-12

Student Textbook page 303

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

7. The limiting reagent is $Mg(NO_3)_2$(aq)
8. 4 g
9. Since $HgCl_2$(aq) is the limiting reagent, there is sufficient Na_2S(aq) to precipitate all of the Hg^{2+}(aq) ions from the solution.
10. 15 g

    $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$
11. **(a)** $CuSO_4(aq) + Sr(NO_3)_2(aq) \rightarrow Cu(NO_3)_2(aq) + SrSO_4(s)$

    (b) The filtrate will be red.

    (c) Priti should expect approximately 1.47 g of precipitate.

    (d) The percentage yield is 97.4%.
12. **(a)** $Na_2SiO_3(aq) + 2AgNO_3(aq) \rightarrow Ag_2SiO_3(s) + 2NaNO_3(aq)$

    (b) Since the concentration and volume of silver nitrate, $AgNO_3$(aq), produces less precipitate, it is the limiting reagent.

(c) The predicted yield is 4.9 g $Ag_2SiO_3(s)$.

(d) Yes, all of the silver ions would be removed from the solution since all of the limiting reagent, which in this case is AgNO3(aq), is consumed in the reaction.

Section 8.1 Review Answers

Student Textbook page 304

1. You need not consider reactants that are in excess, as they do not determine the yield of the reaction; only the limiting reactant will influence the yield. Student analogies will vary. Most students will provide analogies of recipes.

2. (a) The $O_2(g)$ will be in excess because the amount of $P_4(s)$ is set, while the quantity of oxygen in air is virtually limitless.

(b) Gold is far too expensive to be in excess. Due to its prohibitive cost, a chemist would want to use all the gold in the reaction.

(c) The characteristics of a reactant that would make it suitable as an excess reactant would be low cost, high solubility (because most reactions take place in water), and ease of disposal (non-toxic).

3. $Cu(s) + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(\ell)$

$m = 57.4$ g $\quad m = 140$ g $\quad m = ?$ g

$M = 63.55$ g/mol $\quad M = 63.02$ g/mol $\quad M = 187.57$ g/mol

If Cu(s) is limiting:

$$m\mathrm{Cu(NO_3)_2} = 57.4\ \mathrm{g\ Cu} \times \frac{1\ \mathrm{mol\ Cu}}{63.55\ \mathrm{g\ Cu}} \times \frac{1\ \mathrm{mol\ Cu(NO_3)_2}}{1\ \mathrm{mol\ Cu}} \times \frac{187.57\ \mathrm{g\ Cu(NO_3)_2}}{1\ \mathrm{mol\ Cu(NO_3)_2}}$$
$$= 169\ \mathrm{g}$$

If HNO_3 (aq) is limiting:

$$m\mathrm{Cu(NO_3)_2} = 140\ \mathrm{g\ HNO_3} \times \frac{1\ \mathrm{mol\ HNO_3}}{63.02\ \mathrm{g\ HNO_3}} \times \frac{1\ \mathrm{mol\ Cu(NO_3)_2}}{4\ \mathrm{mol\ HNO_3}} \times \frac{187.57\ \mathrm{g\ Cu(NO_3)_2}}{1\ \mathrm{mol\ Cu(NO_3)_2}}$$
$$= 104\ \mathrm{g}$$

(a) Since the $HNO_3(aq)$ will produce the least amount of product, it is the limiting reactant. Therefore, the Cu(s) is the reactant in excess.

(b) The mass of $Cu(NO_3)_2(aq)$ that could be obtained is 156 g.

4. $2CaCO_3(s) + 2SO_2(g) + O_2(g) \rightarrow 2CaSO_4(s) + 2CO_2(g)$

$m = 2000$ kg $\quad m = 1000$ kg

$M = 100.09$ g/mol $\quad M = 64.07$ g/mol

If $CaCO_3(s)$ is limiting:

$$m\mathrm{SO_2} = 2000\ \mathrm{kg\ CaCO_3} \times \frac{1\ \mathrm{mol\ CaCO_3}}{100.09\ \mathrm{g\ CaCO_3}} \times \frac{2\ \mathrm{mol\ SO_2}}{2\ \mathrm{mol\ CaCO_3}} \times \frac{64.07\ \mathrm{g\ SO_2}}{1\ \mathrm{mol\ SO_2}}$$
$$= 1280\ \mathrm{kg}$$

According to the previous calculation, the quantity of $SO_2(g)$ that can be removed is 1280 kg. Since only 1000 kg is present, it will be completely removed.

5. $Pb(NO_3)_2(aq) + Na_2SiO_3(aq) \rightarrow PbSiO_3(s) + 2NaNO_3(aq)$

$m = 7.16$ g $\quad m = 20$ g $\quad m = ?$ g

$M = 331.23$ g/mol $\quad M = 122.07$ g/mol $\quad M = 283.30$ g/mol

If $Pb(NO_3)_2(aq)$ is limiting:

$$m\mathrm{PbSiO_3} = 7.16\ \mathrm{g\ Pb(NO_3)_2} \times \frac{1\ \mathrm{mol\ Pb(NO_3)_2}}{331.23\ \mathrm{g\ Pb(NO_3)_2}} \times \frac{1\ \mathrm{mol\ PbSiO_3}}{1\ \mathrm{mol\ Pb(NO_3)_2}} \times \frac{283.30\ \mathrm{g\ PbSiO_3}}{1\ \mathrm{mol\ PbSiO_3}}$$
$$= 6.1\ \mathrm{g}$$

If $Na_2SiO_3(aq)$ is limiting:

$$m\mathrm{PbSiO_3} = 20\ \mathrm{g\ Na_2SiO_3} \times \frac{1\ \mathrm{mol\ Na_2SiO_3}}{122.07\ \mathrm{g\ Na_2SiO_3}} \times \frac{1\ \mathrm{mol\ PbSiO_3}}{1\ \mathrm{mol\ Na_2SiO_3}} \times \frac{283.30\ \mathrm{g\ PbSiO_3}}{1\ \mathrm{mol\ PbSiO_3}}$$
$$= 46\ \mathrm{g}$$

Since the $Pb(NO_3)_2$ produces the least amount of product, it is the limiting reactant and the mass of precipitate to be collected will be 6.1 g.

6. (a) $Zn(s) + CuCl_2(aq) \rightarrow Cu(s) + ZnCl_2(aq)$

(b) To analyze the reaction, students should record the initial mass of zinc, final mass of zinc, initial colour of the solution, and final colour of the solution.

(c) The presence of the blue colour indicates $Cu^{2+}(aq)$ ions are left over at the end of the reaction, making $CuCl_2(aq)$ the reactant in excess.

(d) $Zn(s) + CuCl_2(aq) \rightarrow Cu(s) + ZnCl_2(aq)$

$m = ?$ g $\quad m = 3.12$ g

$M = 65.39$ g/mol $\quad M = 134.45$ g/mol

$$m\mathrm{Zn} = 3.12\ \mathrm{g\ CuCl_2} \times \frac{1\ \mathrm{mol\ CuCl_2}}{134.45\ \mathrm{g\ CuCl_2}} \times \frac{1\ \mathrm{mol\ Zn}}{1\ \mathrm{mol\ CuCl_2}} \times \frac{165.39\ \mathrm{g\ Zn}}{1\ \mathrm{mol\ Zn}}$$
$$= 1.52\ \mathrm{g}$$

The stoichiometric amount of Zn(s) required to react with the $CuCl_2(aq)$ was 1.52 g. Since some $CuCl_2(aq)$

remained at the end of the reaction, the mass of zinc powder added must have been less than 1.52 g.

7. (a) Yes, all of the sulfuric acid was neutralized.

(b) 0.346 g of sodium hydrogen carbonate remained.

(c) 87 mL of carbon dioxide was produced.

(d) If sodium hydroxide was used to neutralize sulfuric acid, any excess sodium hydroxide would make the spill basic. When sodium hydrogen carbonate is used, the by-products are a neutral salt (sodium sulfate), carbon dioxide, and water. No acid or base remains.

8. Wear gloves, goggles, and an apron. Add a minimum of 266 mL of a 1.00 mol/L solution of sodium chloride to the silver nitrate. (For the sake of safety, it would be wise to use 300 mL of sodium chloride.) The silver ions will precipitate out in the form of silver chloride. Filter the solution using a funnel lined with filter paper situated in an Erlenmeyer flask. Dispose of the filter paper with the precipitate in a solid waste container or dry it and place the silver chloride in a labelled container. A total of about 29 g of silver in the form of silver chloride will be recovered from the solution.

8.2 Predicted and Experimental Yield

Student Textbook pages 305-311

Section Outcomes

In this section, students will:

- calculate the quantities of reactants and products involved in chemical reactions using gravimetric stoichiometric ratios from chemical equations
- interpret stoichiometric ratios from chemical equations
- perform stoichiometric calculations to determine predicted yields
- use appropriate SI notation, fundamental and derived units, and significant digit rules when performing stoichiometric calculations
- calculate predicted yield and determine experimental yield
- explain the discrepancy between predicted and experimental yields, and calculate percentage yield

Key Terms

predicted yield
experimental yield
mechanical losses
percentage yield

Chemistry Background

- Predicted (theoretical) yield is the amount of product that would be produced assuming the limiting reactant was completely consumed in the reaction. Chemical reactions are rarely simple, however. Reversibility of reactions, competing reactions, and experimental error all contribute to the reduced recovery of a product. Chemists will alter reaction conditions and measure the amount of product obtained. Calculation of percentage yield allows scientists to easily identify those conditions that produce the maximum yield.
- Quantitative analysis allows chemists to predict the amount of product that will be produced in a reaction, given a specific amount of reactant, and to assess the performance of a particular chemical process. Qualitative analysis allows for only the identification of ions in aqueous solutions. In this type of analysis, the presence or absence of a particular ion is determined and is usually used to screen samples for further quantitative student. For example, samples of water could be screened for presence of lead(II) ions. Qualitative analysis is dependant on the concentration of ions in the solution; when dealing with very dilute samples, concentration of the solution through evaporation might be performed prior to screening.

Teaching Strategies

- Stress the fact that the calculations used in stoichiometry provide an idealized yield that can only be obtained if the reaction is carried out to completion under the proper conditions. Have students recall their laboratory experiences and compile a list of reasons why predicted yields are not always met. Factors that can be included are: errors in measurement, spills and lab mishaps, incomplete reactions, and other competing rections.
- Continue to reinforce the problem-solving techniques that have been developed in Chapter 7 and Section 8.1.
- A quiz has been prepared for this section. You will find it with the Chapter 8 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  Number (Type) Title
  8.2.1 (AST) Percentage Yield Problems
  8.2.1A (ANS) Percentage Yield Problems Answer Key

SUPPORTING DIVERSE STUDENT NEEDS

If students are having difficulty grasping the percentage yield calculation, approach the problem by using the calculation of classroom marks as an example. If the maximum mark on a test is 50, and a student achieves a 38, what is the student's percentage yield? Once they understand they need to calculate percentages, go back to a stoichiometric problem and have them apply the same process.

Answers to Questions for Comprehension

Student Textbook page 307

Q2. (a) The following five factors can limit or reduce the yield of a chemical reaction: a competing reaction, collection and transfer methods, reactant purity, a reaction that does not proceed to completion, and a slow reaction.

(b) The predicted yield is higher than the experimental yield for a reaction, because predicted yield is the maximum quantity of product expected from a reaction and is rarely met.

Q3. 64%

Answers to Practice Problems 13-19

Student Textbook pages 308–309

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

13. **(a)** 11.4 g Cu(s)
(b) 79% yield

14. 60% yield

15. Trial 1: 95.5%, Trial 2: 94.3%, and Trial 3: 97.2%
Average is 95.7%.

16. 95.2% yield

17. 26.7% yield

18. **(a)** 2.88 g
(b) 97.3% yield

19. **(a)** 15.0 g
(b) 10.5 g
(c) 12.8 g

Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction

Student Textbook pages 309–310

Purpose

The purpose of this investigation is to calculate the percentage yield for a reaction between steel wool and copper(II) chloride. Students will also examine potential sources of error and ways to improve the yield for this reaction.

Outcomes

- 20–D1.5k
- 20–D1.1s
- 20–D2.3k
- 20–D2.4k
- IP–NS3
- ICT C6–4.1
- ICT C6–4.3
- AI–NS3
- AI–NS4
- PR–NS2, 3, 4, 5

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
2 to 3 days before	■ Test all reagents to ensure the reaction goes to completion as expected and to determine the approximate length of time that the reaction will need.
1 day before	■ Set up student stations. ■ Collect apparatus. ■ Provide each student with **BLM 8.2.2 (HAND) Investigation 8.B: Determining the Percentage of a Chemical Reaction** and have students complete the prediction.

Materials
■ 50.0 mL beaker ■ 250 mL beaker ■ 250 mL Erlenmeyer flask ■ plastic funnel ■ retort stand ■ wash bottle ■ drying oven (if available) ■ stirring rod ■ ring clamp or funnel rack ■ filter paper ■ electronic balance ■ large watch glass ■ waste container ■ $CuCl_2{\bullet}2H_2O(s)$ ■ 1 mol/L HCl(aq) ■ rust-free, degreased steel wool ■ de-ionized water

Time Required

60 minutes

Helpful Tips

- Use dry, fine steel wool. This can be obtained at a local hardware store or building centre.
- The filtered copper should be collected and disposed of appropriately, or used for other laboratory investigations.
- Inform students that they are basing their calculations on the assumption that the steel wool is 100% iron.
- Have students print their names with pencil on the filter paper before taking the initial weight so that they can identify their filter paper after it has dried.
- Use a pipette to flow the acid down around the perimeter edge of the filter paper when performing Step 9.

- Use **BLM 8.2.2 (HAND) Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction** and **BLM 8.2.2A (ANS) Investigation 8.B: Determining the Percentage Yield of a Chemical Reaction Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Safety Precautions

Ensure students read and understand "Safety in Your Chemistry Lab and Classroom" in the student textbook (pages xii-xv). Hydrochloric acid is corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled. Dispose of all materials in a proper waste container.

Answers to Analysis Questions

1. $Fe(s) + CuCl_2(aq) \rightarrow Cu(s) + FeCl_2(aq)$

$m = 1.00$ g $\quad m = ?$ g

$M = 55.85$ g/mol $\quad M = 134.45$ g/mol

$$m\text{CuCl}_2 = 1.00\ \cancel{\text{g Fe}} \times \frac{1\ \cancel{\text{mol Fe}}}{55.85\ \cancel{\text{g Fe}}} \times \frac{1\ \cancel{\text{mol CuCl}_2}}{1\ \cancel{\text{mol Fe}}} \times \frac{134.45\ \text{g CuCl}_2}{1\ \cancel{\text{mol CuCl}_2}}$$

$$= 2.41\ \text{g}$$

Since 1.00 g of Fe(s) required only 2.41 g of $CuCl_2(aq)$ to completely react, the addition of 5.00 g of this reactant ensures it is the reactant in excess.

2. Sources of error can include product loss during decanting, an incomplete reaction between the iron and copper(II) chloride, the product not being completely dry, or impure iron in the steel wool.

3. Percentage yield could be improved by altering the type of steel wool used, increasing the concentration of the copper(II) chloride, using a more careful laboratory technique, or allowing for a longer drying period.

Answer to Conclusion Question

4. Use the formula

$$\text{Percentage Yield} = \frac{\text{Experimental Yield}}{\text{Predicted Yield}} \times 100\%$$

Students' will solve using the mass of copper obtained from the experiment and their prediction.

Answer to Extension Question

5. **(a)** The precision of a result is related to the sensitivity of the equipment used to make the measurements.

(b) The precision of the result could be improved by using more sensitive measuring instruments.

(c) The accuracy of the result may have been affected by poor experimental technique, such as a loss of product during decanting or the product not being completely dry before measuring. An incomplete reaction or impure reactants also may have affected the accuracy of the result.

(d) Students should list factors such as improved experimental technique and higher quality steel wool.

Assessment Options

- Collect and assess students' predictions.
- Collect and assess students' responses to the Analysis and Conclusion questions.
- Use Assessment Checklist 3 Performance Task Self-Assessment to assess student participation.
- Use parts of Assessment Checklist 5 Learning Skills and Assessment Checklist 6 Using Math in Science.

Section 8.2 Review Answers

Student Textbook page 311

1. The units used when calculating a percentage yield of a product would have no effect on the calculation, as they will cancel in the equation.

2. If the limiting reactant is impure, the percentage yield of the reaction would decrease, because the amount of limiting reagent would be less than what was used in the prediction.

3. (a) $C_7H_6O_4(s) + CH_3OH(\ell) \rightarrow C_8H_8O_3(\ell) + H2O(\ell)$

$m = 3.50$ g $\quad m = ?$

$M = 138.13 \quad M = 152.16$

$$m(C_8H_8O_3) = 3.50\ \cancel{\text{g } C_7H_6O_3} \times \frac{1\ \cancel{\text{mol } C_7H_6O_3}}{138.13\ \cancel{\text{g } C_7H_6O_3}} \times \frac{1\ \cancel{\text{mol } C_8H_8O_3}}{1\ \cancel{\text{mol } C_7H_6O_3}} \times \frac{152.16\ \text{g } C_8H_8O_3}{1\ \cancel{\text{mol } C_8H_8O_3}}$$

$$= 3.86\ \text{g}$$

(b) $C_7H_6O_4(s) + CH_3OH(\ell) \rightarrow C_8H_8O_3(\ell) + H_2O(\ell)$

$m = 3.50$ g - 2.84 g

$m = 0.66$ g $\quad m = ?$

$M = 138.13 \quad M = 152.16$

$$m(C_8H_8O_3) = 0.66\ \cancel{\text{g } C_7H_6O_3} \times \frac{1\ \cancel{\text{mol } C_7H_6O_3}}{138.13\ \cancel{\text{g } C_7H_6O_3}} \times \frac{1\ \cancel{\text{mol } C_8H_8O_3}}{1\ \cancel{\text{mol } C_7H_6O_3}} \times \frac{152.16\ \text{g } C_8H_8O_3}{1\ \cancel{\text{mol } C_8H_8O_3}}$$

$$= 0.727\ \text{g}$$

(c) $$\text{Percentage Yield} = \frac{\text{Experimental Yield}}{\text{Predicted Yield}} \times 100\%$$

$$= \frac{0.7270\ \text{g}}{3.8555\ \text{g}} \times 100\ \%$$

$$= 18.886\%$$

$$\cong 18.9\%$$

4. (a) $2NaCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2NaNO_3(aq)$

$m = 0.58$ g $\quad m = 3.50$ g $\quad m = ?$ g

$M = 58.44$ g/mol $M = 331.23$ g/mol $M = 278.11$ g/mol

If NaCl is limiting:

$$m\text{PbCl}_2 = 0.58 \text{ g NaCl} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \times \frac{1 \text{ mol PbCl}_2}{2 \text{ mol NaCl}} \times \frac{278.11 \text{ g PbCl}_2}{1 \text{ mol PbCl}_2}$$

$= 1.4$ g

If $Pb(NO_3)_2$ is limiting:

$$m\text{PbCl}_2 = 3.50 \text{ g Pb(NO}_3)_2 \times \frac{1 \text{ mol Pb(NO}_3)_2}{331.23 \text{ g Pb(NO}_3)_2} \times \frac{1 \text{ mol PbCl}_2}{1 \text{ mol Pb(NO}_3)_2} \times \frac{278.11 \text{ g PbCl}_2}{1 \text{ mol PbCl}_2}$$

$= 2.94$ g

Since the NaCl(aq) produces the least amount of product, it is the limiting reactant and the mass of precipitate to be collected will be 1.4 g.

(b) $$\text{Percentage Yield} = \frac{\text{Experimental Yield}}{\text{Predicted Yield}} \times 100 = \frac{1.22 \text{ g}}{1.38 \text{ g}} \times 100 = 88\%$$

The percentage yield is 87%.

5. (a) $Cr_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Cr(\ell)$

$m = 100$ g $\quad m = 54$ g $\quad m = ?$g

$M = 152.00$ g/mol $M = 26.98$ g/mol $M = 52.00$ g/mol

If Cr_2O_3 is limiting:

$$m\text{Cr} = 100 \text{ g Cr}_2\text{O}_3 \times \frac{1 \text{ mol Cr}_2\text{O}_3}{152.00 \text{ g Cr}_2\text{O}_3} \times \frac{2 \text{ mol Cr}}{1 \text{ mol Cr}_2\text{O}_3} \times \frac{52.00 \text{ g Cr}}{1 \text{ mol Cr}}$$

$= 68$ g

If Al is limiting:

$$m\text{Cr} = 54 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \times \frac{1 \text{ mol Cr}}{1 \text{ mol Al}} \times \frac{52.00 \text{ g Cr}}{1 \text{ mol Cr}}$$

$= 104$ g

Since the $Cr_2O_3(s)$ produces the least amount of product, it is the limiting reactant and the mass of precipitate to be collected will be 68 g.

(b) $$\text{Percentage Yield} = \frac{\text{Experimental Yield}}{\text{Predicted Yield}} \times 100 = \frac{60 \text{ g}}{68.4 \text{ g}} \times 100 = 88\%$$

The percentage yield is 88%.

6. The design should include dissolving a known mass of silver nitrate in water and reacting it with excess copper metal. The reaction should be allowed to go to completion, and the silver metal should be recovered by filtration. The predicted yield of product can be calculated stoichiometrically from the mass of the silver nitrate. The percentage yield can be calculated using the mass of silver metal collected in the experiment and the predicted yield.

7. Using cool solvent removes traces of reactants or other products from the precipitate during rinsing. Some of the precipitate will also dissolve in the solvent, but this is limited.

8. It is important for chemists to know the purity of their reactants because impurities can result in reduced yields.

8.3 Acid-Base Titration

Student Textbook pages 312-322

Section Outcomes

In this section, students will:

- describe the function and choice of indicators in titrations
- draw pH titration curve graphs using data from titration experiments involving strong monoprotic acids and strong monoprotic bases
- interpret pH titration curve graphs using data from titration experiments involving strong monoprotic acids and strong monoprotic bases
- identify equivalence points on strong monoprotic acid–strong monoprotic base pH titration curves
- differentiate between the indicator endpoint and the equivalence point
- calculate the quantities of reactants and products involved in neutralization reactions

Key Terms

titration
titrant
equivalence point
endpoint
standardizing
burette
pH titration curve

Chemistry Background

- Titration is a technique where a solution of a known concentration is used to determine the concentration of an unknown solution. The titrant (usually the known solution) is added from a burette to a known quantity of the analyte (usually the unknown solution) until the reaction is complete. When the titrant has reacted with the anlayte completely, the equivalence point or the stoichiometric endpoint has been reached. An indicator is often used to signal the end of the reaction. Terms for varieties of titration can reflect the type of reaction between the titrant and analyte: acid-base, complexometric, chelatometric, oxidation-reduction, and precipitation titrations. Additionally, the terms can reflect the nature of the titrant, such as acidometric, alkalimetric, and iodometric titrations, as well as coulometric titrations, in which the titrant is generated electrolytically rather than being added as a standard solution. Titration is a standard technique that is used extensively in quantitative analysis and will be used again in *Chemistry 30*.

- Solutions must be standardized before they can be used to measure the concentration of the unknown. Standard substances are chosen because they are relatively reactive (e.g., hydrochloric acid is a strong acid, sodium hydroxide is a strong base, potassium permanganate is a strong oxidizing agent) and relatively cheap to purchase. Unfortunately, these substances are not primary standards, and must be standardized prior to use.
- Indicators are weak acids or weak bases. The undissociated form of the substance is a different colour than the dissociated form. Indicators change colour over a range of hydrogen ion concentrations and this colour change interval is expressed as a pH range. Many fruits, vegetables, and flowers contain natural indicators.
- Titrations are often recorded as titration curves or pH curves. The manipulated variable is the volume of the titrant, while the responding variable is the pH of the resulting solution. The equivalence point is a significant point on the graph and can be calculated (beyond the scope of high school chemistry) or estimated through inspection. In this section, only strong monoprotic acid-strong monobasic base pH curves will be examined, however, analysis of weak acid-strong base and strong acid-weak base pH curves will be included in *Chemistry 30* (Chapter 15).

Helpful Resources

Journal Articles

- Arasasingham, R.D., Taagepera, M., Potter, F., and Lonjers, S. "Using Knowledge Space Theory to Assess Student Understanding of Stoichiometry," *Journal of Chemical Education*, Vol. 81, No. 10, October 2004, p.1517.
- Ault, A. "How to Say How Much: Amounts and Stoichiometry," *Journal of Chemical Education*, Vol. 78, No. 10, October 2001, p. 1345.
- Cook, E. and Cook, R.L. "Cross-Proportions: A Conceptual Method for Developing Quantitative Problem-Solving Skills," *Journal of Chemical Education*, Vol. 82, No. 8, August 2005, p. 1187.
- Gabel, D. "Improving Teaching and Learning through Chemistry Education Research: A Look to the Future," *Journal of Chemical Education,* Vol. 76, No. 4, April 1999, p. 548.
- Krieger, C.R. "Stoogiometry: A Cognitive Approach to Teaching Stoichiometry," *Journal of Chemical Education*, Vol. 74, No. 3, March 1997, p. 306.
- Lin, H. and Cheng, H. "The Assessment of Students and Teachers' Understanding of Gas Laws," *Journal of Chemical Education*, Vol. 77, No. 2, February 2000, p. 235.
- Rohrig, B, "Fizzy Drinks: Stoichiometry You Can Taste," *Journal of Chemical Education*, Vol. 77, No. 12, December 2000, p. 1608B.

Teaching Strategies

- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 8 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  Number (Type) Title
  8.3.1 (AST) Acid-Base Titration
  8.3.1A (ANS) Acid-Base Titration Answer Key
  8.3.2 (OH) Titration Step-by-Step
  8.3.3 (AST) Titration Problems
  8.3.3A (ANS) Titration Problems Answer Key
  8.3.5 (OH) pH Titration Curves and Indicators
  8.3.6 (AST) Selecting an Indicator
  8.3.6A (ANS) Selecting an Indicator Answer Key
- Review **BLM 7.2.4 (HAND) Solution Stoichiometry Tutorial**. The process students have previously used to successfully solve stoichiometry problems applies to acid-base neutralization problems as well.
- Challenge students to generate a list of practical applications of titrations outside of the chemistry classroom. Applications may include determining the acidity of carbonated beverages, monitoring industrial processes, and determining the concentrations of household cleaners.
- Emphasize safety at all times during titration experiments. Ensure that students handle concentrated solutions and glass equipment carefully. Demonstrate how to use a pipette and burette. If possible, provide students with pipettes and burettes and have them practice filling and reading the volumes with deionized water.
- Use **BLM 8.3.3 (AST) Titration Problems** to give students additional practice in analyzing titration data. It contains problems in which titration data is provided for a number of experiments. Students will calculate the concentrations of various reactants using the data.
- Produce a titration curve in class by titrating a sample of hydrochloric acid with sodium hydroxide, and by monitoring the pH with a pH meter. The pH can be measured after the addition of 1.00 mL of base (0.1 mL near the equivalence point). Have a student read out the pH measurements as you add the titrant. The class could plot the data points graphically. The students could then compare this curve to the one produced by calculation in the Thought Lab in this section.

SUPPORTING DIVERSE STUDENT NEEDS

- In this section, many new words are introduced. Encourage students who are having difficulty understanding the new terminology to create a 4-point dictionary. On an index card, students write the word on one side and on the opposite side write the definition from the glossary, a definition in their own words, draw a diagram (or structure), and provide examples. These cards can be used as flash cards for studying.
- ESL Students: Use pencil crayons to show the colour of the indicator over the number line. This will help the students associate the colour of the indicator with the name of the colour.
- Students who are colourblind may have difficulty perceiving the colour change of an indicator. Pair these students with others who can see the colour change. Alternatively, consider giving these students the opportunity to work with a pH meter.

Answers to Questions for Comprehension

Student Textbook 314

Q4. The titrant is found in the burette. In this example the titrant is HCl(aq).

Q5. (a) Standardization is using a standard solution (a solution with a precisely known concentration) to determine the concentration of another solution by titration.

(b) Strong acids need to be standardized because over time the acid concentrations changes.

(c) Strong bases need to be standardized as the concentration changes over time, because they tend to absorb carbon dioxide from the air.

Q6. In a titration, an indicator is added which has an endpoint (i.e., changes colour) very close to the equivalence point of the reaction. The purpose of an indicator is to provide a visual cue that equivalence point has been reached.

Q7. (a) 1.5 mol of HCl(aq) are required to neutralize 1.5 mol of KOH(aq) since the mole ratio of HCl(aq) : KOH(aq) is 1:1. The equivalence point occurs when an equal amount (in mol) of HCl(aq) has been added to KOH(aq).

(b) 0.8 mL KOH(aq)

Answers to Practice Problems 20-25

Student Textbook 315

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

20. 1 mol/L

21. 0.210 mol/L

22. 0.19 mol/L

23. 0.26 mol/L KOH(aq)

24. (a) 3×10^1 mL

(b) By performing this calculation before the titration, you know approximately the volume of titrant that will be used. The NaOH(aq) can be added quickly up to a few mL of the endpoint, then proceed to titrate slowly towards the endpoint. Therefore, time is saved in performing the titration.

25. 0.524 mol/L

Investigation 8.C: Standardizing a Hydrochloric Acid Solution

Student Textbook pages 316-317

Purpose

The purpose of this investigation is to standardize a solution of hydrochloric acid using a primary standard of sodium carbonate. Students will gain familiarity with common laboratory glassware, techniques of titration, and will observe the colour change of an indicator.

Outcomes

- 20–D2.4s

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
1 week before	■ Prepare the solutions. (Refer to **BLM 5.4.4 (HAND) Preparing Solutions**)
2 to 3 days before	■ Set up the student stations. ■ Collect the materials.
1 day before	■ Titrate the hydrochloric acid solution and calculate its concentration. ■ Provide each student with **BLM 8.3.4 (HAND) Investigation 8.C – Standardizing a Solution of Hydrochloric Acid Solution** and provide the students with the prediction.

Materials
■ phenolpthtralein ■ deionized water ■ 0.125 mol/L HCl(aq) ■ standard grade sodium carbonate, $Na_2CO_3(s)$ ■ 50 mL burette ■ 10 mL volumetric pipette ■ 50 mL beaker ■ 250 mL beaker ■ 125 mL Erlenmeyer flasks (2) ■ 100 mL volumetric flask ■ glass stirring rod ■ funnel ■ meniscus reader ■ pipette bulb ■ retort stand ■ burette clamp ■ scoopula or spatula ■ electronic balance

Time Required

60 minutes

Helpful Tips

- Students often run out of time before they can repeat enough trials for a more reliable average result. If possible, students should practice the technique of pipetting and titrating before attempting a full investigation.
- Quickly run through a demonstration of the technique for students. Some students will forget about procedures discussed in class on a previous day.
- Use an approximate concentration of 0.20 mol/L to 0.25 mol/L for the hydrochloric acid. Having the titration volume between 10 mL to 20 mL gives the students practice titrating without using too much solution or producing too much waste. Because the students are not given an exact amount of sodium carbonate to use for their standard solution, there will be a range of titration volumes. Students could weigh a given amount so that they all have the same concentration for their standard, but as long as the concentration of the standard is known, the standard can be used.
- Use **BLM 8.3.4 (HAND) Investigation 8.C: Standardizing a Hydrochloric Acid Solution** and **BLM 8.3.4A (ANS) Investigation 8.C: Standardizing a Hydrochloric Acid Solution Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Safety Precautions

- Ensure students read and understand "Safety in Your Chemistry Lab and Classroom" in the front matter of the student textbook (pages xii-xv).
- Hydrochloric acid is corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials down the drain.

Answers to Analysis Questions

1. (a) Students should show clearly their calculations for their answer to this question. Understanding the process is more important at this stage of learning than attaining high accuracy. Lab skills will develop with experience.

Sample answer:

$$V_{ave} = \frac{13.60\text{ mL} + 13.65\text{ mL} + 13.70\text{ mL}}{3}$$

$$= 13.65\text{ mL}$$

(b) Performing multiple trials allows students to use average volumes in calculations. This diminishes the effect of random errors.

2. $Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2CO_3(aq)$
OR
$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(\ell) + CO_2(g)$

3. Students' answers should be close to the value of 0.125 mol/L that was prepared. Assuming that the mass of the sodium carbonate used to make the standard solution is 0.90 g, and using the average volume of HCl(aq) of 13.65 mL, a sample calculation is as follows:

$$c\,\text{HCl(aq)} = \frac{0.90\text{ g } Na_2CO_3}{105.99\text{ g/mol}} \times \frac{10.00\text{ mL}}{100.0\text{ mL}} \times \frac{2\text{ mol HCl(aq)}}{1\text{ mol } Na_2CO_3} \times \frac{1000\text{ mL}}{1\text{ L}} \times \frac{1}{13.65\text{ mL}}$$

$$= 0.124\text{ mol/L}$$

4. Any results outside the range of 0.120–0.130 mol/L should be discarded. The rest of the class results should be averaged and used as the concentration for Investigation 8.D.

Answers to Conclusion Questions

5. The class average should be reasonably close to the value of 0.125 mol/L.

6. Students' answers will depend on the data they collect. In general the class average should be relatively close to the actual value of 0.125 mol/L, as the greater the number of values used to calculate the class average, the more accurate the average becomes (one of the reasons scientists carry out multiple trials). One common source of error is failing to discard unreasonable results prior to calculating average volumes. This error should be corrected before students respond to question 7.

7. Possible sources of error include:
- inaccurate judgment of end point
- inaccurate pipetting
- inaccurate reading of burette
- spillage and contamination of solution
- inadequate time to gather data from enough trials to minimize sources of error

Answer to Extension Question

8. Sodium carbonate, also known as washing soda, enhances the effectiveness of surfactants (detergents) by maintaining a basic environment in the washing machine. A basic environment prevents the minerals in hard water from reacting with the surfactants to form a sludgy precipitate.

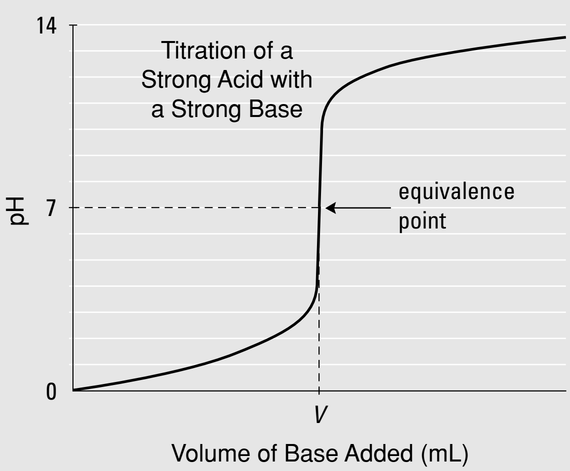
Assessment Options

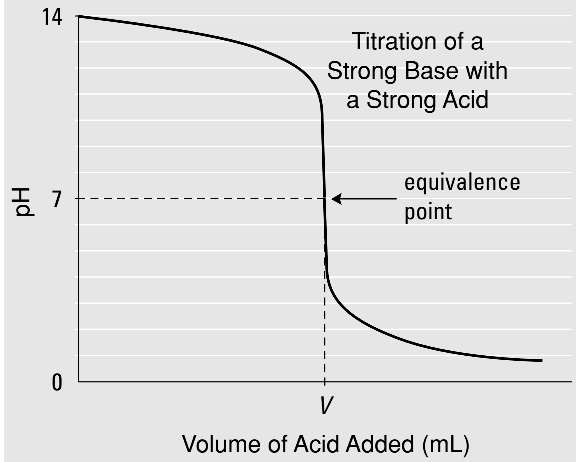
- Collect and assess students' predictions.
- Collect and assess students' responses to the Analysis, Conclusion, and Extension questions.

Answers to Questions for Comprehension

Student Textbook page 319

Q8. A titration curve in which the acid is the titrant would start at a very high pH (the sample is a base). The curve would slope sharply downwards near the equivalence point and then flatten out at a low pH. A titration curve in which the base is the titrant would start at a very low pH (the sample is an acid). The curve would slope sharply upwards near the equivalence point and then flatten out at a high pH.





Q9. The equivalence point of the reaction on an acid-base titration curve for a strong acid and a strong base will always occur at pH 7. H appears at the midpoint of the vertical portion of the titration curve.

Q10. The steep slope indicates that it takes very little titrant to make a drastic change in the pH of the solution at the equivalence point.

Thought Lab 8.2: Plotting a Titration Curve

Student Textbook page 319

Purpose

The purpose of this exercise is to create and interpret a titration curve for an acid-base experiment. Students will plot given points using a spreadsheet program, label the equivalence point and select appropriate indicators for the titration.

Outcomes

- 20–D2.5k
- 20–D2.6k
- 20–D2.7k
- 20–D2.3s

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Book the computer lab.
1 day before	■ Photocopy **BLM 8.3.7 (HAND) Thought Lab 8.2: Plotting a Titration Curve**. If the computer lab is not available, students can plot the graph by hand or do the assignment at home.

Time Required

40 minutes

Helpful Tips

- If possible, obtain a pH meter and perform the titration in class as a demonstration. A student could be recruited to perform the titration while another monitors the pH of the sample at 5.00 mL increments (0.5 mL increments near the equivalence point). Have students compare this pH curve to the one generated by the spreadsheet program obtained in this exercise.
- Ensure that an adequate supply of graph paper is available for the class.
- Use **BLM 8.3.7 (HAND) Thought Lab 8.2: Plotting a Titration Curve** and **BLM 8.3.7A (ANS) Thought Lab 8.2: Plotting a Titration Curve Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

Answers to Analysis Questions

1. Student graphs should be similar to the curve in Figure 8.9 on p. 318 of the student textbook. The best-fit lines should be smooth with a relatively sharp increase near the equivalence point (the corners should be curved and not sharp). Strongly discourage a "connect the dots" approach.

2. The equivalence point should be labelled at pH 7.

3. Students could select:

- methyl orange 3.2–4.4
- bromocresol green 3.8–5.4
- methyl red 4.8–6.0
- chlorophenol red 5.2–6.8
- bromothymol blue 6.0–7.6
- phenol red 6.6–8.0
- phenolphthalein 8.2–10.0

All of these indicators change colour in the steep portion of the curve. Phenolphthalein and phenol red are less appropriate because they change colour before equvalance. Methyl orange acid bromocresol green are less appropriate because they change colour well after equivalence.

4. The curve may be shifted left or right (due to concentration differences) but overall the shape should be similar to Figure 8.8. Students should point out that their curve is a mirror image of the curve in Figure 8.9.

5. The concentration of KOH(aq) is 0.100 mol/L. It will be obvious to some students that the concentration of the acid is the same as the concentration of the base because 50.00 mL of acid was required to neutralize 50.00 mL of base. Still, encourage students to show their work. For example:

$c\ \text{KOH(aq)}$

$$= \frac{0.100\ \text{mol}\ \cancel{\text{HNO}_3\text{(aq)}}}{1\ \text{L}} \times \frac{50.00\ \text{mL}}{1} \times \frac{1\ \text{mol}\ \cancel{\text{KOH(aq)}}}{1\ \text{mol}\ \cancel{\text{HNO}_3\text{(aq)}}} \times \frac{1}{50.00\ \text{mL}\ \cancel{\text{KOH(aq)}}}$$

$$= 0.100\ \text{mol/L}$$

Answer to Extension Question

6. Methyl violet would not be a suitable indicator, as it changes colour much too early in the titration, before the steep portion of the graph.

Assessment Options

- Collect and assess answers to Analysis Questions.
- Use Assessment Checklist 2 Laboratory Report.

Connections (Science and Technology): Sulfur from Sour Gas

Student Textbook page 320

Teaching Strategies

- Hydrogen sulphide is found in gas deposits across Alberta, mostly in the foothills regions where one-third of natural gas wells contain hydrogen sulphide, and also in Saskatchewan and British Columbia. (It's also a natural component of many substances—including intestinal gas produced by humans.)
- Sour gas is toxic at high concentrations and is a hazard to those working on such wells; those who have died have usually been exposed to the gas at high concentration in confined or poorly ventilated spaces (or been involved in well explosions). Members of the general public are at much less risk, but many may be aware of what the industry calls "fugitive emissions" because of the distinctive rotten egg smell. In addition, sour gas processing does create sulfur dioxide emissions. This may be a controversial topic for students, and they may want to discuss local concerns, particularly because there is little research on the effects of intermittent, low-level exposure.
- In 2003-2004 students in The University of Calgary Environmental Science Program, ENSC 502 Project 2003-2004 did a study entitled "Impacts of Airborne Pollution from the Sour Gas Industry on Southern Alberta." Results of their study can be found at www.fp.ucalgary.ca/ENSC/sgimpacts/sgimpacts2.html

Answers to Questions

1. (a) $m\,\text{S} = 100\ \cancel{\text{L}} \times \frac{1\ \cancel{\text{mol}}}{24.8\ \cancel{\text{L}}} \times \frac{1\ \cancel{\text{mol S}}}{1\ \cancel{\text{mol}}\ \text{H}_2\text{S}} \times \frac{32.07\ \text{g}\ \cancel{\text{S}}}{1\ \cancel{\text{mol S}}}$

$= 129\ \text{g S}$

(b) $2S(\ell) + 2H_2O(\ell) + O_2(g) \rightarrow 2H_2SO_4(aq)$

$m = 1.00$ kg $\quad v = ?$ L

$M = 32.07$ g/mol $\quad c = 6.0$ mol/L

$$V_{H_2SO_4} = 1000\ \cancel{g\ S} \times \frac{1\ \cancel{mol\ S}}{32.07\ \cancel{g\ S}} \times \frac{2\ \cancel{mol\ H_2SO_4}}{2\ \cancel{mol\ S}} \times \frac{1\ L}{6.0\ \cancel{mol\ H_2SO_4}} = 5.2\ L$$

2. The natural gas must go through further processing and incineration to extract another percent of $H_2S(g)$ from the gas. It is important to remove $H_2S(g)$ because when $H_2S(g)$ is burned it creates $SO_2(g)$, which leads to the formation of acid rain.

Investigation 8.D: Titrating a Strong Base with a Strong Acid

Student Textbook page 321

Purpose

The purpose of this lab is to determine the concentration of a solution of sodium hydroxide. Students will perform a titration of the unknown solution with the hydrochloric acid they standardized in Investigation 8.C and select an appropriate indicator.

Outcomes

- 20–D2.1s
- 20–D2.2s

Advance Preparation

When to Begin	What to Do
2 to 3 weeks before	■ Ensure all materials and chemicals are available.
1 week before	■ Prepare the solutions. (Refer to **BLM 5.4.4 (HAND) Preparing Solutions**)
3 days before	■ Provide the students with **BLM 8.3.8 (HAND) Investigation 8.D – Titrating a Strong Base with a Strong Acid** in order to design the method.
2 days before	■ Take in student procedures to ensure that each group has a workable design. ■ Set up the student stations. ■ Collect the materials.
1 day before	■ Titrate the sodium hydroxide solution and calculate its concentration. ■ Provide the students with an approximate concentration in order to complete the prediction.

Materials
■ methyl orange, phenolphthalein, bromothymol blue (or other suitable indicators) ■ deionized water ■ 0.125 mol/L HCl(aq) (standarized in Investigation 8.C) ■ 0.150 mol/L NaOH(aq) ■ electronic balance ■ 50.0 mL burette ■ 10.0 mL volumetric pipette ■ 50 mL beaker ■ 250 mL beaker ■ 125 mL Erlenmeyer flasks (2) ■ 100.0 mL volumetric flask ■ glass stirring rod ■ funnel ■ meniscus reader ■ pipette bulb ■ retort stand ■ burette clamp ■ scoopula or spatula

Time Required

60 minutes

Helpful Tips

- A sound procedure should include or demonstrate:
  - between 5 and 10 steps
  - steps that are sufficient to obtain the kind of data needed to answer the problem
  - a good control of variables
  - a step for cleaning the burette and pipette
  - a suitable indicator and knowledge of what to observe (the colour change at the endpoint)
  - modest sample sizes (5 mL, 10 mL, 20 mL)
  - repetition of the titration for accuracy
  - clean-up/disposal considerations

  This list could be given to students to help them prepare their procedure.
- Use **BLM 8.3.8 (HAND) Investigation 8.D: Titrating a Strong Base with a Strong Acid** and **BLM 8.3.8A (ANS) Investigation 8.D: Titrating a Strong Base with a Strong Acid Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

- Hydrochloric acid and sodium hydroxide are corrosive. Phenolphthalein solution is toxic and flammable. Make sure students inform you immediately if these substances are spilled.
- The following is an example procedure that uses bromothymol blue or phenolphthalein:
  – Using a pipette, place 10.0 mL of NaOH(aq) into an Erlenmeyer flask and add 3 to 5 drops of bromothymol blue or phenolphthalein indicator.
  – Set up the burette to contain HCl(aq).
  – Place 70 to 80 mL of HCl(aq) into a clean dry beaker.
  – Pour HCl(aq) into the burette using a funnel.
  – Record the initial burette reading to 0.1 mL.
  – Titrate the NaOH(aq) with HCl(aq) until a single drop produces a permanent change from blue to bluish-green if using bromothymol blue or from pink to clear if using phenolphthalein.
  – Record the final burette reading to 0.1 mL.
  – Repeat until three consistent volumes of hydrochloric acid are obtained.

Safety Precautions

- Ensure students read and understand "Safety in Your Chemistry Lab and Classroom" in the front matter of the Student Textbook (pages xii-xv).
- Hydrochloric acid and sodium hydroxide are corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure your eye wash station has been tested recently and any eye wash bottles are filled.

Answers to Analysis Questions

1. Students should clearly show their calculations for their answer to this question. The average volume of titrant used should be approximately 1.2 times greater than the volume of sample titrated.

2. $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

3. Students should clearly show their calculations for their answer to this question. The value should be close to 0.150 mol/L.

Answers to Conclusion Questions

4. Students' answers will depend on their experimental design. The value obtained should be close to 0.150 mol/L.

5. Possible sources of error include:
- inaccurate judgment of endpoint
- inaccurate pipetting
- inaccurate reading of burette
- spillage and contamination of solution
- inadequate time to gather data from enough trials to minimize sources of error

6. Students' answers will depend on the data they collect and the errors they report. Suggested improvements should be consistent with their reported errors. For example, if students report they had an inaccurate endpoint, they may suggest preparing a standard to which they will compare the colour. A general "be more careful" is not adequate.

Answers to Extension Questions

7. Since the drain cleaner is concentrated, it must be diluted before it can be analyzed. If not, it would require a large volume of acid to react. This would make the titration lengthy and tedious.

8. Suggestions for bases could include: ammonia, drain cleaner, detergents, antacid tablets or liquids, or soaps. Suggestions for acids could include: lemon juice, vinegar, vitamin C tablets, or rust and lime cleaners.

Assessment Options

- Use Assessment Checklist 3 for self-evaluation by each student. (Consider providing this rubric to each student before they design their experiment.)
- A sample experimental plan is:
  1. Set up the titration apparatus as demonstrated by the teacher. Rinse the burette with de-ionized water, then with the standardized hydrochloric acid.
  2. Fill the burette with the standardized hydrochloric acid.
  3. Measure and record the initial burette reading.
  4. Use a clean pipette to obtain 10.0 mL of the aqueous sodium hydroxide solution and deliver it to a clean 125 mL Erlenmeyer flask.
  5. Add 2 to 3 drops of methyl orange (or another suitable indicator) to the sample in the flask and note the initial indicator colour.
  6. Titrate the aqueous sodium hydroxide sample with the hydrochloric acid until a distinct endpoint is observed (the colour change should be described at this point, in this case the solution changes from yellow to orange or red). Record the final burette reading.
  7. Repeat steps 3 to 6 until you have performed three consecutive titrations with differences within a $\pm$ 0.2 mL range.
  8. Clean up your laboratory station and dispose of all wastes as instructed by the teacher.
- Check that the following points are included in the experimental plan:
  - cleaning of apparatus
  - measurements of volume
  - recording of colour
  - stating number of drops of indicator
  - clean up instructions
  - recording instructions

- Use Assessment Checklist 2 to assess each student's laboratory report.
- Use Assessment Checklist 6 to assess Analysis calculations.

Section 8.3 Review Answers

Student Textbook page 322

1. (a) $KOH(aq) + HClO_3(aq) \rightarrow KClO_3(aq) + H_2O(\ell)$

(b) $HI(aq) + NaOH(aq) \rightarrow NaI(aq) + H_2O(\ell)$

(c) $HBr(aq) + RbOH(aq) \rightarrow RbBr(aq) + H_2O(\ell)$

(d) $NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(\ell)$

(e) $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(\ell) + CO_2(g)$

2. (a) The endpoint is the pH at which an indicator changes colour. The equivalence point is the pH at which stoichiometrically equivalent amounts of reactants combine. A suitable endpoint occurs with the addition of one drop of extra titrant beyond the equivalence point.

(b) The endpoint pH range and the equivalence point pH need not be identical, but they ought to be very close. The pH changes dramatically at equivalence, so a close endpoint pH range will suffice.

3. $H_2SO_4(aq) + NaOH(aq) \rightarrow 2NaCl(aq) + 2H2O(\ell)$

$V = 23.00\text{ mL} - 1.05\text{ mL}$ $\quad V = 10.00\text{ mL}$

$= 21.95\text{ mL}$

$c = 0.118\ \frac{\text{mol}}{\text{L}}$ $\quad c = ?\text{ mol/L}$

$$c\,NaOH = 21.95\text{ mL} \times \frac{0.118\text{ mol } H_2SO_4}{1\text{ L}} \times \frac{2\text{ mol NaOH}}{1\text{ mol } H_2SO_4} \times \frac{1}{10.00\text{ mL}}$$

$= 0.518\text{ mol/L}$

4. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

Discard trial #1.

$$V_{ave(NaOH)} = \frac{22.00\text{ mL} + 22.02\text{ mL} + 22.04\text{ mL}}{3}$$

$= 22.02\text{ mL}$

$V = 10.00\text{ mL}$ $\quad V = 22.02\text{ mL}$

$c = ?$ $\quad c = 0.06649\ \frac{\text{mol}}{\text{L}}$

$$c\,HCl = 22.02\text{ mL} \times \frac{0.06649\text{ mol NaOH}}{1\text{ L}} \times \frac{1\text{ mol HCl}}{1\text{ mol NaOH}} \times \frac{1}{10.00\text{ mL}}$$

$= 0.1464\text{ mol/L}$

5. $3KOH(aq) + H_3C_6H_5O_7(aq) \rightarrow K_3C_6H_5O_7(aq) + 3H_2O(\ell)$

$V = 18.2\text{ mL}$ $\quad V = 10.00\text{ mL}$

$c = 0.100\text{ mol/L}$ $\quad c = ?\text{ mol/L}$

$$c\,H_3C_6H_5O_7 = 18.2\text{ mL} \times \frac{0.100\text{ mol KOH}}{1\text{ L}} \times \frac{1\text{ mol } H_3C_6H_5O_7}{3\text{ mol KOH}} \times \frac{1}{10.00\text{ mL}}$$

$= 0.0607\text{ mol/L}$

6. (a) This mistake would dilute the acid, requiring a lower volume of titrant and yielding a lower calculated [HCl(aq)].

(b) A wet Erlenmeyer flask would have no effect. It is the amount of reactant in the pipetted sample that matters, not its concentration in the Erlenmeyer flask.

(c) This mistake would create the impression that a greater volume of titrant was necessary, and yield a higher calculated [HCl(aq)]—the tip of most analytical burettes holds about 1 mL of titrant. This mistake could have contributed to the discrepancy in the problem.

(d) This would create the false impression that lower volume of titrant was necessary and yield a lower calculated [HCl(aq)]. That said, the effect would be so small as to be within the limits of human error—one drop of titrant is about 0.05 mL.

Chapter 8 Review Answers

Student Textbook pages 324-325

Answers to Understanding Concepts Questions

1. A limiting reactant is a reactant that is completely consumed in a chemical reaction.
2. When reactants are present in stoichiometric amounts they are present in amounts that correspond exactly to the mole ratios.
3. A company may choose to use a large excess of one reactant instead of using stoichiometric amounts of all reactants to ensure that the more expensive or scarcer reactant is consumed and not wasted.
4. The yield of a chemical reaction can be lower than the predicted amount if there is a competing reaction, if the reaction is slow, or the reactant are impure.
5. A certain percentage of the desired compound is lost in every step of an industrial process. A greater percentage is lost as the number of steps increases. For example, it would seem that a recovery of 90% would be good. However, if you recover 90% of the products in every step of a four step process, the final percentage recovered would be:

   $0.90 \times 0.90 \times 0.90 \times 0.90 = 0.66$ or 66%.
6. The equivalence point is reached first in an acid-base titration. The indicator will just begin to change colour at the equivalence point. The end-point comes when the indicator has completely changed colour or after the pH has completed its change. The equivalence point is at the

mid point of the change in pH when there is exactly the same amount of acid and base present in the solution.

(b) The Erlenmeyer flask may be wet without affecting the data as no volumes are measured in the Erlenmeyer flask and water has no effect on the neutralization reaction taking place.

7. The solution placed in the burette is called the titrant.

Answers to Applying Concepts Questions

8. The student's calculated acid concentration would be higher than the acid's true concentration. The indicator changes outside the steep rise of the curve and well past the equivalence point. As a result, the student would add more base than is actually necessary to neutralize the acid.

9. (a) If the burette is wet, this will dilute the titrant and it will appear as if a greater amount of titrant is required to react with the sample. This will increase the calculated concentration of the sample. If the pipette is wet, this will dilute the sample and a smaller amount of titrant will be required to react with the sample. This will decrease the calculated concentration of the sample.

(b) A wet Erlenmeyer flask would have no effect. It is the amount of reactant in the pipetted sample that matters, not its concentration in the Erlenmeyer flask.

10. (a) i. very low (around pH 1 to 2)

ii. very high (around pH 12 to 13)

(b) i. the same volume as the sample

ii. the same volume as the sample

(c) i. pH 7

ii. pH 7

(d) i. phenolphthalein (or bromothymol blue)

ii. methyl orange (or bromothymol blue)

(e) i. very high (around pH 11 to 12)

ii. very low (around pH 2 to 3)

Answers to Solving Problems Questions

11. (a) $Zn(s) + CuCl_2(aq) \rightarrow ZnCl_2(aq) + Cu(s)$

(b) The chemist might look for a precipitate or a colour change.

(c) The limiting reactant was zinc.

(d) About 1.5 g of zinc was added.

12. (a) The limiting reactant was carbon.

(b) 23 g of calcium silicate

13. (a) The limiting reactant was oxygen.

(b) 2.58 g of carbon dioxide were produced.

(c) 284 g of excess pentane remained

14. (a) 32.7 g of zinc were produced

(b) ZnO was the limiting reactant.

(c) 14.0 g of carbon monoxide remained after the reaction was complete.

15. (a) The maximum amount of oxygen that could be produced was 0.220 mol or 7.04 g.

(b) The percentage yield was 93%.

(c) 34.4g of nitrogen was formed.

16. (a) The maximum amount of carbon dioxide that could be produced was 52.5 mol or 2.31×10^3 g.

(b) 1.76×10^3 g of carbon dioxide would be predicted.

17. (a) $NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq)$

(b) The predicted yield of ammonium nitrate would be 80 t.

(c) The percentage yield was 79%.

18. The concentration of the sodium hydroxide solution was 0.020 mol/L

19. The concentration of the nitric acid solution was 0.0842 mol/L.

20. $2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$

$V = 18.0$ mL $V = 15.0$ mL

$c = 0.500$ mol/L $c = ?$ L

$$c\,H_2SO_4 = 18.0\ \cancel{mL} \times \frac{0.500\ \cancel{mol\ NaOH}}{1\ L} \times \frac{1\ mol\ H_2SO_4}{2\ \cancel{mol\ NaOH}} \times \frac{1}{15.0\ \cancel{mL}}$$

$$= 0.300\ mol/L$$

21. $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

$V = 25.00$ mL $V = 30.21$ mL

$c = ?$ mol/L $c = 1.986$ mol/L

(a) $$c\,NaOH = 30.21\ \cancel{mL} \times \frac{1.986\ \cancel{mol\ HCl}}{1\ L} \times \frac{1\ mol\ NaOH}{1\ \cancel{mol\ HCl}} \times \frac{1}{25.00\ \cancel{mL}}$$

$$= 2.40\ mol/L$$

(b) A molar concentration of 2.40 mol/L corresponds to a concentration of 9.60 g/100 mL. This solution is below the acceptable level and therefore cannot be reused.

(c) Workers should wear safety glasses, rubber aprons, and gloves as this solution is very corrosive.

22. (a) $3Ag^+(aq) + AsO_4^{3-}(aq) \rightarrow As_3AsO_4(s)$

(b) $V = 25.0$ mL $m = ?$ g

$c = 0.102$ mol/L $M = 138.92$ g/mol

$$m\,AsO_4^{3-} = 25.0\ mL \times \frac{0.102\ mol\ Ag^+}{1\ L} \times \frac{1\ mol\ AsO_4^{3-}}{3\ mol\ Ag^+} \times \frac{138.92\ g\ AsO_4^{3-}}{1\ mol\ AsO_4^{3-}}$$

$$= 118\ mg$$

(c) $$m\,As = 118\ mg\ AsO_4^{3-} \times \frac{74.92\ g\ As}{138.92\ g\ AsO_4^{3-}}$$

$$= 63.6\ mg\ As$$

$$\%\ As = \frac{0.0636\ g}{1.22\ g} \times 100 = 5.21\%$$

23. $$CH_3COOH(aq) + NaOH(aq) \rightarrow NaCH_3COO(aq) + H_2O(\ell)$$

$V = 2.50$ mL $V = 34.9$ mL

$c = ?$ L $c = 0.0960$ mol/L

$$c\,CH_3COOH = 34.9\ mL \times \frac{0.0960\ mol\ NaOH}{1\ L} \times \frac{1\ mol\ CH_3COOH}{1\ mol\ NaOH} \times \frac{1}{2.50\ mL}$$

$$= 1.34\ mol/L$$

$$m\,CH_3COOH = 2.00\ L \times \frac{1.34\ mol\ CH_3COOH}{1\ L} \times \frac{60.06\ g\ CH_3COOH}{1\ mol\ CH_3COOH}$$

$$= 161\ g$$

Answers to Making Connections Questions

24. (a) The phosphate-contaminated water could be treated with a solution containing calcium or magnesium ions. (These ions were chosen as they are normally present in hard water.) The precipitate could be removed by settling and then disposed of appropriately.

(b) Suggested methods may include using detergents or cleaners that do not contain phosphate, replacing phosphate in cleaners with other ions, or treating the water with a biological agent to remove the phosphate (such as a bacterium).

Career Focus: Ask a Pharmaceutical Chemist

Student Textbook pages 326-327

Purpose

Students are exposed to new applications of stoichiometry, specifically for drug research. An introductory overview of pharmaceutical development from the point of view of a research chemist is presented.

Teaching Strategies

Ask students to think about the areas of research in which container molecules are being applied as mentioned in the text. Have students think of other areas beyond the pharmaceutical industry where this chemistry can be applied. If time allows, have students research and create 3-D models of their own container molecules with an accompanying explanation.

Go Further... Answers

1. Targeted drugs are more specific, less toxic, and more effective with enhanced solubility and stability. These drugs can target passively or actively in the system. The better targeted the drug is, the less waste there will be and a better pharmacological response will result.

2. The container molecules (guest) can entrap the material of interest (host) to separate the host from contaminants, as in the case of water purification. The container molecule can then be removed from the host by one or more means of chemical separation. Answers may vary, but should reflect that container molecules can completely recognize and encapsulate smaller substrates; selectively recognize substrates; stabilize and characterize highly reactive chemical species; and demonstrate stereoisomerism.

Unit 4 Review Answers

Student Textbook pages 328-331

Answers to Understanding Concepts Questions

1. (a) The coefficients in a balanced chemical equation represent the number of atoms, molecules, or ions participating in the reaction.

(b) The coefficients also represent the number of moles of a specific atom, molecule, or ion participating in the reaction.

2. The mass of products and the mass of reactants in a balanced equation are equal. Since the same numbers of atoms, molecules, or ions remain the same so must the masses of these substances.

3. (a) $H_2(g) + CuO(s) \rightarrow Cu(s) + H_2O(g)$ single replacement

(b) $16Ag(s) + S_8(s) \rightarrow 8Ag_2S(s)$ formation

(c) $C_4H_8(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)$ combustion

(d) $2MgO(s) \rightarrow 2Mg(s) + O_2(g)$ decomposition

(e) $Al_2(SO_4)_3(aq) + 3K_2CrO_4(aq) \rightarrow 3K_2SO_4(aq) + Al_2(CrO_4)_3(s)$ double replacement

4. (a) $2CH_3OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$ combustion

(b) $P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$ formation

(c) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ decomposition

(d) $3Sr(NO_3)_2(aq) + 2K_3PO_4(aq) \rightarrow Sr_3(PO_4)_2(s) + 6KNO_3(aq)$ double replacement

(e) $2Li_3N(s) \rightarrow 6Li(s) + N_2(g)$ decomposition

(f) $Ca(s) + 2H_2O(\ell) \rightarrow Ca(OH)_2(s) + H_2(g)$ single replacement

5. (a) high solubility

(b) high solubility

(c) high solubility

(d) low solubility

(e) low solubility

6. (a) $2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g)$

(b) $Cd(s) + Pb(NO_3)_2(aq) \rightarrow Pb(s) + Cd(NO_3)_2(aq)$

(c) $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

(d) $Sr(OH)_2(aq) + H_2SO_3(aq) \rightarrow SrSO_3(s) + 2H_2O(\ell)$

(e) $8HgS(s) \rightarrow 8Hg(\ell) + S_8(s)$

7. $Al_2(SO_4)_3(aq) \rightarrow 2Al^{3+}(aq) + 3SO_4^{2-}(aq)$

8. (a) $Pb(NO_3)_2(aq) + 2NaBr(aq) \rightarrow PbBr_2(s) + 2NaNO_3(aq)$

(b) $Pb^{2+}(aq) + 2NO_3^-(aq) + 2Na^+(aq) + 2Br^-(aq) \rightarrow PbBr_2(s) + 2NO_3^-(aq) + 2Na^+(aq)$

(c) The spectator ions are $NO_3^-(aq)$ and $Na^+(aq)$.

(d) $Pb^{2+}(aq) + 2Br^-(aq) \rightarrow PbBr_2(s)$

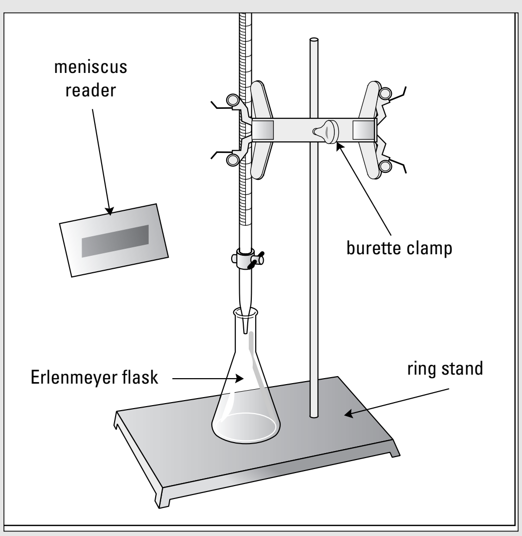
9. $2Ag^+(aq) + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s)$

10. $2HCl(aq) + Ba(OH)_2(aq) \rightarrow BaCl_2(aq) + 2H_2O(\ell)$

Since the number of moles of hydrochloric acid and barium hydroxide are equal, the hydrochloric acid will be the limiting reactant and the barium hydroxide will be in excess. In order to be in stoichiometric amounts, twice as many moles of acid would need to be present to completely react with the base.

11. (a) ring stand, burette clamp, burette, burette funnel, beakers, Erlenmeyer flasks, volumetric pipette, meniscus reader pipette bulb

(b)



12. The equivalence point of a reaction occurs when the reactants are present in stoichiometric amounts. The endpoint occurs when the indicator changes colour. A satisfactory endpoint occurs with the addition of one drop of titrant that drives the pH beyond the equivalence point.

13. A burette should be thoroughly rinsed with de-ionized water, then rinsed with the titrant before filling it with the titrant.

14. A total ionic equation lists all the entities involved in a chemical reaction. A net ionic equation represents only those entities that change during the course of the reaction.

15. A sample equation is as follows.

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

Answers to Applying Concepts Questions

16. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

A total of 200 molecules of hydrogen chloride will be produced. The chlorine gas is in excess and 100 molecules of the gas will remain.

17. $Li_2SO_4(s)$

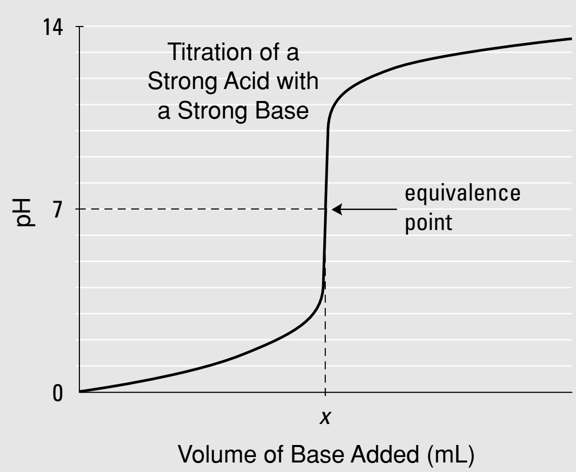
18. Student answers may vary. One such sequence would be $NaCH_3COO(aq)$, $NaCl(aq)$, followed by $Na_2SO_4(aq)$

19. Students' answers will vary. Designs can include titration with hydrochloric acid to determine which antacid neutralizes the most stomach acid or the pH of a sample of acid when the antacid is added. In each case, the dose of the antacid should be controlled. The manipulated variable is the brand of antacid and the responding variable is the volume of acid neutralized/pH of the solution (depending on design).

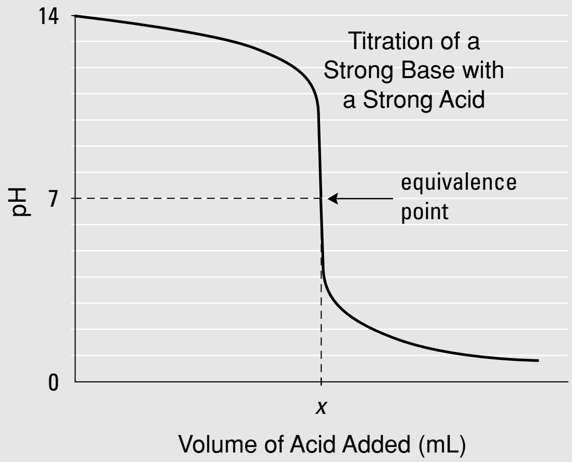
20. $Cu^{2+}(aq) + S^{2-}(aq) \rightarrow CuS(s)$

Copper(II) sulfide is the precipitate.

21. (a) The pH curve begins at a relatively low pH and remains low until a very steep rise near the equivalence point at pH 7. Slightly after the equivalence point, the curve flattens out at a relatively high pH.



(b) The pH curve begins at a relatively high pH and remains high until a very steep drop near the equivalence point at pH 7. After the steep drop, the curve flattens out at a relatively low pH.



These two curves are inverse of each other (if you flip the curve vertically).

22. A diluted sample of the drain cleaner will be titrated with a standardized solution of hydrochloric acid using methyl orange as the indicator.

A sound procedure ought to have:

- between 5 and 10 steps
- steps that are sufficient to obtain the kind of data/information needed to answer the problem
- a good control of variables
- a clean burette and pipette
- a suitable indicator and knowledge of what to observe (the colour change at the endpoint)
- modest sample size (5 mL, 10 mL, 20 mL)
- repetition of the titration for accuracy
- clean-up/disposal considerations

A good exemplar would be:

1. Set up the titration apparatus as demonstrated by your teacher. Rinse the burette with de-ionized water, then with the standardized hydrochloric acid.
2. Fill the burette with the standardized hydrochloric acid.
3. Measure and record the initial burette reading.
4. Use a clean pipette to obtain 10.0 mL of the diluted drain cleaner solution and deliver it to a clean 125 mL Erlenmeyer flask.
5. Add 2–3 drops of methyl orange (or other suitable indicator) to the sample in the flask and note the initial indicator colour.
6. Titrate the diluted drain cleaner sample with the hydrochloric acid until a distinct endpoint is observed (the colour change should be described at this point, in this case the solution changes from yellow to orange or red). Record the final burette reading.
7. Repeat steps 3 to 6 until you have performed three consecutive titrations with differences within a +/– 0.1 mL range.
8. Clean up your laboratory station and dispose of all waste as instructed by your teacher.

Answers to Solving Problems Questions

23. $3H_2SO_4(aq) + Ca_3(PO_4)_2(s) + 6H_2O(\ell) \rightarrow 2H_3PO_4(aq) + 3CaSO_4{\bullet}2H_2O(s)$

$m = 1.00$ kg $m = ?$ Kg

$M = 310.18$ g/mol $M = 172.19$ g/mol

$$m\ CaSO_4{\bullet}2H_2O = 1.00\ \text{kg}\ Ca_3(PO_4)_2 \times \frac{1\ \text{mol}\ Ca_3(PO_4)_2}{310.18\ \text{g}\ Ca_3(PO_4)_2} \times \frac{3\ \text{mol}\ CaSO_4{\bullet}2H_2O}{1\ \text{mol}\ CaSO_4{\bullet}2H_2O} \times \frac{172.19\ \text{g}\ CaSO_4{\bullet}2H_2O}{1\ \text{mol}\ CaSO_4{\bullet}2H_2O}$$

$= 1.67$ kg

24. $C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$

$m = ?$ Ig $m = 1.1$ Tg

$M = 30.08$ g/mol $M = 28.06$ g/mol

$$m\ C_2H_4 = 1.1\ \text{Tg}\ C_2H_4 \times \frac{1\ \text{mol}\ C_2H_4}{28.06\ \text{g}\ C_2H_4} \times \frac{1\ \text{mol}\ C_2H_6}{1\ \text{mol}\ C_2H_4} \times \frac{30.08\ \text{g}\ C_2H_6}{1\ \text{mol}\ C_2H_6}$$

$= 1.2$ Tg

25. $Pb(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Pb(NO_3)_2(aq)$

$m = 1.0$ g $m = ?$ g

$M = 207.21$ g/mol $M = 63.55$ g/mol

$$m\ Cu = 1.0\ \text{g Pb} \times \frac{1\ \text{mol Pb}}{207.21\ \text{g Pb}} \times \frac{1\ \text{mol Cu}}{1\ \text{mol Pb}} \times \frac{63.55\ \text{g Cu}}{1\ \text{mol Cu}}$$

$= 0.31$ g

26. $CaCO_3(s) + 2CH_3COOH(aq) \rightarrow Ca(CH_3COO)_2(aq) + CO_2(g) + H_2O(\ell)$

$m = ?$ g $m = 12.5$ g

$M = 100.09$ g/mol $M = 60.06$ g/mol

$$m\ CaCO_3 = 12.5\ \text{g}\ CH_3COOH \times \frac{1\ \text{mol}\ CH_3COOH}{60.06\ \text{g}\ CH_3COOH} \times \frac{1\ \text{mol}\ CaCO_3}{2\ \text{mol}\ CH_3COOH} \times \frac{100.09\ \text{g}\ CaCO_3}{1\ \text{mol}\ CaCO_3}$$

$= 10.4$ g

Since 12.5 g of ethanoic acid will react completely with only 10.4 g of calcium carbonate, the lime scale will not be completely removed.

27. **(a)** $Pb(CH_3COO)_2(aq) + 2NH_4Cl(aq) \rightarrow PbCl_2(s) + 2NH_4CH_3COO(aq)$

(b) $V = 21.0$ mL $\quad m = ?$ g

$c = 0.125$ g/mol $\quad M = 278.11$ g/mol

$$m\,PbCl_2 = 21.0\ \text{mL} \times \frac{0.125\ \text{mol}\ NH_4Cl}{1\ \text{L}} \times \frac{1\ \text{mol}\ PbCl_2}{2\ \text{mol}\ NH_4Cl} \times \frac{278.11\ \text{g}\ PbCl_2}{1\ \text{mol}\ PbCl_2}$$

$$= 365\ \text{mg}$$

28. $HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(\ell)$

$V = 2.68$ L $\quad V = 3.17$ L $\quad m = ?$ g

$c = 2.11$ mol/L $\quad c = 2.29$ mol/L $\quad M = 74.55$ g/mol

If the HCl is limiting

$$m\,KCl = 2.68\ \text{L} \times \frac{2.11\ \text{mol HCl}}{1\ \text{L}} \times \frac{1\ \text{mol KCl}}{1\ \text{mol HCl}} \times \frac{74.55\ \text{g KCl}}{1\ \text{mol KCl}}$$

$$= 422\ \text{g}$$

If the KOH is limiting

$$m\,KCl = 3.17\ \text{L} \times \frac{2.29\ \text{mol KOH}}{1\ \text{L}} \times \frac{1\ \text{mol KCl}}{1\ \text{mol KOH}} \times \frac{74.55\ \text{g KCl}}{1\ \text{mol KCl}}$$

$$= 541\ \text{g}$$

Since HCl(aq) produces the least mass of product, it is the limiting reactant and the mass of KCl(aq) produced will be 422 g.

29. $H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(\ell)$

$V = 25.0$ mL $\quad V = 38.93$ mL

$c = ?$ mol/L $\quad c = 4.50$ mmol/L

$$c\,H_2SO_4 = 38.93\ \text{mL} \times \frac{4.50\ \text{mmol KOH}}{1\ \text{L}} \times \frac{1\ \text{mol}\ H_2SO_4}{2\ \text{mol KOH}} \times \frac{1}{25.0\ \text{mL}}$$

$$= 3.50\ \text{mmol/L}$$

30. $Ca(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow CaSO_4(s) + 2NaNO_3(aq)$

$V = 50.0$ mL $\quad V = 200$ mL

$c = 0.200$ mol/L $\quad c = 0.180$ mol/L

$$n\,Na_2SO_4 = 50.0\ \text{mL} \times \frac{0.200\ \text{mol}\ Ca(NO_3)_2}{1\ \text{L}} \times \frac{1\ \text{mol}\ Na_2SO_4}{1\ \text{mol}\ Ca(NO_3)_2}$$

$$= 10.0\ \text{mmol}$$

$$n\,Na_2SO_4\ \text{remaining} = 36.0\ \text{mmol} - 10.0\ \text{mmol} = 26.0\ \text{mmol}$$

$$c\,Na_2SO_4 = \frac{26.0\ \text{mmol}}{250\ \text{mL}} = 0.104\ \text{mol/L}$$

31. $AgNO_3(aq) + KCl(aq) \rightarrow AgCl(s) + KNO_3(aq)$

$V = 25.0$ mL $\quad m = 0.842$ g

$c = ?$ mol/L $\quad M = 143.32$ g/mol

$$c\,AgNO_3 = 0.842\ \text{g AgCl} \times \frac{1\ \text{mol AgCl}}{143.32\ \text{g AgCl}} \times \frac{1\ \text{mol}\ AgNO_3}{1\ \text{mol AgCl}} \times \frac{1}{25.0\ \text{mL}} \times \frac{1000\ \text{mL}}{1\ \text{L}}$$

$$= 0.235\ \text{mol/L}$$

32. $S_8(s) + 12O_2(g) + 8H_2O(\ell) \rightarrow 8H_2SO_4(\ell)$

$m = 1.00$ kg $\quad m = ?$ g

$M = 256.56$ g/mol $\quad M = 98.09$ g/mol

$$m\,H_2SO_4 = 1.00\ \text{kg}\ S_8 \times \frac{1\ \text{mol}\ S_8}{256.56\ \text{g}\ S_8} \times \frac{8\ \text{mol}\ H_2SO_4}{1\ \text{mol}\ S_8} \times \frac{98.09\ \text{g}\ H_2SO_4}{1\ \text{mol}\ H_2SO_4}$$

$$= 3.06\ \text{kg}$$

33. **(a)** $P_4S_3\,(g) + 8O_2(g) \rightarrow P_4O_{10}(g) + 3SO_2(g)$

(b) $$V = 5.3\ \text{L}\ O_2(g) \times \frac{3\ \text{L}\ SO_2\ (g)}{8\ \text{L}\ O_2\ (g)} = 2.0\ \text{L}\ SO_2\ (g)$$

(c) $$m = \frac{5.3\ \text{L}\ O_2(g)}{22.4\ \text{L/mol}\ O_2(g)} \times \frac{1\ \text{mol}\ P_4S_3(s)}{8\ \text{mol}\ O_2(g)} \times \frac{220.09\ \text{g}\ P_4S_3(s)}{1\ \text{mol}\ P_4S_3(s)}$$

$$= 6.5\ \text{g}\ P_4S_3(s)$$

34. $3CH_4(g) + 6H_2O(\ell) + 4N_2(g) \rightarrow 8NH_3(g) + 3CO_2(g)$

$m = 1000$ kg $\quad V = ?$ L

$M = 16.05$ g/mol $\quad T = 300$ K

$P = 100$ kPa

(a) $$V\,NH_3 = 1000\ \text{kg}\ CH_4 \times \frac{1\ \text{mol}\ CH_4}{16.05\ \text{g}\ CH_4} \times \frac{8\ \text{mol}\ NH_3}{3\ \text{mol}\ CH_4} \times \frac{8.314\ \text{kPa}\bullet\text{L/mol}\bullet\text{K} \times 300\ \text{K}}{100\ \text{kPa}}$$

$$= 4.15 \times 10^6\ \text{L}$$

(b) $$m\,NH_3 = 1000\ \text{kg}\ CH_4 \times \frac{1\ \text{mol}\ CH_4}{16.05\ \text{g}\ CH_4} \times \frac{8\ \text{mol}\ NH_3}{3\ \text{mol}\ CH_4} \times \frac{17.04\ \text{g}\ NH_3}{1\ \text{mol}\ NH_3}$$

$$= 2831\ \text{kg}$$

(c) $V = 2831\ \text{kg} \times \dfrac{\text{m}^3}{681.91\ \text{kg}} = 4.15\ \text{m}^3$

35. $C_9H_8O_4(aq) + NaOH(aq) \rightarrow NaC_9H_7O_4(aq) + H_2O(\ell)$

$m = ?\ \text{g}$ $V = 13.4\ \text{mL}$

$M = 180.17\ \text{g/mol}$ $c = 0.132\ \text{mol/L}$

(a) $m\ C_9H_8O_4 = 13.4\ \text{m}\cancel{\text{L}} \times \dfrac{0.132\ \cancel{\text{mol NaOH}}}{1\ \cancel{\text{L}}} \times \dfrac{1\ \cancel{\text{mol } C_9H_8O_4}}{1\ \cancel{\text{mol NaOH}}} \times \dfrac{180.17\ \text{g } C_9H_8O_4}{1\ \cancel{\text{mol } C_9H_8O_4}}$

$= 319\ \text{mg}$

(b) $\%\ \text{Yield} = \dfrac{319\ \text{mg}}{325\ \text{mg}} \times 100 = 98.2\%$

(c) A small piece of the tablet could have broken off due to the tablets bumping against each other and against the bottle.

36. $Ca^{2+}(aq) + 2HF(aq) \rightarrow CaF_2(s) + 2H^+(aq)$

$V = 2.8\ \text{L}$ $V = ?\ \text{L}$

$c = 2.5\ \text{mmol/L}$ $c = 1.5\ \text{mol/L}$

$v\ \text{HF} = 2.8\ \text{L} \times \dfrac{2.5\ \cancel{\text{mmol } Ca^{2+}}}{1\ \cancel{\text{L}}} \times \dfrac{2\ \cancel{\text{mol HF}}}{1\ \cancel{\text{mol } Ca^{2+}}} \times \dfrac{1\ \cancel{\text{L}}}{1.5\ \cancel{\text{mol HF}}}$

$= 9.3\ \text{mL}$

37. $2C_4H_9SH(\ell) + NaOCl(aq) \rightarrow (C_4H_9)_2S(\ell) + NaCl(aq) + H_2O(\ell)$

$m = ?\ \text{g}$ $V = 5.00\ \text{mL}$

$M = 90.21\ \text{g/mol}$ $c = 0.0986\ \text{mol/L}$

$m\ C_4H_9SH = 5.00\ \text{m}\cancel{\text{L}} \times \dfrac{0.0986\ \cancel{\text{mol NaOCl}}}{1\ \cancel{\text{L}}} \times \dfrac{2\ \cancel{\text{mol } C_4H_9SH}}{1\ \cancel{\text{mol NaOCl}}} \times \dfrac{90.21\ \text{g } C_4H_9SH}{1\ \cancel{\text{mol } C_4H_9SH}}$

$= 88.9\ \text{mg}$

38. $Fe_2O_3(s) + 6H_2C_2O_4(aq) \rightarrow 2Fe(C_2O_4)_3^{3-}(aq) + 3H_2O(\ell) + 6H^+(aq)$

$m = ?\ \text{g}$ $V = 500\ \text{mL}$

$M = 159.70\ \text{g/mol}$ $c = 0.11\ \text{g/mol}$

$m\ Fe_2O_3 = 500\ \text{mL} \times \dfrac{0.11\ \cancel{\text{mol } H_2C_2O_4}}{1\ \text{L } H_2C_2O_4} \times \dfrac{1\ \cancel{\text{mol } Fe_2O_3}}{6\ \text{mol } \cancel{H_2C_2O_4}} \times \dfrac{159.70\ \text{g } Fe_2O_3}{1\ \cancel{\text{mol } Fe_2O_3}}$

$= 1.46\ \text{g}$

Since only 1.0 g of red rust is present, there is more than enough oxalic acid to completely remove it.

39. $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$

$n = ?\ \text{mol}$ $V = 27.9\ \text{mL}$

$c = 0.250\ \text{mol/L}$ $c = 0.230\ \text{mol/L}$

$n\ H_2SO_4 = 27.9\ \text{m}\cancel{\text{L}} \times \dfrac{0.230\ \cancel{\text{mol NaOH}}}{1\ \cancel{\text{L}}} \times \dfrac{1\ \text{mol } H_2SO_4}{2\ \cancel{\text{mol NaOH}}}$

$= 3.21\ \text{mmol remains}$

$n\ H_2SO_4\ \text{originally present} = 50.0\ \text{m}\cancel{\text{L}} \times \dfrac{0.250\ \text{mol } H_2SO_4}{1\ \cancel{\text{L}}}$

$= 12.5\ \text{mmol}$

$n\ H_2SO_4\ \text{that reacted} = 12.5\ \text{mmol} - 3.21\ \text{mmol}$

$= 9.3\ \text{mmol}$

$n\ NH_3 = 9.3\ \text{mmol}\ \cancel{H_2SO_4} \times \dfrac{2\ \cancel{\text{mol}}\ NH_3}{1\ \cancel{\text{mol } H_2SO_4}}$

$= 18.6\ \text{mmol}$

$n\ (NH_4)_2SO_4 = 18.6\ \text{m}\cancel{\text{mol } NH_3} \times \dfrac{1\ \cancel{\text{mol}}\ (NH_4)_2SO_4}{2\ \cancel{\text{mol } NH_3}}$

$= 9.3\ \text{mmol}$

$m\ (NH_4)_2SO_4 = 9.3\ \text{m}\cancel{\text{mol } (NH_4)_2SO_4} \times \dfrac{132.17\ \text{g } (NH_4)_2SO_4}{1\ \cancel{\text{mol } (NH_4)_2SO_4}}$

$= 1.23\ \text{g}$

$\text{percentage} = (1.23\ \text{g} / 10.0\ \text{g}) \times 100 = 12.3\%$

40. **(a)** 7.32 g $H_2O(g)$

Complete Solution

$n_{SiO_2(s)} = \dfrac{m_{SiO_2(s)}}{M_{SiO_2(s)}}$

$= \dfrac{12.2\ \text{g } SiO_2(s)}{60.09 \dfrac{\text{g } SiO_2(s)}{\text{mol } SiO_2(s)}}$

$= 0.203\ \text{mol } SiO_2(s)$

$n_{H_2O(g)} = 0.203\ \text{mol } SiO_2(s) \times \dfrac{2\ \text{mol } H_2O(g)}{1\ \text{mol } SiO_2(s)}$

$= 0.406\ \text{mol } H_2O(g)$

$m_{H_2O(g)} = n_{H_2O(g)} M_{H_2O(g)}$

$= 0.406\ \text{mol } H_2O(g) \times \dfrac{18.02\ \text{g } H_2O(g)}{1\ \text{mol } H_2O(g)}$

$= 7.32\ \text{g } H_2O(g)$

(b) 34.2% yield

Complete Solution

$$\text{percentage yield} = \frac{\text{experimental yield}}{\text{predicted yield}} \times 100\%$$

$$= \frac{2.50 \text{ g}}{7.32 \text{ g}} \times 100\%$$

$$= 34.2\% \text{ yield}$$

(c) 7.22 g of $SiF_4(s)$ would be formed.

Complete Solution

$$n_{H_2O(g)} = \frac{m_{H_2O(g)}}{M_{H_2O(g)}}$$

$$= \frac{2.50 \text{ g } H_2O(g)}{18.02 \frac{\text{g } H_2O(g)}{\text{mol } H_2O(g)}}$$

$$= 0.139 \text{ mol } H_2O(g)$$

$$n_{SiF_4(s)} = 0.139 \text{ mol } H_2O(g) \times \frac{1 \text{ mol } SIF_4(s)}{2 \text{ mol } H_2O(g)}$$

$$= 0.0694 \text{ mol } SIF_4(s)$$

$$m_{SiF_4(s)} = n_{SiF_4(s)} M_{SiF_4(s)}$$

$$= 0.694 \text{ mol } SIF_4(s) \times \frac{104.09 \text{ g } SIF_4(s)}{1 \text{ mol } SIF_4(s)}$$

$$= 7.22 \text{ g } SIF_4(s)$$

41. 36.6% yield

Complete Solution

$$n_{Na_2SO_4(s)} = \frac{m_{Na_2SO_4(s)}}{M_{Na_2SO_4(s)}}$$

$$= \frac{4.36 \text{ g } Na_2SO_4(s)}{142.05 \frac{\text{g } Na_2SO_4(s)}{\text{mol } Na_2SO_4(s)}}$$

$$= 0.0307 \text{ mol } Na_2SO_4(s)$$

$$n_{SiF_4(s)} = 0.0307 \text{ mol } Na_2SO_4(s) \times \frac{1 \text{ mol } BaSO_4(s)}{1 \text{ mol } Na_2SO_4(s)}$$

$$= 0.0307 \text{ mol } BaSO_4(s)$$

$$m_{SiF_4(s)} = n_{SiF_4(s)} M_{SiF_4(s)}$$

$$= 0.0307 \text{ mol } BaSO_4(s) \times \frac{233.40 \text{ g}}{1 \text{ mol } BaSO_4(s)}$$

$$= 7.16 \text{ g } BaSO_4(s)$$

$$\text{percentage yield} = \frac{\text{experimental yield}}{\text{predicted yield}} \times 100\%$$

$$= \frac{2.62 \text{ g}}{7.16 \text{ g}} \times 100\%$$

$$= 36.6\% \text{ yield}$$

42. (a) 15.1 g $C_6H_5Br(\ell)$

$$n_{C_6H_6(\ell)} = \frac{m_{C_6H_6(\ell)}}{M_{C_6H_6(\ell)}}$$

$$= \frac{7.50 \text{ g } C_6H_6(\ell)}{\frac{78.12\text{g } C_6H_6(\ell)}{\text{mol } C_6H_6(\ell)}}$$

$$= 0.0960 \text{ mol } C_6H_6(\ell)$$

$$n_{C_6H_5Br(\ell)} = 0.0960 \text{ mol } C_6H_6(\ell) \times \frac{1 \text{ mol } C_6H_5Br(\ell)}{1 \text{ mol } C_6H_6(\ell)}$$

$$= 0.0960 \text{ mol } C_6H_5Br(\ell)$$

$$m_{C_6H_5Br(\ell)} = n_{C_6H_5Br(\ell)} M_{C_6H_5Br(\ell)}$$

$$= 0.0960 \text{ mol } C_6H_5Br(\ell) \times \frac{157.01 \text{ g } C_6H_5Br(\ell)}{1 \text{ mol } C_6H_5Br(\ell)}$$

$$= 15.1 \text{ g } C_6H_5Br(\ell)$$

(b) 0.414 g

Complete Solution

$$n_{C_6H_4Br_2(\ell)} = \frac{m_{C6H4Br2(\ell)}}{M_{C6H4Br2(\ell)}}$$

$$= \frac{1.25 \text{ g } C_6H_4Br_2(\ell)}{235.9 \frac{\text{g } C_6H_4Br_2(\ell)}{\text{mol } C_6H_4Br_2(\ell)}}$$

$$= 0.00530 \text{ mol } C_6H_4Br_2(\ell)$$

$$n_{C_6H_6(\ell)} = 0.00530 \text{ mol } C_6H_4Br_2(\ell) \times \frac{1 \text{ mol } C_6H_6(\ell)}{1 \text{ mol } C_6H_4Br_2(\ell)}$$

$$= 0.00530 \text{ mol } C_6H_6(\ell)$$

$$m_{C_6H_6(\ell)} = n_{C_6H_6(\ell)} M_{C_6H_6(\ell)}$$

$$= 0.00530 \text{ mol } C_6H_6(\ell) \times \frac{78.12 \text{ g } C_6H_6(\ell)}{1 \text{ mol } C_6H_6(\ell)}$$

$$= 0.414 \text{ g } C_6H_6(\ell)$$

(c) 14.2 g of bromobenzene were formed.

(d) The yield was 94.5 %.

Answers to Making Connections Questions

43. The words "air bags" and "airbags" in a Google search bring up a number of excellent resources for high school students. Most of the entries list the pros for the use of air bags, but some sites do investigate the cons. These sites also describe the specific conditions in which air bags should not be used. A number of questionable sites, lacking scientific basis, also appeared in the search. Discuss the difference between reputable sources (e.g., Canadian Safety Council) and less reputable sources (e.g., joe'swebpage.com) and how to use internet resources judiciously.

Pros

- deaths from impact injuries in collisions are reduced

- injuries due to automobile accidents are reduced
- health care costs due to automobile accidents are reduced

Cons

- driver and passenger must be properly seated in car (proper distance from front of car)
- small children cannot be in the front seat with an airbag
- rear-facing infant seats cannot be used with an air bag
- air bags may cause injury

44. Students should support their position with specific examples. If they agree, they may make reference to the cost of developing a market for the by-products, the cost of shipping by-products to be used in another process, or the cost of research into new products made from by-products that ultimately translates into consumer costs. If students disagree, they may make reference to environmental costs of disposal, the sheer volume of by-products and how this may have environmental costs, potential profits from using by-products, or utilizing our natural resources fully (fewer resources have to be processed to provide a variety of different of products).

45. Vitamin C, or ascorbic acid, is an acid. The concentration of an acid in a solution can be determined using acid-base titration.

Variables:

Manipulated: type of orange juice

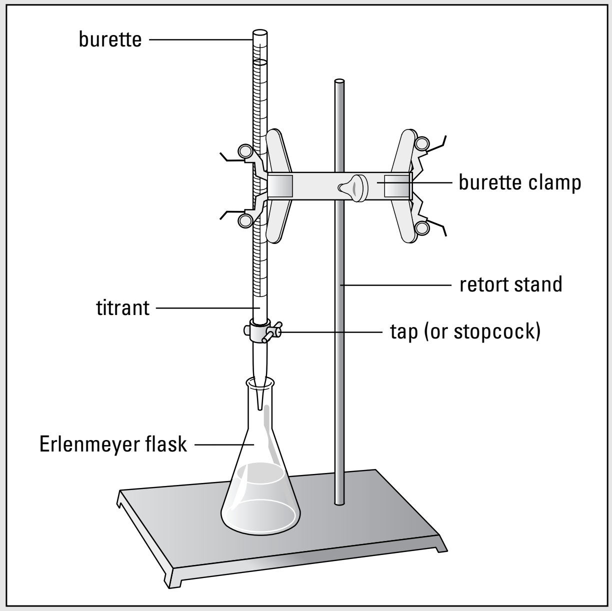
Responding: the volume of base required to reach equivalence (as measured by the indicator endpoint)

Controlled: the volume of orange juice; the concentration of the base; the indicator used

Data Table: Volume of base required to neutralize the vitamin C in a 250 mL glass of orange juice

	Trial 1	Trial 2	Trial 3	Trial 4
Final burette volume (mL)				
Initial burette volume (mL)				
Volume of base added (mL)				

Diagram:



Sample Calculation:

From the four trials, average the volume of base required to reach equivalence point. This is the volume of base.

A sample balanced equation is shown below.

$$2NaOH(aq) + H_2C_6H_6O_6(aq) \rightarrow Na_2C_6H_6O_6(aq) + 2H_2O(\ell)$$

$$n_{NaOH(aq)} = c_{NaOH(aq)} \times V_{NaOH(aq)} = nNaOH(aq)$$

$$n_{H_2C_6H_6O_6(aq)} = nNaOH(aq) \times \frac{1 \text{ mol } H_2C_6H_6O_6(aq)}{2 \text{ mol } NaOH(aq)} = nH_2C_6H_6O_6(aq)$$

$$c_{H_2C_6H_6O_6(aq)} = \frac{n_{H_2C_6H_6O_6(aq)}}{V_{H_2C_6H_6O_6(aq)}} = \frac{nH_2C_6H_6O_6(aq)}{0.250 \text{ L}} = cH_2C_6H_6O_6(aq)$$