INTRODUCTORY CHEMISTRY
INTRODUCTORY CHEMISTRY

Fifth Edition

Nivaldo J. Tro
Westmont College
To Annie

About the Author

Nivaldo Tro, is a Professor of Chemistry at Westmont College in Santa Barbara, California, where he has been a faculty member since 1990. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultra high vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Since coming to Westmont, Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, from Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honored as Westmont’s outstanding teacher of the year three times and has also received the college’s outstanding researcher of the year award. Professor Tro lives in Santa Barbara with his wife, Ann, and their four children, Michael, Ali, Kyle, and Kaden. In his leisure time, Professor Tro enjoys mountain biking, surfing, reading to his children, and being outdoors with his family.
Brief Contents

Preface xviii

1 The Chemical World 2
2 Measurement and Problem Solving 12
3 Matter and Energy 56
4 Atoms and Elements 94
5 Molecules and Compounds 128
6 Chemical Composition 166
7 Chemical Reactions 204
8 Quantities in Chemical Reactions 248
9 Electrons in Atoms and the Periodic Table 284
10 Chemical Bonding 324
11 Gases 358
12 Liquids, Solids, and Intermolecular Forces 410
13 Solutions 446
14 Acids and Bases 486
15 Chemical Equilibrium 528
16 Oxidation and Reduction 574
17 Radioactivity and Nuclear Chemistry 610
18 Organic Chemistry 642
19 Biochemistry 696

Appendix: Mathematics Review MR-1
Glossary G-1
Answers to Odd-Numbered Exercises A-1
Photo Credits PC-1
Index I-1
Contents

Preface xviii

1 The Chemical World 2

1.1 Soda Pop Fizz 3
1.2 Chemicals Compose Ordinary Things 5
1.3 All Things Are Made of Atoms and Molecules 5
1.4 The Scientific Method: How Chemists Think 6
1.5 A Beginning Chemist: How to Succeed 8

CHAPTER IN REVIEW
KEY TERMS 10
EXERCISES 10

2 Measurement and Problem Solving 12

2.1 Measuring Global Temperatures 13
2.2 Scientific Notation: Writing Large and Small Numbers 13
2.3 Significant Figures: Writing Numbers to Reflect Precision 16
    Counting Significant Figures 17
    Exact Numbers 18
2.4 Significant Figures in Calculations 20
    Multiplication and Division 20
    Rounding 20
    Addition and Subtraction 21
    Calculations Involving Both Multiplication/Division and Addition/Subtraction 22
2.5 The Basic Units of Measurement 24
    The Base Units 24
    Prefix Multipliers 25
    Derived Units 26
2.6 Problem Solving and Unit Conversion 27
    Converting Between Units 27
    General Problem-Solving Strategy 29

Problem-Solving Procedure Solving Unit Conversion Problems 30
2.7 Solving Multistep Unit Conversion Problems 31
2.8 Units Raised to a Power 33
CHEMISTRY AND HEALTH Drug Dosage 34
2.9 Density 36
    Calculating Density 36
    Density as a Conversion Factor 37
CHEMISTRY AND HEALTH Density, Cholesterol, and Heart Disease 39
2.10 Numerical Problem-Solving Strategies and the Solution Map 39
Problem-Solving Procedure Solving Numerical Problems 40

CHAPTER IN REVIEW
KEY TERMS 47
EXERCISES 47
3 Matter and Energy

3.1 In Your Room 57
3.2 What Is Matter? 57
3.3 Classifying Matter According to Its State: Solid, Liquid, and Gas 59
3.4 Classifying Matter According to Its Composition: Elements, Compounds, and Mixtures 60
3.5 Differences in Matter: Physical and Chemical Properties 63
3.6 Changes in Matter: Physical and Chemical Changes 65
Separating Mixtures Through Physical Changes 66
3.7 Conservation of Mass: There Is No New Matter 67
3.8 Energy

CHEMISTRY IN THE ENVIRONMENT
Getting Energy out of Nothing? 69
Units of Energy 69
3.9 Energy and Chemical and Physical Change 71
3.10 Temperature: Random Motion of Molecules and Atoms 72
3.11 Temperature Changes: Heat Capacity

EVERYDAY CHEMISTRY Coolers, Camping, and the Heat Capacity of Water 77

3.12 Energy and Heat Capacity Calculations 77
CHAPTER IN REVIEW 81
KEY TERMS 86
EXERCISES 86

4 Atoms and Elements

4.1 Experiencing Atoms at Tiburon 95
4.2 Indivisible: The Atomic Theory 96
EVERYDAY CHEMISTRY Atoms and Humans 97
4.3 The Nuclear Atom 97
4.4 The Properties of Protons, Neutrons, and Electrons
EVERYDAY CHEMISTRY Solid Matter? 100
4.5 Elements: Defined by Their Numbers of Protons 101
4.6 Looking for Patterns: The Periodic Law and the Periodic Table 104
4.7 Ions: Losing and Gaining Electrons
Ions and the Periodic Table 109
4.8 Isotopes: When the Number of Neutrons Varies 111
4.9 Atomic Mass: The Average Mass of an Element’s Atoms

CHEMISTRY IN THE ENVIRONMENT
Radioactive Isotopes at Hanford, Washington 114
CHAPTER IN REVIEW 116
KEY TERMS 119
EXERCISES 119

5 Molecules and Compounds

5.1 Sugar and Salt 129
5.2 Compounds Display Constant Composition 130
5.3 Chemical Formulas: How to Represent Compounds 131
Polyatomic Ions in Chemical Formulas 133
Types of Chemical Formulas 134
5.4 A Molecular View of Elements and Compounds 135
Atomic Elements 135
Molecular Elements 135
Molecular Compounds 135
Ionic Compounds 136
5.5 Writing Formulas for Ionic Compounds 138
Writing Formulas for Ionic Compounds Containing Only Monoatomic Ions 138

Problem-Solving Procedure Writing Formulas for Ionic Compounds 138
6 Chemical Composition 166

6.1 How Much Sodium? 167
6.2 Counting Nails by the Pound 168
6.3 Counting Atoms by the Gram 169
Converting between Moles and Number of Atoms 169
Converting between Grams and Moles of an Element 170
Converting between Grams of an Element and Number of Atoms 173
6.4 Counting Molecules by the Gram 174
Converting between Grams and Moles of a Compound 174
Converting between Grams of a Compound and Number of Molecules 176
6.5 Chemical Formulas as Conversion Factors 177
Converting between Grams of a Compound and Moles of a Constituent Element 178
Converting between Grams of a Compound and Grams of a Constituent Element 179
CHEMISTRY IN THE ENVIRONMENT Chlorine in Chlorofluorocarbons 181
6.6 Mass Percent Composition of Compounds 182
6.7 Mass Percent Composition from a Chemical Formula 183

CHEMISTRY AND HEALTH Fluoridation of Drinking Water 185
6.8 Calculating Empirical Formulas for Compounds 185
Calculating an Empirical Formula from Experimental Data 186
Problem-Solving Procedure Obtaining an Empirical Formula from Experimental Data 187
6.9 Calculating Molecular Formulas for Compounds 188
CHAPTER IN REVIEW 190
KEY TERMS 196
EXERCISES 196
7.5 Aqueous Solutions and Solubility: Compounds Dissolved in Water Solubility  214

7.6 Precipitation Reactions: Reactions in Aqueous Solution That Form a Solid Predicting Precipitation Reactions  218

Problem-Solving Procedure Writing Equations for Precipitation Reactions  220

7.7 Writing Chemical Equations for Reactions in Solution: Molecular, Complete Ionic, and Net Ionic Equations  221

7.8 Acid–Base and Gas Evolution Reactions Acid–Base (Neutralization) Reactions  223
Gas Evolution Reactions  224

Chemistry and Health Neutralizing Excess Stomach Acid  226

7.9 Oxidation–Reduction Reactions Combustion Reactions  227

7.10 Classifying Chemical Reactions Classifying Chemical Reactions by What Atoms Do  229
Classification Flowchart  231

Chemistry in the Environment The Reactions Involved in Ozone Depletion  233

Chapter in Review  233
Key Terms  239
Exercises  239

8 Quantities in Chemical Reactions  248

8.1 Climate Change: Too Much Carbon Dioxide  249
8.2 Making Pancakes: Relationships between Ingredients  250
8.3 Making Molecules: Mole-to-Mole Conversions  251
8.4 Making Molecules: Mass-to-Mass Conversions  253

Chemistry in the Media The Controversy over Oxygenated Fuels  254

8.5 More Pancakes: Limiting Reactant, Theoretical Yield, and Percent Yield  257
8.6 Limiting Reactant, Theoretical Yield, and Percent Yield from Initial Masses of Reactants  260
8.7 Enthalpy: A Measure of the Heat Evolved or Absorbed in a Reaction  264

Everyday Chemistry Bunsen Burners
Sign of $H_{\text{rxn}}$  265
Stoichiometry of $H_{\text{rxn}}$  266

Chapter in Review  268
Key Terms  272
Exercises  273

9 Electrons in Atoms and the Periodic Table  284

9.1 Blimps, Balloons, and Models of the Atom  285
9.2 Light: Electromagnetic Radiation  286
9.3 The Electromagnetic Spectrum  288

Chemistry and Health Radiation Treatment for Cancer  290

9.4 The Bohr Model: Atoms with Orbits  291
9.5 The Quantum-Mechanical Model: Atoms with Orbitals
Baseball Paths and Electron Probability Maps
From Orbits to Orbitals  295

9.6 Quantum-Mechanical Orbitals and Electron Configurations  294
Quantum-Mechanical Orbitals  296
Electron Configurations: How Electrons Occupy Orbitals  298

9.7 Electron Configurations and the Periodic Table  302

9.8 The Explanatory Power of the Quantum-Mechanical Model  305
### Contents

**Periodic Trends: Atomic Size, Ionization Energy, and Metallic Character**
- Atomic Size 307

**CHEMISTRY AND HEALTH**
- Pumping Ions: Atomic Size and Nerve Impulses 309
- Ionization Energy 309
- Metallic Character 311

**CHAPTER IN REVIEW**
- Key Terms 316
- Exercises 316

## 10 Chemical Bonding

### 10.1 Bonding Models and AIDS Drugs 325
### 10.2 Representing Valence Electrons with Dots 326
### 10.3 Lewis Structures of Ionic Compounds: Electrons Transferred 327
### 10.4 Covalent Lewis Structures: Electrons Shared Double and Triple Bonds 329
### 10.5 Writing Lewis Structures for Covalent Compounds 330
- **Problem-Solving Procedure** Writing Lewis Structures for Covalent Compounds 331
- Writing Lewis Structures for Polyatomic Ions Exceptions to the Octet Rule 333
### 10.6 Resonance: Equivalent Lewis Structures for the Same Molecule 334
### 10.7 Predicting the Shapes of Molecules
- **CHEMISTRY AND ENVIRONMENT** The Lewis Structure of Ozone 336
- **Problem-Solving Procedure** Predicting Geometry Using VSEPR Theory 339
- Representing Molecular Geometries on Paper 339
- **CHEMISTRY AND HEALTH** Fooled by Molecular Shape 340
### 10.8 Electronegativity and Polarity: Why Oil and Water Don’t Mix 341
- Electronegativity 341
- Polar Bonds and Polar Molecules 343
- **EVERYDAY CHEMISTRY** How Soap Works 345
### 10.9 Mixtures of Gases: Why Deep-Sea Divers Breathe a Mixture of Helium and Oxygen 385
- Deep-Sea Diving and Partial Pressure 387
- Collecting Gases over Water 388
### 10.10 Gases in Chemical Reactions 389
- Molar Volume at Standard Temperature and Pressure 392
- **CHEMISTRY IN THE ENVIRONMENT** Air Pollution 394

**CHAPTER IN REVIEW**
- Key Terms 395
- Exercises 400

## 11 Gases

### 11.1 Extra-Long Straws 359
### 11.2 Kinetic Molecular Theory: A Model for Gases 360

**CHEMISTRY IN THE ENVIRONMENT** Air Pollution 394

**CHAPTER IN REVIEW**
- Key Terms 400
- Exercises 400
12 Liquids, Solids, and Intermolecular Forces

12.1 Interactions between Molecules 411
12.2 Properties of Liquids and Solids 412
12.3 Intermolecular Forces in Action: Surface Tension and Viscosity 413
   Surface Tension 414
   Viscosity 414
EVERYDAY CHEMISTRY Why Are Water Drops Spherical? 415
12.4 Evaporation and Condensation 415
   Boiling 417
   Energetics of Evaporation and Condensation 418
   Heat of Vaporization 419
12.5 Melting, Freezing, and Sublimation 420
   Energetics of Melting and Freezing 421
   Heat of Fusion 421
   Sublimation 423
12.6 Types of Intermolecular Forces: Dispersion, Dipole–Dipole, Hydrogen Bonding, and Ion–Dipole 425
   Dispersion Force 425
   Dipole–Dipole Force 426
   Hydrogen Bonding 428
   Ion–Dipole Force 429

CHEMISTRY AND HEALTH Hydrogen Bonding in DNA 430
12.7 Types of Crystalline Solids: Molecular, Ionic, and Atomic 432
   Molecular Solids 432
   Ionic Solids 433
   Atomic Solids 433
12.8 Water: A Remarkable Molecule 434
   CHEMISTRY IN THE ENVIRONMENT Water Pollution 435

CHAPTER IN REVIEW 436
KEY TERMS 440
EXERCISES 440

13 Solutions

13.1 Tragedy in Cameroon 447
13.2 Solutions: Homogeneous Mixtures 448
13.3 Solutions of Solids Dissolved in Water: How to Make Rock Candy 449
   Solubility and Saturation 450
   Electrolyte Solutions: Dissolved Ionic Solids 451
   How Solubility Varies with Temperature 452
   Rock Candy 452
13.4 Solutions of Gases in Water: How Soda Pop Gets Its Fizz 452
13.5 Specifying Solution Concentration: Mass Percent 454
   Mass Percent 454
   Using Mass Percent in Calculations 455
13.6 Specifying Solution Concentration: Molarity 457
   CHEMISTRY IN THE ENVIRONMENT Antifreeze in Frogs 458
   Using Molarity in Calculations 459
   Ion Concentrations 461
13.7 Solution Dilution 461
13.8 Solution Stoichiometry 463
13.9 Freezing Point Depression and Boiling Point Elevation: Making Water Freeze Colder and Boil Hotter 466
   Freezing Point Depression 466
   EVERYDAY CHEMISTRY Antifreeze in Frogs 468
   Boiling Point Elevation 468
13.10 Osmosis: Why Drinking Salt Water Causes Dehydration 470
   CHEMISTRY AND HEALTH Solutions in Medicine 471

CHAPTER IN REVIEW 472
KEY TERMS 478
EXERCISES 478
14 Acids and Bases 486

14.1 Sour Patch Kids and International Spy Movies 487
14.2 Acids: Properties and Examples 488
14.3 Bases: Properties and Examples 489
14.4 Molecular Definitions of Acids and Bases 490
  The Arrhenius Definition  490
  The Brønsted–Lowry Definition 491
14.5 Reactions of Acids and Bases 493
  Neutralization Reactions 493
  Acid Reactions 494
EVERYDAY CHEMISTRY What Is in My Antacid? 496
  Base Reactions 496
14.6 Acid–Base Titration: A Way to Quantify the Amount of Acid or Base in a Solution 496
14.7 Strong and Weak Acids and Bases 499
  Strong Acids 499
  Weak Acids 500
  Strong Bases 503
  Weak Bases 503
14.8 Water: Acid and Base in One 504
14.9 The pH and pOH Scales: Ways to Express Acidity and Basicity 507

15 Chemical Equilibrium 528

15.1 Life: Controlled Disequilibrium 529
15.2 The Rate of a Chemical Reaction 530
  Collision Theory 530
  How Concentration Affects the Rate of a Reaction 532
  How Temperature Affects the Rate of a Reaction 533
15.3 The Idea of Dynamic Chemical Equilibrium 534
15.4 The Equilibrium Constant: A Measure of How Far a Reaction Goes 537
  Writing Equilibrium Constant Expressions for Chemical Reactions 537
  The Significance of the Equilibrium Constant 538
15.5 Heterogeneous Equilibria: The Equilibrium Expression for Reactions Involving a Solid or a Liquid 540
15.6 Calculating and Using Equilibrium Constants 541
  Calculating Equilibrium Constants 541
  Using Equilibrium Constants in Calculations 543
15.7 Disturbing a Reaction at Equilibrium: Le Châtelier’s Principle 544
15.8 The Effect of a Concentration Change on Equilibrium 546
15.9 The Effect of a Volume Change on Equilibrium 548
    CHEMISTRY AND HEALTH How a Developing Fetus Gets Oxygen from Its Mother 550
15.10 The Effect of a Temperature Change on Equilibrium 551
15.11 The Solubility-Product Constant 553
  Using K_{sp} to Determine Molar Solubility 554
EVERYDAY CHEMISTRY Hard Water 555
15.12 The Path of a Reaction and the Effect of a Catalyst 556
  How Activation Energies Affect Reaction Rates 556
  Catalysts Lower the Activation Energy 558
  Enzymes: Biological Catalysts 559
CHAPTER IN REVIEW 560
KEY TERMS 564
EXERCISES 564
16 Oxidation and Reduction

16.1 The End of the Internal Combustion Engine? 575
16.2 Oxidation and Reduction: Some Definitions 576
16.3 Oxidation States: Electron Bookkeeping 579

EVERYDAY CHEMISTRY  The Bleaching of Hair 581

16.4 Problem-Solving Procedure Balancing Redox Equations Using the Half-Reaction Method 583

CH Emistry in the Environment  Photosynthesis and Respiration: Energy for Life 587

16.5 The Activity Series: Predicting Spontaneous Redox Reactions 587
16.6 Batteries: Using Chemistry to Generate Electricity 591
Dry-Cell Batteries 593
Lead-Acid Storage Batteries 594
Fuel Cells 594
16.7 Electrolysis: Using Electricity to Do Chemistry 595
16.8 Corrosion: Undesirable Redox Reactions 596

EVERYDAY CHEMISTRY  The Fuel-Cell Breathalyzer 597

CHAPTER IN REVIEW 598
KEY TERMS 602
EXERCISES 602

17 Radioactivity and Nuclear Chemistry

17.1 Diagnosing Appendicitis 611
17.2 The Discovery of Radioactivity 612
17.3 Types of Radioactivity: Alpha, Beta, and Gamma Decay 613
Alpha (α) Radiation 614
Beta (β) Radiation 616
Gamma (γ) Radiation 617
Positron Emission 618
17.4 Detecting Radioactivity 620
17.5 Natural Radioactivity and Half-Life 621

CHEMISTRY AND HEALTH  Environmental Radon 622
A Natural Radioactive Decay Series 623
17.6 Radiocarbon Dating: Using Radioactivity to Measure the Age of Fossils and Other Artifacts 624

CH Emistry in the Media  The Shroud of Turin 625
17.7 The Discovery of Fission and the Atomic Bomb 626

17.8 Nuclear Power: Using Fission to Generate Electricity 628
17.9 Nuclear Fusion: The Power of the Sun 629
17.10 The Effects of Radiation on Life 630
Acute Radiation Damage 630
Increased Cancer Risk 630
Genetic Defects 631
Measuring Radiation Exposure 631
17.11 Radioactivity in Medicine 631
Isotope Scanning 631
Radiotherapy 632

CHAPTER IN REVIEW 633
KEY TERMS 636
EXERCISES 636

18 Organic Chemistry

18.1 What Do I Smell? 643
18.2 Vitalism: The Difference between Organic and Inorganic 644
18.3 Carbon: A Versatile Atom 645

CHEMISTRY IN THE MEDIA  The Origin of Life 646
18.4 Hydrocarbons: Compounds Containing Only Carbon and Hydrogen 647
18.5  Alkanes: Saturated Hydrocarbons  648

   CHEMISTRY IN THE MEDIA  Environmental Problems Associated with Hydrocarbon Combustion  649

18.6  Isomers: Same Formula, Different Structure  653

18.7  Naming Alkanes  654

   Problem-Solving Procedure  Naming Alkanes  655

18.8  Alkenes and Alkynes  657

   Naming Alkenes and Alkynes  659

18.9  Hydrocarbon Reactions  660

   Alkane Substitution Reactions  661
   Alkene and Alkyne Addition Reactions  661

18.10  Aromatic Hydrocarbons  662

   Naming Aromatic Hydrocarbons  663

18.11  Functional Groups  665

18.12  Alcohols  666

   Naming Alcohols  666
   About Alcohols  667

18.13  Ethers  667

   Naming Ethers  667
   About Ethers  668

18.14  Aldehydes and Ketones  668

   Naming Aldehydes and Ketones  669
   About Aldehydes and Ketones  669

18.15  Carboxylic Acids and Esters  670

  Naming Carboxylic Acids and Esters  671
   About Carboxylic Acids and Esters  671

18.16  Amines  673

18.17  Polymers  674

   EVERYDAY CHEMISTRY  Kevlar: Stronger Than Steel  676

CHAPTER IN REVIEW  677

KEY TERMS  681

EXERCISES  682

19  Biochemistry  696

19.1  The Human Genome Project  697

19.2  The Cell and Its Main Chemical Components  698

19.3  Carbohydrates: Sugar, Starch, and Fiber  698

   Monosaccharides  699
   Disaccharides  700
   Polysaccharides  701

19.4  Lipids  703

   Fatty Acids  703
   Fats and Oils  704
   Other Lipids  706

   CHEMISTRY AND HEALTH  Dietary Fats  708

19.5  Proteins  709

19.6  Protein Structure  713

   Primary Structure  714
   Secondary Structure  714

   EVERYDAY CHEMISTRY  Why Hair Gets Longer When It Is Wet  716

   Tertiary Structure  716
   Quaternary Structure  717

19.7  Nucleic Acids: Molecular Blueprints  718

19.8  DNA Structure, DNA Replication, and Protein Synthesis  720

   DNA Structure  721
   DNA Replication  722
   Protein Synthesis  723

   CHEMISTRY AND HEALTH  Drugs for Diabetes  725

CHAPTER IN REVIEW  725

KEY TERMS  728

EXERCISES  728

Appendix: Mathematics Review  MR-1

Glossary  G-1

Answers to Odd-Numbered Exercises  A-1

Photo Credits  PC-1

Index  I-1
## Problem-Solving Procedures

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solving Unit Conversion Problems</td>
<td>30</td>
</tr>
<tr>
<td>Solving Numerical Problems</td>
<td>40</td>
</tr>
<tr>
<td>Writing Formulas for Ionic Compounds</td>
<td>138</td>
</tr>
<tr>
<td>Obtaining an Empirical Formula from Experimental Data</td>
<td>187</td>
</tr>
<tr>
<td>Writing Balanced Chemical Equations</td>
<td>212</td>
</tr>
<tr>
<td>Writing Equations for Precipitation Reactions</td>
<td>220</td>
</tr>
<tr>
<td>Writing Lewis Structures for Covalent Compounds</td>
<td>331</td>
</tr>
<tr>
<td>Predicting Geometry Using VSEPR Theory</td>
<td>339</td>
</tr>
<tr>
<td>Balancing Redox Equations Using the Half-Reaction Method</td>
<td>583</td>
</tr>
<tr>
<td>Naming Alkanes</td>
<td>655</td>
</tr>
</tbody>
</table>
This book is for you, and every text feature is meant to help you learn. I have two main goals for you in this course: to see chemistry as you never have before and to develop the problem-solving skills you need to succeed in chemistry.

I want you to experience chemistry in a new way. I have written each chapter to show you that chemistry is not just something that happens in a laboratory; chemistry surrounds you at every moment. I have worked with several outstanding artists to develop photographs and art that will help you visualize the molecular world. From the opening example to the closing chapter, you will see chemistry. My hope is that when you finish this course, you will think differently about your world because you understand the molecular interactions that underlie everything around you.

My second goal is for you to develop problem-solving skills. No one succeeds in chemistry—or in life, really—without the ability to solve problems. I can’t give you a formula for problem solving, but I can give you strategies that will help you develop the chemical intuition you need to understand chemical reasoning.

Look for several recurring structures throughout this book designed to help you master problem solving. The most important ones are (1) a four-step process (Sort, Strategize, Solve, and Check) designed to help you learn how to solve problems; (2) the solution map, a visual aid that helps you navigate your way through problems; (3) the two-column Examples, in which the left column explains in clear and simple language the purpose of each step of the solution shown in the right column; and (4) the three-column Examples, which describe a problem-solving procedure while demonstrating how it is applied to two different Examples. In addition, you will find a For More Practice feature at the end of each worked Example that directs you to the end-of-chapter problems that provide more opportunity to practice the skill(s) covered in the Example. In this edition, I have added a new tool for you at the end of each chapter: a Self-Assessment Quiz. These quizzes are designed to help you test yourself on the core concepts and skills of each chapter. You can also use them as you prepare for exams. Before an exam, take the quiz associated with each chapter that the exam will cover. The questions you miss on the quiz will reveal the areas you need to spend the most time studying.

Lastly, I hope this book leaves you with the knowledge that chemistry is not reserved only for those with some superhuman intelligence level. With the right amount of effort and some clear guidance, anyone can master chemistry, including you.

Sincerely,

Nivaldo J. Tro
tro@westmont.edu
To the Instructor

I thank all of you who have used any of the first four editions of *Introductory Chemistry*—you have made this book the most widely selling book in its market, and for that I am extremely grateful. The preparation of the fifth edition has enabled me to continue to refine the book to meet its fundamental purpose: teaching chemical skills in the context of relevance.

*Introductory Chemistry* is designed for a one-semester, college-level, introductory or preparatory chemistry course. Students taking this course need to develop problem-solving skills—but they also must see why these skills are important to them and to their world. *Introductory Chemistry* extends chemistry from the laboratory to the student’s world. It motivates students to learn chemistry by demonstrating the role it plays in their daily lives.

This is a visual book. Wherever possible, I have used images to help communicate the subject. In developing chemical principles, for example, I worked with several artists to develop multipart images that show the connection between everyday processes visible to the eye and the molecular interactions responsible for those processes. This art has been further refined and improved in the fifth edition, making the visual impact sharper and more targeted to student learning. For example, you will note a hierarchical system of labeling in many of the images: The white-boxed labels are the most important, the tan-tint boxes are the second most important, and unboxed labels are the third most important. This allows me to treat related labels and annotations within an image in the same way, so that the relationships between them are immediately evident. My intent is to create an art program that teaches and that presents complex information clearly and concisely. Many of the illustrations showing molecular depictions of a real-world object or process have three parts: macroscopic (what we can see with our eyes); molecular and atomic (space-filling models that depict what the molecules and atoms are doing); and symbolic (how chemists represent the molecular and atomic world). The goal is for the student to begin to see the connections between the macroscopic world, the molecular world, and the representation of the molecular world with symbols and formulas.

I have also refined the problem-solving pedagogy to include four steps: Sort, Strategize, Solve, and Check. The solution map, which has been part of this book since the first edition, is now part of the Strategize step. This four-step procedure is meant to guide students as they learn chemical problem solving. Extensive flowcharts are also incorporated throughout the book, allowing students to visualize the organization of chemical ideas and concepts. The color scheme used in both the solution maps and the flowcharts is designed to have pedagogical value. More specifically, the solution maps utilize the colors of the visible spectrum—always in the same order, from violet to red.

Throughout the worked Examples in this book, I use a two- or three-column layout in which students learn a general procedure for solving problems of a particular type as they see this procedure applied to one or two worked Examples. In this format, the explanation of how to solve a problem is placed directly beside the actual steps in the solution of the problem. Many of you have said that you use a similar technique in lecture and office hours. Since students have specifically asked for connections between Examples and end-of-chapter problems, I include a For More Practice feature at the end of each worked Example that lists the review examples and end-of-chapter problems that provide additional opportunities to practice the skill(s) covered in the Example.
A successful new feature in the second edition was the Conceptual Checkpoints, a series of short questions that students can use to test their mastery of key concepts as they read through a chapter. Emphasizing understanding rather than calculation, they are designed to be easy to answer if the student has grasped the essential concept but difficult if he or she has not. Your positive remarks on this new feature prompted me to continue adding more of these to the fifth edition, including questions that highlight visualization of the molecular world.

This edition has allowed me to add four new global features to the book: Learning Outcomes (LOs), Group Questions, Self-Assessment Quizzes, and Interactive Worked Examples. You will find the learning outcomes underneath most section heads—many of the LOs are repeated in the end of chapter material with an associated worked example. You will find the Group Questions following the chapter exercises. You can assign these as homework if you would like, but you can also use them as in class activities to encourage active learning and peer-to-peer engagement. The Self-Assessment Quizzes are at the very beginning of the chapter review material. These quizzes are designed so that students can test themselves on the core concepts and skills of each chapter. I encourage my students to use these quizzes as they prepare for exams. For example, if my exam covers Chapters 5–8, I assign the quizzes for those chapters for credit (you can do this in MasteringChemistry®). Students then get a sort of pretest on the core material that will be on the exam. The Interactive Worked Examples are a new digital asset that we created for this edition. These examples are available in MasteringChemistry® and at the following website: www.pearsonhighered.com/irc. Each Interactive Worked Example walks the student through a key example from the book (the examples that have been made interactive are marked with a play icon in the book). At a key point in the Interactive Worked Example, the video pauses and the student is asked a question. These questions are designed to encourage students to be active in the learning process. Once the student answers the question, the video resumes to the end. A follow-up question can then be assigned for credit in MasteringChemistry®.

My goal in this new edition is to continue to help you make learning a more active (rather than passive) process for your students. The new Group Questions can help make your classroom more active. The new Conceptual Checkpoints, along with the new Self-Assessment Quizzes, make reading the book a more active process. The addition of the Interactive Worked Examples makes the media experience active as well. Research consistently shows that students learn better when they are actively engaged in the process. I hope the tools that I have provided here continue to aid you in teaching your students more effectively. Please feel free to e-mail me with any questions or comments you might have. I look forward to hearing from you as you use this book in your course.

Sincerely,

Nivaldo J. Tro
tro@westmont.edu
Preface

New to This Edition

NEW! Key Learning Outcomes have been added to each chapter section. Learning outcomes correlate to the Chemical Skills and Examples in the end-of-chapter material and to MasteringChemistry®. Each section (after the introductory sections) has at least one learning outcome that summarizes the key learning objective of the material to help students focus their learning and assess their progress.

NEW! Self-Assessment Quizzes. Each chapter contains a 10-15 question multiple choice self-assessment quiz. These quizzes are designed to help students review the chapter material and prepare for exams.

NEW! 3–4 Questions for Group Work have been added to the end-of-chapter problems in each chapter to facilitate guided-inquiry learning both inside and outside the classroom.

NEW! 20 Interactive Worked Examples. Interactive Worked Examples are digital versions of the text’s worked examples that make Tro’s unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital versions, students are instructed how to break down problems using Tro’s proven Sort, Strategize, Solve, and Check technique. The Interactive Worked Examples can be accessed by scanning the QR code on the back cover allowing students to quickly access an office-hour type experience.

These problems are incorporated into MasteringChemistry® as assignable tutorial activities and are also available for download and distribution via the Instructor Resource Center (IRC) for instructional and classroom use.

More than 20 New Conceptual Checkpoints are in the fifth edition and are designed to make reading the book an active process. The checkpoints encourage students to stop and think about the ideas just presented before moving on and also provide a tool for self-assessment.

Interest Box Questions are now numbered in the Everyday Chemistry, Chemistry in the Environment, Chemistry in the Media, and Chemistry and Health boxes so that they can easily be assigned.

Cross-references to the Math Appendix, now indicated by a +/- icon in the fifth edition, are more visible and allow students to locate additional resources more easily.

Additional Features

- A student-friendly, step-by-step, problem-solving approach is presented throughout the book (fully introduced and explained in Chapter 2): Tro’s unique two-and three-column examples help guide students through problems
step-by-step using Sort, Strategize, Solve, and Check. “Relationships Used” are also included in most worked examples.

- **In all chapters, figure labels follow a consistent hierarchy.** Three types of labels appear in the art. The most important information is in white shadow boxes; the second most important is in tinted boxes (with no border); and the third level of labels is unboxed.
- **All figures and figure captions have been carefully examined, and images and labels have been replaced or revised when needed** to improve the teaching focus of the art program.
- **Every end-of-chapter question has been carefully reviewed** by the author and editor and accordingly revised and/or replaced when necessary.

Some significant improvements have been made to key content areas as well. These include:

- To reflect recent changes made by IUPAC that introduce more uncertainty in atomic masses, the periodic tables on the inside front cover of the book and all subsequent periodic tables in the text containing atomic masses now include the modified following atomic masses: Li 6.94; S 32.06; Ge 72.63; Se 78.97; and Mo 95.95.
- In Chapter 1, *The Chemical World*, key wording about chemicals as well as the definition of chemistry have been changed to more strongly reflect particles and properties connection.
- In Section 2.3, *Significant Figures: Writing Numbers to Reflect Precision*, clarification has been added about trailing zeros in the significant digits discussion in Section 2.3.
- In Section 3.8, *Energy*, a new schematic has been added to the photo of the dam to better illustrate the concept of potential energy, and there is a new figure, Figure 3.15, *Potential Energy of Raised Weight*.
- Several new subheadings have been added to Chapter 5 to help students better navigate the material; Table 5.3, *Some Common Polyatomic Ions*, has been moved to an earlier place in Chapter 5; and fourth edition Example 5.7, *Writing Formulas for Ionic Compounds*, has been replaced with fifth edition Example 5.7, *Writing Formulas for Ionic Compounds Containing Polyatomic Ions*.
- In Chapter 6, Chemistry in the Environment box *Chlorine in Chlorofluorocarbons* has been revised and updated. Figure 6.3, *The Ozone Shield*, has been updated and revised to include a molecular perspective and be a better teaching tool and Figure 6.4, *Growth of the Ozone Hole*, has been updated with 2010 data.
- The transition between balancing chemical equations to investigating types of reactions at the beginning of Section 7.5, *Aqueous Solutions and Solubility: Compounds Dissolved in Water*, has been sharpened to help students relate Section 7.5 to the previous section.
- Figure 7.7, *Solubility Rules Flowchart*, has been edited so that Ca$^{2+}$, Sr$^{2+}$, and Ba$^{2+}$ are in periodic table order throughout for easier memorization.
- The phrase “global warming” has been replaced with “climate change” throughout Chapter 8, *Quantities in Chemical Reactions*, and Figure 8.2, *Climate Change*, has been updated to include global temperature data for 2011 and 2012.
- In Section 9.1, *Blimps, Balloons, and Models of the Atom*, more emphasis has been placed on the relationship between atomic structure and properties in the discussion of helium and hydrogen.
- In Section 9.4, *The Bohr Model: Atoms with Orbits*, new introductory material has been added to emphasize the relationship between light emission and electron motion.
Preface

• Orbital representations in figures throughout Chapter 9 have been modified to be more accurate.
• Throughout Chapter 10, Chemical Bonding, the term Lewis theory has been replaced with Lewis model.
• In Chapter 11, Gases, an update about how newer jets pressurize their cabins has been added to the Everyday Chemistry box, Airplane Cabin Pressurization, and Table 11.5, Changes in Pollutant Levels for Major U.S. Cities, 1980–2010, has been updated to include the most recent available data.
• Content has been revised and material has been added to improve clarity in the subsection entitled Surface Tension in Section 12.3, Intermolecular Forces in Action: Surface Tension and Viscosity. Also, the caption for Figure 12.5, Origin of Surface Tension, has been revised and the phase inset figures in Figure 12.16, Heating Curve during Melting, have been corrected to show the phases more accurately.
• The new title for Section 12.6, Types of Intermolecular Forces: Dispersion, Dipole–Dipole, Hydrogen Bonding, and Ion–Dipole, reflects new content and new material about ion–dipole forces, including new Figure 12.25, Ion–Dipole Forces. Also, ion–dipole forces have been added to Table 12.5, Types of Intermolecular Forces, and the art in the table now depicts space-filling models of the molecules.
• Content in Section 13.3, Solutions of Solids Dissolved in Water: How to Make Rock Candy, links the discussion of solvent–solute interactions to the discussion of intermolecular forces in Chapter 12.
• Figure 14.19, How Buffers Resist pH Change, has been changed to be more useful and easier for students to understand.
• Section 14.11, Acid Rain: An Environmental Problem Related to Fossil Fuel Combustion, has been cut.
• New, brief introductory statements have been added to Section 15.6, Calculating and Using Equilibrium Constants, and in Section 15.10, The Effect of a Temperature Change on Equilibrium, numbers that indicate sequence have been added to the three unnumbered equations that indicate how equilibrium changes when heat is added or removed from exothermic and endothermic reactions.
• The title of Figure 16.12, Used Voltaic Cell, has been corrected, and the art has been slightly modified.
• Figure 16.18, Schematic Diagram of a Fuel-Cell Breathalyzer, in the box Everyday Chemistry: The Fuel-Cell Breathalyzer has also been modified for accuracy.
• Clarification has been added in Section 18.10, Aromatic Hydrocarbons, in the discussion of the carbon–carbon bonds in benzene.

The design and features of this text have been conceived to work together as an integrated whole with a single purpose: to help students understand chemical principles and to master problem-solving skills in a context of relevance. Students must be able not only to grasp chemical concepts and solve chemical problems, but also to understand how those concepts and problem-solving skills are relevant to their other courses, their eventual career paths, and their daily lives.

Teaching Principles

The development of basic chemical principles—such as those of atomic structure, chemical bonding, chemical reactions, and the gas laws—is one of the main goals of this text. Students must acquire a firm grasp of these principles in order to succeed in the general chemistry sequence or the chemistry courses that support the
allied health curriculum. To that end, the book integrates qualitative and quantitative material and proceeds from concrete concepts to more abstract ones.

**Organization of the Text**

The main divergence in topic ordering among instructors teaching introductory and preparatory chemistry courses is the placement of electronic structure and chemical bonding. Should these topics come early, at the point where models for the atom are being discussed? Or should they come later, after the student has been exposed to chemical compounds and chemical reactions? Early placement gives students a theoretical framework within which they can understand compounds and reactions. However, it also presents students with abstract models before they understand why they are necessary. I have chosen a later placement for the following reasons:

1. **A later placement provides greater flexibility.** An instructor who wants to cover atomic theory and bonding earlier can simply cover Chapters 9 and 10 after Chapter 4. However, if atomic theory and bonding were placed earlier, it would be more difficult for the instructor to skip these chapters and come back to them later.

2. **A later placement allows earlier coverage of topics that students can more easily visualize.** Coverage of abstract topics too early in a course can lose some students. Chemical compounds and chemical reactions are more tangible than atomic orbitals, and their relevance is easier to demonstrate to the beginning student.

3. **A later placement gives students a reason to learn an abstract theory.** Once students learn about compounds and reactions, they are more easily motivated to learn a theory that explains compounds and reactions in terms of underlying causes.

4. **A later placement follows the scientific method.** In science, we normally make observations, form laws, and then build models or theories that explain our observations and laws. A later placement follows this ordering.

Nonetheless, I know that every course is unique and that each instructor chooses to cover topics in his or her own way. Consequently, I have written each chapter for maximum flexibility in topic ordering. In addition, the book is offered in two formats. The full version, *Introductory Chemistry*, contains 19 chapters, including organic chemistry and biochemistry. The shorter version, *Introductory Chemistry Essentials*, contains 17 chapters and omits these topics.

---

**Print and Media Resources**

**For the Instructor**

*MasteringChemistry®*

*MasteringChemistry®* is the first adaptive-learning online homework and tutorial system. Instructors can create online assignments for their students by choosing from a wide range of items, including end-of-chapter problems and research-enhanced tutorials. Assignments are automatically graded with up-to-date diagnostic information, helping instructors pinpoint where students struggle either individually or for the class as a whole. These questions can be used asynchro-
nously outside of class as well. For the fifth edition, 20 new Interactive Worked Examples have been added to the Study Area. Icons appear next to examples indicating that a digital version is available.

NEW! Learning Catalytics™
Learning Catalytics™ is a “bring your own device” student engagement, assessment, and classroom intelligence system. With Learning Catalytics™ you can:

• Assess students in real time, using open-ended tasks to probe student understanding.
• Understand immediately where students are and adjust your lecture accordingly.
• Improve your students’ critical-thinking skills.
• Access rich analytics to understand student performance.
• Add your own questions to make Learning Catalytics™ fits your course exactly.
• Manage student interactions with intelligent grouping and timing.

Learning Catalytics™ is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction. Learning Catalytics™ is included with the purchase of Mastering with eText. Students purchasing Mastering without eText will be able to upgrade their Mastering accounts to include access to Learning Catalytics™. Michael Everest of Westmont College has written a set of questions in Learning Catalytics™ that correlates directly to the topics and concepts in Introductory Chemistry, 5e and encourages group-based inquiry learning.

NEW! Adaptive Follow-up Assignments in MasteringChemistry®
Instructors now have the ability to assign adaptive follow-up assignments to students. Content delivered to students as part of adaptive learning will be automatically personalized for each individual based on strengths and weaknesses identified by his or her performance on Mastering parent assignments.

NEW! Dynamic Study Modules, designed to enable students to study effectively on their own, as well as help students quickly access and learn the nomenclature they need to be more successful in chemistry. These modules can be accessed on smartphones, tablets, and computers and results can be tracked in the MasteringChemistry® Gradebook. How it works:

1. Students receive an initial set of questions and benefit from the metacognition involved with asking them to indicate how confident they are with their answer.
2. After answering each set of questions, students review their answers.
3. Each question has explanation material that reinforces the correct answer response and addresses the misconceptions found in the wrong answer choices.
4. Once students review the explanations, they are presented with a new set of questions. Students cycle through this dynamic process of test-learn-retest until they achieve mastery of the material.

Instructor’s Manual with Complete Solutions (0-321-94906-4) by Mark Ott of Jackson Community College, and Matthew Johll of Illinois Valley Community College. This manual features lecture outlines with presentation suggestions, teaching tips, suggested in-class demonstrations, and topics for classroom discussion. It also contains full solutions to all the end-of-chapter problems from the text.
TestGen Testbank (0-321-94933-1) by Michael Hauser of St. Louis Community College. This download-only test bank includes more than 2000 questions and is available on the Instructor’s Resource Center.

Instructor’s Resource Materials (0-321-94932-3) This resource provides an integrated collection of resources to help instructors make efficient and effective use of their time and is available for download from the Instructor’s Resource Center. The package features the following:

- All the art from the text, including figures and tables in JPG and PDF formats; movies; animations; Interactive Molecules; and the Instructor’s Resource Manual files.
- Four PowerPoint™ presentations: (1) a lecture outline presentation for each chapter, (2) all the art from the text, (3) the worked Examples from the text, and (4) clicker questions.
- TestGen, a computerized version of the Test Item File that allows instructors to create and tailor exams to fit their needs.

Instructor’s Guide for Student’s Guided Activity Workbook (0-321-96118-8) by Michael Everest of Westmont College. This manual features assessible outcomes, facilitation tips, and demonstration suggestions to help integrate guided-inquiry learning in the classroom and is available for download on the Instructor’s Resource Center.

For the Student


Study Guide (0-321-94905-6) by Donna Friedman of St. Louis Community College—Florissant Valley. Each chapter of the Study Guide contains an overview, key learning outcomes, a chapter review, as well as practice problems for each major concept in the text. Each chapter is followed by two or three self-tests with answers so students can check their work.

Student’s Selected Solution Manual (0-321-94907-2) by Matthew Johll of Illinois Valley Community College. The manual provides solutions to those problems that have a short answer in the text’s Answers section (problems numbered in blue in the text).

NEW! Student’s Guided Activity Workbook (0-321-94908-0) by Michael Everest of Westmont College. This set of guided-inquiry activities enables students to construct chemical knowledge and related skills on their own. Each activity begins by presenting some information (as a table, figure, graph, text, etc.). Students, working in groups of 3–4, answer questions designed to draw their attention to the important concepts and trends exemplified in the information. Through their active participation in the learning process, students learn not only chemistry, but also a wide range of additional skills such as information processing, problem solving, deductive reasoning, and teamwork. There are approximately three complete worksheets to accompany each chapter in Introductory Chemistry, and each worksheet should take students from 50–60 minutes to complete. The activities can be used in place of, or as a supplement to, a lecture-based pedagogy. This supplement is available through Pearson Custom Library www.pearsoncustomlibrary.com.
Acknowledgments

This book has been a group effort, and there are many people whose help has meant a great deal to me. First and foremost, I would like to thank my editors, Adam Jaworski and Chris Hess. I appreciate your commitment to and energy for this project. You are both incredibly bright and insightful editors, and I am lucky to get to work with you. As always, I am grateful to Paul Corey, the president of the Science Division at Pearson, for his unwavering support.

I am also in a continual state of awe and gratitude to Erin Mulligan, my development editor and friend. Thanks, Erin, for all your outstanding help and advice. Thanks also to my project editor, Coleen Morrison. Coleen, your guidance and attention to details kept this project running smoothly from start to finish. I am so grateful. I would also like to thank Jonathan Cottrell, my marketing manager, whose creativity in describing and promoting the book is without equal. Thanks also to the MasteringChemistry® team who continue to provide and promote the best online homework system on the planet.

I also appreciate the expertise and professionalism of my copy editor, Betty Pessagno, as well as the skill and diligence of Francesca Monaco and her colleagues at codeMantra. I am a picky author, and they always accommodated my seemingly endless requests. Thank you, Francesca. Thanks as well to my project manager, Beth Sweeten, managing editor Gina Cheselka, and the rest of the Pearson team—they are part of a first-class operation. This text has benefited immeasurably from their talents and hard work. I owe a special debt of gratitude to Quade Paul, who continues to make my ideas come alive in his chapter-opener and cover art.

I am grateful for the support of my colleagues Allan Nishimura, David Marten, Stephen Contakes, Kristi Lazar, Carrie Hill, Michael Everest, and Heidi Henes-Vanbergen, who have supported me in my department while I worked on this book. I am also grateful to Katherine Han, who helped me with the Self-Assessment Quizzes. I owe a special debt of gratitude to Michael Tro. He has been helping me with manuscript preparation, proofreading, organizing art manuscripts, and tracking changes in end-of-chapter material for the past three years. Michael has been reliable, accurate, and invaluable. Thanks Mikee!

I am grateful to those who have given so much to me personally while writing this book. First on that list is my wife, Ann. Her patience and love for me are beyond description. I also thank my children, Michael, Ali, Kyle, and Kaden, whose smiling faces and love of life always inspire me. I come from a large Cuban family, whose closeness and support most people would envy. Thanks to my parents, Nivaldo and Sara; my siblings, Sarita, Mary, and Jorge; my siblings-in-law, Jeff, Nachy, Karen, and John; my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

Lastly, I am indebted to the many reviewers, listed next, whose ideas are scattered throughout this book. They have corrected me, inspired me, and sharpened my thinking on how best to teach this subject we call chemistry. I deeply appreciate their commitment to this project.
Reviewers of the 5th Edition

Alyse Dilts  
Harrisburg Area Community College

Claire Cohen  
University of Toledo

Craig McClure  
University of Alabama — Birmingham

Ebru Buyuktanir  
Stark State College

Edward Lee  
Texas Tech University

James Zubricky  
University of Toledo

Janice Webster  
Ivy Tech Community College — Terre Haute

Jennifer Firestine  
Lindenwood University

Kathy Flynn  
College of the Canyons

Michael Hauser  
St. Louis Community College — Meramec

Michael Rodgers  
Southeast Missouri State University

Robert Culp  
California State University — Fresno

Rosa Davila  
College of Southern Idaho

Sara Harvey  
Los Angeles Pierce College

Scott Bunge  
Kent State University

Sylvia Esjornson  
Southwestern Oklahoma State University

Virginia Miller  
Montgomery College

5th Edition Accuracy Reviewers

Alyse Dilts  
Harrisburg Area Community College

Connie Lee  
Montgomery County Community College

Kent McCorkle  
Fresno City College

Lance Lund  
Anoka-Ramsey Community College

Stevenson Flemer Jr.  
University of Vermont

Reviewers of the 4th Edition

Brian G. Dixon  
Massachusetts Maritime Academy

Bruce E. Hodson  
Baylor University

Carmela Byrnes  
MiraCosta College

Carmela Magliocchi Brynes  
MiraCosta College

Chuck Laland  
Black Hawk College

Clarissa Sorenson-Unruh  
Central New Mexico Community College

David Vanderlinden  
Des Moines Area Community College

Donald R. Jones  
Lincoln Land Community College

Donna Friedman  
St. Louis Community College — Florissant Valley

Farkhondeh Khalili  
Massachusetts Bay Community College

Geoff Mitchell  
Washington International School

Guy Dadson  
Fullerton College

Jack F. McKenna  
St. Cloud State University

Jason Serin  
Glendale Community College

Jeannine Eddleton  
Virginia Tech

Jeffrey Allison  
Austin Community College

Jerod Gross  
Roanoke Benson High School

Jie Song  
University of Michigan — Flint

John Petty  
University of South Alabama

Joseph Bergman  
Illinois Central College

Kelly Beefus  
Anoka-Ramsey Community College

Lara Baxley  
California Polytechnic State University

Laurie Leblanc  
Cuyamaca College

Luther D. Giddings  
Salt Lake Community College

Marcus Giotto  
Quinsigamond Community College

Margaret Kiminsky  
Monroe Community College

Maria Cecilia D. de Mesa  
Baylor University

Martha R. Kellner  
Westminster College

Maru Grant  
Ohlone College

Meg Osterby  
Western Technical College

Melodie Graber  
Oakton Community College

Michael A. Hauser  
St. Louis Community College

Mikhail V. Barybin  
The University of Kansas

Nancy Lee  
MiraCosta College

Rebecca Krystyniak  
Saint Cloud State

Richard Lavallee  
Santa Monica College

Ron Erickson  
University of Iowa

Simon Bott  
University of Houston

Steven Socol  
McHenry Community College

Tamara E. Hanna  
Texas Tech University

Tammy S. Gumsheimer  
Schenectady County Community College

Timothy Dudley  
Vilanova University

Vicki MacMurdo  
Anoka-Ramsey Community College

Vidyullata C. Waghule  
St. Louis Community — Meramec

Virginia Miller  
Montgomery College

Youngju Sohn  
Florida Institute of Technology
Preface

Reviewers of the 3rd Edition

Anthony P. Toste
Missouri State University
Benjamin Arrowood
Ohio University
Carol A. Martinez
Central New Mexico Community College
Carrie Woodcock
Eastern Michigan University
Donna G. Friedman
St. Louis Community College
Erick Fuoco
Daley College
Joe Bergman
Illinois Central College
John Thurston
University of Iowa
Kathleen Thrush Shaginaw
Particular Solutions, Inc.
Kresimir Rupnik
Louisiana State University
Kurt Allen Teets
Oxaloosa-Walton College
Laurie LeBlanc
Grossmont College
Martha R. Joseph
Westminster College
Mary Sohn
Florida Tech
Melodie A. Graber
Oakton Community College
Michael A. Hauser
St Louis Community College, Meramec Campus
Pong (David) Shieh
Wharton College
Sharlene J. Dzugan
University of Cumberlands
Thomas Dzugan
University of Cumberlands
Timothy Dudley
Villanova University
Timothy Kreider
University of Medicine & Dentistry of New Jersey

Reviewers of the 2nd Edition

Blake Key
Northwestern Michigan College
Bryan E. Breyfogle
Southwest Missouri State University
Carl A. Hoeger
University of California—San Diego
Carol A. Martinez
Albuquerque Technical Vocational Institute
Charles Michael McCallum
University of the Pacific
Colin Bateman
Brevard Community College
Crystal Gambino
Manatee Community College
David S. Ballantine, Jr.
Northern Illinois University
Deborah G. Simon
Santa Fe Community College
Donald R. Jones
Lincoln Land Community College
Donna G. Friedman
St. Louis Community College—Florissant Valley
Donna K. Howell
Angelo State University
Eric L. Trump
Emporia State University
Frank Carey
Wharton County Junior College
James G. Tarter
College of Southern Idaho
Kirk Kawagoe
Fresno City College
Laurie LeBlanc
Cuyamaca College
Lynne Zeman
Kirkwood Community College
Mary Sohn
Florida Institute of Technology
Mary Urban
College of Lake County
Michael Hauser
St. Louis Community College—Meramec
Michele Berkey
San Juan College
Michelle Driessen
University of Minnesota—Minneapolis
Morris Bramlett
University of Arkansas—Monticello
Newton P. Hillard, Jr.
Eastern New Mexico University
Nichole Jackson
Odessa College
Peter-John Stanskas
San Bernardino Valley College
Rebecca A. Krystyniak
St. Cloud State University
Richard Watt
University of New Mexico
Robby C. Culp
Fresno City College
Robin McCann
Shippensburg University
Ronald C. Marks
Warner Southern College
Roy Kennedy
Massachusetts Bay Community College
Ruth M. Topich
Virginia Commonwealth University
Steve Gunther
Albuquerque Technical Vocational Institute
Steven R. Boone
Central Missouri State University
T. G. Jackson
University of South Alabama
Theodore Sakano
Rockland Community College
Victor Ryzhov
Northern Illinois University
Reviewers of the 1st Edition

Bill Nickels
Schoolcraft College

Bob Perkins
Kwantlen University College

Bryan E. Breyfogle
Southwest Missouri State University

C. Michael McCallum
University of the Pacific

Calvin D. Tormanen
Central Michigan University

Carl J. Carrano
Southwest Texas State University

Caryn Prudenté
University of Southern Maine

Christine V. Bilicki
Pasadena City College

Connie M. Roberts
Henderson State University

Danny R. Bedgood
Arizona State University

Donald C. Davis
College of Lake County

Donna G. Friedman
St. Louis Community College at Florissant Valley

Dwayne Gergens
San Diego Mesa College

Eric L. Trump
Emporia State University

George Goth
Skyline College

Jan Gryko
Jacksonville State University

Jeffery A. Schneider
SUNY—Oswego

Kathy Mitchell
St. Petersburg Junior College

Kim D. Summerhays
University of San Francisco

Laura Andersson
Big Bend Community College

Leslie Wo-Mei Fung
Loyola University of Chicago

Lori Allen
University of Wisconsin—Parkside

Mark Porter
Texas Tech University

Rill Ann Reuter
Winona State University

Ronald H. Takata
Honolulu Community College

Roy Kennedy
Massachusetts Bay Community College

Warren Bosch
Elgin Community College
A Consistent Problem-Solving Strategy

Drawing from Professor Tro’s experience in the classroom with his own students, *Introductory Chemistry, Fifth Edition* brings chemistry out of the laboratory and into the world—helping you learn chemistry by showing you how it manifests in your daily lives. Clear, specific examples are woven throughout to tell the story of chemistry. The *Fifth Edition* is also available with MasteringChemistry®, the premier online homework and assessment tool.

**A CONSISTENT STRATEGY FOR SOLVING PROBLEMS** helps you develop the skills you need to succeed in your chemistry course. Tro’s unique two- and three-column examples help guide students through problems step-by-step using Sort, Strategize, Solve, and Check.

**Two-Column Examples**

All but the simplest examples are presented in a unique two-column format.

- The left column explains the meaning of each part of the problem statement.
- The right column shows how to solve the problem step-by-step using Sort, Strategize, Solve, and Check.

**Three-Column Examples**

Procedures for solving certain problems are presented in a unique three-column format.

- The first column outlines the general procedure for solving the problem.
- The second column shows how to solve the problem step-by-step using Sort, Strategize, Solve, and Check.
- The third column is a solution map that helps you see the relationship between the steps.

**Solution Maps**

Many of the examples use a unique visual approach in the Strategize Step, where you’ll be shown how to draw a solution map for a problem.

**Skillbuilder Exercises**

Every worked example is followed by at least one similar (but unworked) Skillbuilder exercise.

**For More Practice**

These follow every worked example, linking you to in-chapter examples and end-of-chapter problems that give you a chance to practice the skills explained in each worked example.
NEW! INTERACTIVE WORKED EXAMPLES

Interactive Worked Examples are digital versions of the text’s worked examples that make Tro’s unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital versions, students are instructed how to break down problems using Tro’s proven Sort, Strategize, Solve, and Check technique. The Interactive Worked Examples can be accessed by scanning the QR code on the back cover allowing students to quickly access an office-hour type experience.

These problems are incorporated into MasteringChemistry® as assignable tutorial activities and are also available for download and distribution via the Instructor Resource Center (IRC) for instructional and classroom use.

CONCEPTUAL UNDERSTANDING completes the picture. In every chemistry course you take, success requires more than problem-solving skills. Real understanding of concepts will help you see why these skills are important to you and to your world.

Conceptual Checkpoints

Conceptual questions enhance understanding of chemical principles, encourage you to stop and think about the ideas just presented, and provide a tool to assess your own progress. Answers and explanations are given at the end of each chapter. More than 20 new Conceptual Checkpoints have been added—many with a focus on visualization and drawing.
Visualizing Chemistry Creates Deeper Understanding

BY CONNECTING the macroscopic and microscopic worlds, visualizing concepts brings chemistry to life and creates a deeper understanding that will serve you throughout the course.

Chapter Openers
Dr. Tro opens each chapter with a specific example of a concept to grab your attention, stepping back to make a more general and relatable analogy, and then going back to specifics. This style reflects Dr. Tro’s teaching methodology, effectively used in his own classroom.

INTEREST BOXES
Four different types of interest boxes apply chemistry to everyday events and topics. The questions within these boxes have been numbered so they may be assigned.

• Chemistry in the Environment boxes discuss environmental issues that are closely tied to chemistry, such as the reactions involved in ozone depletion.

• Everyday Chemistry boxes demonstrate the importance of chemistry in everyday situations, such as bleaching your hair.

• Chemistry in the Media boxes discuss chemical topics that have been in the news recently, such as the reactions involved in ozone depletion.

• Chemistry and Health boxes focus on personal health and fitness topics, as well as biomedical topics.

MACROSCOPIC TO MICROSCOPIC ART
The goal is for you to connect what you see and experience with the molecules responsible and with the way chemists represent those molecules.

Many illustrations have three parts:
• a macroscopic image (what you can see with your eyes)
• a microscopic image (what the molecules are doing)
• a symbolic representation (how chemists represent the process with symbols and equations)

THE DOSAGES GIVEN IN THE DRUG MASS PER PIL FOR COMMON PAIN RELIEVERS

Drug Mass per Pill for Common Pain Relievers

<table>
<thead>
<tr>
<th>Pain Reliever</th>
<th>Mass of Active Ingredient per Pill</th>
</tr>
</thead>
<tbody>
<tr>
<td>ibuprofen (Advil) 200 mg</td>
<td></td>
</tr>
<tr>
<td>acetaminophen (Tylenol) 325 mg</td>
<td></td>
</tr>
<tr>
<td>aspirin 325 mg</td>
<td></td>
</tr>
<tr>
<td>naproxen, extra strength (Aleve) 500 mg</td>
<td></td>
</tr>
<tr>
<td>naproxen, extra strength (Naprosyn) 500 mg</td>
<td></td>
</tr>
<tr>
<td>ibuprofen, extra strength (Motrin) 600 mg</td>
<td></td>
</tr>
<tr>
<td>ibuprofen, extra strength (Feldene) 200 mg</td>
<td></td>
</tr>
<tr>
<td>ibuprofen, extra strength (Imuran) 200 mg</td>
<td></td>
</tr>
</tbody>
</table>

When we choose to express drug dosage in the micro (or macro) image, we usually refer to a single active ingredient present in each tablet, such as the number of tablets to take per dose. The following table shows the mass of the active ingredient per pill in several common pain relievers, all reported as milligrams. The remainder of each tablet is composed of inactive ingredients such as cellulose (a fiber) and starch.

On most drugstore shelves, there are many different brands of regular-strength ibuprofen, some sold under the generic name of ibuprofen. Yet these pain relievers will most likely have different prices. Choose the least expensive. If you need to be more specific, ask about the strengths.

B2.C. CAN YOU ANSWER THIS?
Counts each of the doses in 8.6 with or without aspirin.

What is drug dosage not ideal for?
Chemical Principles

The left column summarizes the key principles that you should take away from the chapter, and the right column tells why each topic is important for you to understand.

**NEW! Chemical Skills with Key Learning Outcomes**

The left column describes the key skills you should know after reading the chapter, which often correlate to a Key Learning Outcome that has been added at the section level. The right column contains a worked example illustrating that skill.

**Chemical Principles**

Units: The density of a substance is a measure of the number of moles of substance per mass. Density is a fundamental property of a substance, and the tracking of units throughout calculations is essential.

The density of a substance is an important characteristic of the mixture and helps determine its usefulness. These properties help make predictions about the characteristics of different substances. Density is a fundamental property of a substance, and the tracking of units throughout calculations is essential.

**NEW!** Chapter Self-Assessment Quiz

The end of each chapter consists of 10–15 multiple-choice questions that are similar to those on other standardized exams and will also be assignable and randomized in MasteringChemistry®.

**CHAPTER IN REVIEW**

Consistent review material at the end of each chapter helps reinforce what you’ve learned.

**Questions for Group Work**

Discuss these questions with the group and record your consensus answer.

**NEW!** Group-Based Questions have been added to the end-of-chapter problems in each chapter, facilitating guided-inquiry learning both inside and outside the classroom. A new Guided Activity Workbook (available in the Pearson Custom Library (www.pearsoncustomlibrary.com)) has also been created to use alongside Tro’s textbook. A set of interactive Critical Thinking Questions that is tailored toward guided learning is also available for instructors at the Instructor Resource Center (www.pearsonhighered.com/irc).

**Enhanced End-of-Chapter Material**

**QUESTIONS FOR GROUP WORK**

Discuss these questions with the group and record your consensus answer.

**NEW!** Additional End-of-Chapter Features

- Key Terms
- Review Questions
- Problems by Topic
- Cumulative Problems
- Conceptual Problems
- Highlight Problems
MASTERING CHEMISTRY® TUTORIALS guide you through the most challenging topics while helping to make connections between related chemical concepts. Immediate feedback and tutorial assistance help you understand and master concepts and skills in chemistry—allowing you to retain more knowledge and perform better in this course and beyond.

MASTERING CHEMISTRY® is the only system to provide instantaneous feedback specific to the most common wrong answers. You can submit an answer and receive immediate, error-specific feedback. Simpler subproblems—hints—are provided upon request.

NEW! Pause and Predict Video Quizzes ask you to predict the outcome of experiments and demonstrations as you watch the videos; a set of multiple choice questions challenges you to apply the concepts from the video to related scenarios. These videos are also available in web and mobile-friendly formats through the Study Area of MasteringChemistry and in the Pearson eText.

Math Remediation links found in selected tutorials launch algorithmically generated math exercises that give you unlimited opportunity for practice and mastery of math skills. Math Remediation exercises provide additional practice and free up class and office-hour time to focus on the chemistry. Exercises include guided solutions, sample problems, and learning aids for extra help and offer helpful feedback when you enter incorrect answers.

NEW! Simulations, assignable in MasteringChemistry, include those developed by the PhET Chemistry Group, and the leading authors in simulation development covering some of the most difficult chemistry concepts.
NEW! Learning Catalytics™ is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics™ you can:

• Assess students in real time, using open-ended tasks to probe student understanding.
• Understand immediately where students are and adjust your lecture accordingly.
• Improve your students’ critical-thinking skills.
• Access rich analytics to understand student performance.
• Add your own questions to make Learning Catalytics™ fit your course exactly.
• Manage student interactions with intelligent grouping and timing.

Learning Catalytics™ is included with the purchase of Mastering with eText. Students purchasing Mastering without eText will be able to upgrade their Mastering accounts to include access to Learning Catalytics™.

NEW! Adaptive Follow-Up Assignments
Instructors now have the ability to assign adaptive follow-up assignments to students. Content delivered to students as part of adaptive learning will be automatically personalized for each individual based on strengths and weaknesses identified by his or her performance on Mastering parent assignments.

NEW! Dynamic Study Modules, designed to enable students to study effectively on their own as well as help students quickly access and learn the nomenclature they need to be more successful in chemistry. These modules can be accessed on smartphones, tablets, and computers and results can be tracked in the MasteringChemistry® Gradebook. How it works:

1. Students receive an initial set of questions and benefit from the metacognition involved with asking them to indicate how confident they are with their answer.
2. After answering each set of questions, students review their answers.
3. Each question has explanation material that reinforces the correct answer response and addresses the misconceptions found in the wrong answer choices.
4. Once students review the explanations, they are presented with a new set of questions. Students cycle through this dynamic process of test-learn-retest until they achieve mastery of the material.

NEW! Learning Outcomes
Let Mastering do the work in tracking student performance against your learning outcomes:

• Add your own or use the publisher provided learning outcomes.
• View class performance against the specified learning outcomes.
• Export results to a spreadsheet that you can further customize and share with your chair, dean, administrator, or accreditation board.