McGraw-Hill Ryerson

# Chemistry 12


## Author Team

**Dr. Frank Mustoe**
The University of Toronto Schools
Toronto, Ontario

**Michael P. Jansen**
Crescent School
Toronto, Ontario

**Dr. Michael Webb**
Michael J. Webb Consulting Inc.
Toronto, Ontario

**Christy Hayhoe**
Professional Writer
Toronto, Ontario

**Dr. Andrew Cherkas**
Stouffville District Secondary School
Stouffville, Ontario

**Jim Gaylor**
Formerly with St. Michael
Catholic Secondary School
Stratford, Ontario

## Contributing Author

**Jonathan Bocknek**
Professional Writer
Slocan Park, British Columbia

**Christa Bedry**
Professional Writer
Cochrane, Alberta

## Consultants

**Greg Wisnicki**
Anderson Collegiate and Vocational Institute
Whitby, Ontario

**Dr. Audrey Chastko**
Springbank Community High School
Calgary, Alberta

**Ted Doram**
Bowness High School
Calgary, Alberta

## Probeware Specialist

**Kelly Choy**
Minnedosa Collegiate
Minnedosa, Manitoba

## Technology Consultants

**Alex Annab**
Head of Science
Iona Catholic Secondary School
Mississauga, Ontario



McGraw-Hill Ryerson

Toronto Montréal Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco
St. Louis Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan New Delhi Santiago Seoul Singapore Sydney Taipei

*McGraw-Hill Ryerson Limited*
*A Subsidiary of The McGraw-Hill Companies*

*COPIES OF THIS BOOK MAY BE OBTAINED BY CONTACTING:*
McGraw-Hill Ryerson Ltd.

E-MAIL:
*orders@mcgrawhill.ca*

TOLL FREE FAX:
1-800-463-5885

TOLL FREE CALL:
1-800-565-5758

OR BY MAILING YOUR ORDER TO:
McGraw-Hill Ryerson
Order Department,
300 Water Street,
Whitby ON, L1N 9B6

Please quote the ISBN and title when placing your order.



0-07-088686-5

*http://www.mcgrawhill.ca*

2 3 4 5 6 7 8 9 0 TRI 0 9 8 7 6 5 4 3 2 1

Printed and bound in Canada



**National Library of Canada Cataloguing in Publication Data**

Main entry under title:

McGraw-Hill Ryerson chemistry 12

Includes index.

ISBN 0-07-088686-5

1. Chemistry. I. Webb, Michael II. Title. III. Title: Chemistry 12. IV. Title: Chemistry twelve. V. Title: McGraw-Hill Ryerson chemistry twelve.

QD33. M334 2002 540 C2002-900241-9

**The Chemistry 12 Team**

SCIENCE PUBLISHER: Jane McNulty

PROJECT MANAGER: David Spiegel

SENIOR DEVELOPMENTAL EDITOR: Jonathan Bocknek

DEVELOPMENTAL EDITORS: Christa Bedry, Sara Goodchild, Christy Hayhoe, Winnie Siu

SENIOR SUPERVISING EDITOR: Linda Allison

PROJECT CO-ORDINATOR: Valerie Janicki

PROJECT ASSISTANTS: Melissa Nippard, Janie Reeson

COPY EDITORS: Paula Pettitt-Townsend, May Look

PERMISSIONS EDITOR: Pronk&Associates

SPECIAL FEATURES CO-ORDINATOR: Keith Owen Richards

PRODUCTION CO-ORDINATOR: Jennifer Wilkie

PRODUCTION SUPERVISOR: Yolanda Pigden

DESIGN AND ELECTRONIC PAGE MAKE-UP: Pronk&Associates

SET-UP PHOTOGRAPHY: Ian Crysler

SET-UP PHOTOGRAPHY CO-ORDINATOR: Shannon O'Rourke

TECHNICAL ILLUSTRATION: Theresa Sakno, Jun Park, Pronk&Associates

COVER IMAGE: Ken Edwards/Science Source/Photo Researchers Inc.

## Acknowledgements

We extend sincere thanks to the following people: Greg Wisnicki, for his extremely helpful suggestions in his role as consultant and for writing and testing labs during the development of Unit 5; Audrey Chastko, whose astute and detailed comments contributed greatly to the development of this textbook; and Ted Doram, for his excellent insights as a consultant and for testing labs during the development of Unit 1. We are deeply grateful as well to Dr. Frank Mustoe for his help with the set-up photography sessions, and we thank the students of the University of Toronto Schools who participated in these sessions. We also wish to thank the following professional writers who authored the Special Features in *Chemistry 12*: Jess Aldred, Jeremy Boxen, Kirsten Craven, Natasha Marko, Denyse O'Leary, Patrick Rengger, and Erik Spigel. We thank the designers at Pronk&Associates, who collaborated closely with us to bring this book to life. Finally, the *Chemistry 12* development team benefited greatly from the many thoughtful ideas and recommendations provided by our reviewers from across the country, as well as from the comments supplied by our safety reviewer. The authors, publisher, consultants, and editors convey their profound thanks to these talented and dedicated educators. Finally, we acknowledge, with gratitude and respect, Trudy Rising, who initiated McGraw-Hill Ryerson's senior science program, and who worked tirelessly in support of the program, its authors, and its development team.

### Pedagogical and Academic Reviewers

**Christina Clancy**
Loyola Catholic Secondary School
Mississauga, Ontario

**Charles Cohen**
Community Hebrew
Academy of Toronto
Toronto, Ontario

**André Dumais**
Hearst High School
Hearst, Ontario

**John Eix**
Formerly with Upper Canada College
Toronto, Ontario

**Christopher Freure**
South Lincoln High School
Smithville, Ontario

**Theresa H. George**
St. Paul Catholic Secondary School
Mississauga, Ontario

**Gail Gislason**
Crescent Heights High School
Calgary, Alberta

**Dana Griffiths**
Bishops College
St. John's, Newfoundland

**Sarah Houlden**
Twin Lakes Secondary School
Orillia, Ontario

**Stephen Houlden**
Formerly with Toronto
District School Board
Toronto, Ontario

**Doug Jones**
Sir Winston Churchill Collegiate and
Vocational Institute
Thunder Bay, Ontario

**Dorothy Lai**
Anderson Collegiate and
Vocational Institute
Whitby, Ontario

**Cheryl Madeira**
Marshall McLuhan
Catholic Secondary School
Toronto, Ontario

**Glen McLeod**
Lakehead Public School Board
Thunder Bay, Ontario

**Dr. Penny McLeod**
Formerly with York Region
District School Board
Aurora, Ontario

**Henry Pasma**
Cawthra Park Secondary School
Mississauga, Ontario

**Cheryl Perkins**
Education Consultant
St. John's, Newfoundland

**Chris Schramek**
John Paul II Catholic
Secondary School
London, Ontario

**Brian Schroder**
Our Lady of Mount Carmel
Secondary School
Mississauga, Ontario

**James Sniatenchuk**
Bluevale Collegiate Institute
Waterloo, Ontario

**Donna Stack-Durward**
St. Mary's High School
Hamilton, Ontario

**Laurie Swackhammer**
Head of Science
Ancaster High School
Ancaster, Ontario

**Frank Villella**
St. Thomas More Catholic
Secondary School
Hamilton, Ontario

### Accuracy Reviewers

**Dr. Michael C. Baird**
Queen's University
Kingston, Ontario

**Dr. Christopher Flinn**
Memorial University
of Newfoundland
St. John's, Newfoundland

**Dr. R.J. Gillespie**
Department of Chemistry
McMaster University
Hamilton, Ontario

**Ian Krouse**
Formerly with University of Calgary
Calgary, Alberta
Purdue University
West Lafayette, Indiana

### Safety Reviewer

**John Henry**
Science Teachers Association
of Ontario Safety Committee
Toronto, Ontario

**Our cover:** The image on our cover shows a computer-generated model of a $C_{60}$ fullerene molecule, containing a molecule of methanol. Fullerenes are spherical molecules of carbon. Since their discovery in 1985, they have fascinated scientists with their perfect geometry and their range of potential applications, including superconductors, rocket fuels, and lubricants. Scientists can manipulate the properties of a fullerene by inserting an atom or a small molecule into it, as shown here, or by bonding a different chemical group to its outside surface. You will examine the connections between structure, bonding, and properties in Unit 2.

# Contents


**Safety in Your Chemistry Laboratory and Classroom** *viii*
**Introducing Chemistry 12** *xii*
**Concepts and Skills Review** *xiv*

**UNIT 1 Organic Chemistry** 2

**Chapter 1 Classifying Organic Compounds** 4

**1.1** Bonding and the Shape of Organic Molecules 5
*ExpressLab:* Molecular Shapes 6
**1.2** Hydrocarbons 12
**Careers in Chemistry:** The Art and Science of Perfumery 17
**1.3** Single-bonded Functional Groups 21
*ThoughtLab:* Comparing Intermolecular Forces 24
**1.4** Functional Groups with the C═O Bond 35
**Tools & Techniques:** Infrared Spectroscopy 38
*Investigation 1-A:* Preparing a Carboxylic Acid Derivative 42
*Investigation 1-B:* Comparing Physical Properties 49
Chapter 1 Review 52

**Chapter 2 Reactions of Organic Compounds** 56

**2.1** The Main Types of Organic Reactions 57
**2.2** Reactions of Functional Groups 65
**Canadians in Chemistry:** Dusanka Filipovic 69
*Investigation 2-A*: Oxidizing Alcohols 74
**2.3** Molecules on a Larger Scale: Polymers and Biomolecules 81
*Investigation 2-B*: Synthesis of a Polymer 86
**Chemistry Bulletin:** Degradable Plastics: Garbage That Takes Itself Out 89
**2.4** Organic Compounds and Everyday Life 97
*ThoughtLab*: Risk-Benefit Analyses of Organic Products 100
*ThoughtLab*: Problem Solving with Organic Compounds 103
Chapter 2 Review 105
Unit 1 Issue: Contemporary Issues Related to Organic Chemistry 110
Unit 1 Review 112

**UNIT 2 Structure and Properties** 116

**Chapter 3 Atoms, Electrons, and Periodic Trends** 118

**3.1** The Nuclear Atomic Model 119
*Investigation 3-A*: Atomic Emission Spectra (Teacher Demonstration) 124
**Careers in Chemistry:** Nuclear Medicine 129
**3.2** The Quantum Mechanical Model of the Atom 131

**3.3** Electron Configurations and Periodic Trends 139
*ThoughtLab*: Periodic Connections 151
Chapter 3 Review 159

**Chapter 4 Structure and Properties of Substances 162**

**4.1** Chemical Bonding 163
*Investigation 4-A*: Properties of Substances 164
**4.2** Molecular Shape and Polarity 173
*ExpressLab*: Using Soap Bubbles to Model Molecular Shape 180
**Tools & Techniques:** AIM Theory and Electron Density Maps 186
**4.3** Intermolecular Forces in Liquids and Solids 190
*ThoughtLab*: Properties of Liquids 196
**Canadians in Chemistry:** Dr. R.J. Le Roy 200
*Investigation 4-B*: Determining the Type of Bonding in Substances 202
**Chemistry Bulletin:** Ionic Liquids: A Solution to the Problem of Solutions 203
Chapter 4 Review 209
Unit 2 Project: Materials Convention 212
Unit 2 Review 214

**UNIT 3 Energy Changes and Rates of Reaction 218**

**Chapter 5 Energy and Change 220**

**5.1** The Energy of Physical, Chemical, and Nuclear Processes 221
**5.2** Determining Enthalpy of Reaction by Experiment 234
*Investigation 5-A*: Determining the Enthalpy of a Neutralization Reaction 240
**5.3** Hess's Law of Heat Summation 243
*Investigation 5-B*: Hess's Law and the Enthalpy of Combustion of Magnesium 248
**5.4** Energy Sources 256
*ThoughtLab*: Comparing Energy Sources 258
**Careers in Chemistry:** Nuclear Safety Supervisor 259
**Chemistry Bulletin:** Hot Ice 260
Chapter 5 Review 263

**Chapter 6 Rates of Chemical Reactions 266**

**6.1** Expressing and Measuring Reaction Rates 267
*ThoughtLab*: Average and Instantaneous Reaction Rates 270
*Investigation 6-A*: Studying Reaction Rates 274
**6.2** The Rate Law: Reactant Concentration and Rate 278
**6.3** Theories of Reaction Rates 289

**6.4** Reaction Mechanisms and Catalysts 297
*ThoughtLab*: Researching Catalysts 305
*Investigation 6-B*: Determining the Rate Law Equation for a Catalyzed Reaction 306
**Canadians in Chemistry:** Dr. Maud L. Menten 308
Chapter 6 Review 311
Unit 3 Project: Developing a Bulletin about Catalysts and Enzymes 314
Unit 3 Review 316

**UNIT 4 Chemical Systems and Equilibrium 320**

**Chapter 7 Reversible Reactions and Chemical Equilibrium 322**

**7.1** Recognizing Equilibrium 323
*ExpressLab*: Modelling Equilibrium 325
**7.2** Thermodynamics and Equilibrium 328
**7.3** The Equilibrium Constant 334
*Investigation 7-A*: Measuring an Equilibrium Constant 340
**7.4** Predicting the Direction of a Reaction 354
*Investigation 7-B*: Perturbing Equilibrium 358
**Chemistry Bulletin:** Le Châtelier's Principle: Beyond Chemistry 362
**Careers in Chemistry:** Anesthesiology: A Career in Pain Management 371
Chapter 7 Review 372

**Chapter 8 Acids, Bases, and pH 376**

**8.1** Explaining the Properties of Acids and Bases 377
*ExpressLab*: Comparing Acid-Base Reactions 378
**8.2** The Equilibrium of Weak Acids and Bases 388
*Investigation 8-A*: $K_a$ of Acetic Acid 394
**8.3** Bases and Buffers 404
**8.4** Acid-Base Titration Curves 412
Chapter 8 Review 415

**Chapter 9 Aqueous Solutions and Solubility Equilibria 418**

**9.1** The Acid-Base Properties of Salt Solutions 419
*ExpressLab*: Testing the pH of Salt Solutions 420
**9.2** Solubility Equilibria 430
*Investigation 9-A*: Determining $K_{sp}$ for Calcium Hydroxide 434
**Canadians in Chemistry:** Dr. Joseph MacInnis 439
**9.3** Predicting the Formation of a Precipitate 443
*ThoughtLab*: A Qualitative Analysis 450
Chapter 9 Review 452
Unit 4 Issue: Earth in Equilibrium 456
Unit 4 Review 458

**UNIT 5 Electrochemistry** 462

**Chapter 10 Oxidation-Reduction Reactions** 464

**10.1** Defining Oxidation and Reduction 465
**Chemistry Bulletin:** Aging: Is Oxidation a Factor? 469
*Investigation 10-A*: Single Displacement Reactions 470

**10.2** Oxidation Numbers 473
*ThoughtLab*: Finding Rules for Oxidation Numbers 475

**10.3** The Half-Reaction Method for Balancing Equations 482
**Tools & Techniques:** The Breathalyzer Test: A Redox Reaction 491
*Investigation 10-B*: Redox Reactions and Balanced Equations 492

**10.4** The Oxidation Number Method for Balancing Equations 495
Chapter 10 Review 499

**Chapter 11 Cells and Batteries** 504

**11.1** Galvanic Cells 505
*Investigation 11-A*: Measuring Cell Potentials of Galvanic Cells 510
**Careers in Chemistry:** Explosives Chemist 514

**11.2** Standard Cell Potentials 516
*ThoughtLab*: Assigning Reference Values 522

**11.3** Electrolytic Cells 524
*Investigation 11-B*: Electrolysis of Aqueous Potassium Iodide 532

**11.4** Faraday's Law 538
*Investigation 11-C*: Electroplating 542

**11.5** Issues Involving Electrochemistry 546
**Canadians in Chemistry:** Dr. Viola Birss 552
Chapter 11 Review 555
Unit 5 Design Your Own Investigation: Electroplating 558
Unit 5 Review 560

Chemistry Course Challenge: The Chemistry of Human Health 564

Appendix A: Answers to Selected and Numerical Chapter and Unit Review Questions 574

Appendix B: Supplementary Practice Problems 579

Appendix C: Alphabetical List of Elements and Periodic Table of the Elements 587

Appendix D: Math and Chemistry 590

Appendix E: Chemistry Data Tables 595

Appendix F: Titration Guidelines 600

Glossary 602

Index 612

Credits 621