

# General Chemistry

THE ESSENTIAL CONCEPTS

Fourth Edition

NEEDS AMPLIFY NOT FOR RESALE  
DONATION ONLY IDASADG

Raymond  
**CHANG**







## List of the Elements with Their Symbols and Atomic Masses\*

Element	Symbol	Atomic Number	Atomic Mass <sup>†</sup>	Element	Symbol	Atomic Number	Atomic Mass <sup>†</sup>
Actinium	Ac	89	(227)	Meitnerium	Mt	109	(266)
Aluminum	Al	13	26.98	Mendelevium	Md	101	(256)
Americium	Am	95	(243)	Mercury	Hg	80	200.6
Antimony	Sb	51	121.8	Molybdenum	Mo	42	95.94
Argon	Ar	18	39.95	Neodymium	Nd	60	144.2
Arsenic	As	33	74.92	Neon	Ne	10	20.18
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.3	Nickel	Ni	28	58.69
Berkelium	Bk	97	(247)	Niobium	Nb	41	92.91
Beryllium	Be	4	9.012	Nitrogen	N	7	14.01
Bismuth	Bi	83	209.0	Nobelium	No	102	(253)
Bohrium	Bh	107	(262)	Osmium	Os	76	190.2
Boron	B	5	10.81	Oxygen	O	8	16.00
Bromine	Br	35	79.90	Palladium	Pd	46	106.4
Cadmium	Cd	48	112.4	Phosphorus	P	15	30.97
Calcium	Ca	20	40.08	Platinum	Pt	78	195.1
Californium	Cf	98	(249)	Plutonium	Pu	94	(242)
Carbon	C	6	12.01	Polonium	Po	84	(210)
Cerium	Ce	58	140.1	Potassium	K	19	39.10
Cesium	Cs	55	132.9	Praseodymium	Pr	59	140.9
Chlorine	Cl	17	35.45	Promethium	Pm	61	(147)
Chromium	Cr	24	52.00	Protactinium	Pa	91	(231)
Cobalt	Co	27	58.93	Radium	Ra	88	(226)
Copper	Cu	29	63.55	Radon	Rn	86	(222)
Curium	Cm	96	(247)	Rhenium	Re	75	186.2
Darmstadtium	Ds	110	(281)	Rhodium	Rh	45	102.9
Dubnium	Db	105	(260)	Rubidium	Rb	37	85.47
Dysprosium	Dy	66	162.5	Ruthenium	Ru	44	101.1
Einsteinium	Es	99	(254)	Rutherfordium	Rf	104	(257)
Erbium	Er	68	167.3	Samarium	Sm	62	150.4
Europium	Eu	63	152.0	Scandium	Sc	21	44.96
Fermium	Fm	100	(253)	Seaborgium	Sg	106	(263)
Fluorine	F	9	19.00	Selenium	Se	34	78.96
Francium	Fr	87	(223)	Silicon	Si	14	28.09
Gadolinium	Gd	64	157.3	Silver	Ag	47	107.9
Gallium	Ga	31	69.72	Sodium	Na	11	22.99
Germanium	Ge	32	72.59	Strontium	Sr	38	87.62
Gold	Au	79	197.0	Sulfur	S	16	32.07
Hafnium	Hf	72	178.5	Tantalum	Ta	73	180.9
Hassium	Hs	108	(265)	Technetium	Tc	43	(99)
Helium	He	2	4.003	Tellurium	Te	52	127.6
Holmium	Ho	67	164.9	Terbium	Tb	65	158.9
Hydrogen	H	1	1.008	Thallium	Tl	81	204.4
Indium	In	49	114.8	Thorium	Th	90	232.0
Iodine	I	53	126.9	Thulium	Tm	69	168.9
Iridium	Ir	77	192.2	Tin	Sn	50	118.7
Iron	Fe	26	55.85	Titanium	Ti	22	47.88
Krypton	Kr	36	83.80	Tungsten	W	74	183.9
Lanthanum	La	57	138.9	Uranium	U	92	238.0
Lawrencium	Lr	103	(257)	Vanadium	V	23	50.94
Lead	Pb	82	207.2	Xenon	Xe	54	131.3
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0	Yttrium	Y	39	88.91
Magnesium	Mg	12	24.31	Zinc	Zn	30	65.39
Manganese	Mn	25	54.94	Zirconium	Zr	40	91.22

\*All atomic masses have four significant figures. These values are recommended by the Committee on Teaching of Chemistry, International Union of Pure and Applied Chemistry.

†Approximate values of atomic masses for radioactive elements are given in parentheses.



Raymond  
**CHANG**  
Williams College

# General Chemistry

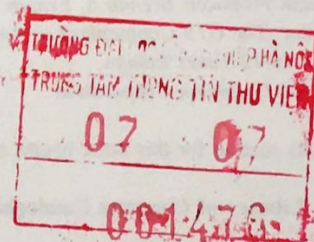
THE ESSENTIAL CONCEPTS

Fourth Edition



**GIFT OF THE ASIA FOUNDATION  
NOT FOR RE-SALE**

**QUÀ TẶNG CỦA QUỸ CHÂU Á  
KHÔNG ĐƯỢC BÁN LẠI**



**Higher Education**

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 Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto





## Higher Education

### GENERAL CHEMISTRY: THE ESSENTIAL CONCEPTS, FOURTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2006, 2003, 2000, 1996 by The McGraw-Hill Companies, Inc. All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4  
1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4

ISBN 0-07-282838-2

ISBN 0-07-298025-7 (Annotated Instructor's Edition)

Editorial Director: *Kent A. Peterson*

Sponsoring Editor: *Thomas D. Timp*

Managing Developmental Editor: *Shirley R. Oberbroeckling*

Senior Marketing Manager: *Tamara L. Good-Hodge*

Senior Project Manager: *Gloria G. Schiesl*

Senior Production Supervisor: *Kara Kudronowicz*

Lead Media Project Manager: *Judi David*

Senior Media Technology Producer: *Jeffrey Schmitt*

Senior Designer: *David W. Hash*

Cover/Interior Designer: *Jamie E. O'Neal*

(USE) Cover Image: ©*Larry Stepanowicz, FUNDAMENTAL PHOTOGRAPHS, NYC*

Senior Photo Research Coordinator: *John C. Leland*

Photo Research: *Chris Hammond/PhotoFind, LLC*

Supplement Producer: *Brenda A. Erzen*

Compositor: *The GTS Companies/Los Angeles, CA Campus*

Typeface: *10/12 Times Roman*

Printer: *Von Hoffmann Corporation*

The credits section for this book begins on page C-1 and is considered an extension of the copyright page.

#### Library of Congress Cataloging-in-Publication Data

Chang, Raymond.

General chemistry : the essential concepts / Raymond Chang. — 4th ed.  
p. cm.

Includes index.

ISBN 0-07-282838-2 (alk. paper) — ISBN 0-07-298025-7 (annotated instructor's ed. : alk. paper)  
I. Chemistry—Textbooks. I. Title.

QD33.2.C48 2006

540—dc22

2004021193

CIP

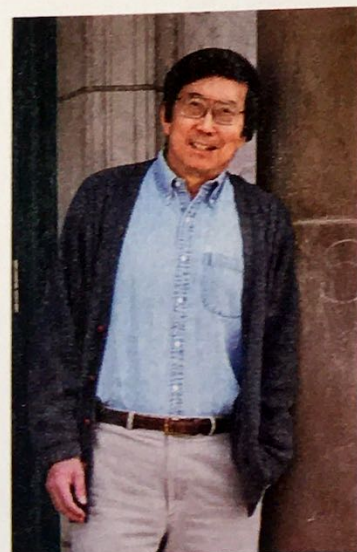


# About the Author

**Raymond Chang** was born in Hong Kong and grew up in Shanghai, China, and Hong Kong. He received his B.Sc. degree in chemistry from London University, England, and his Ph.D. in chemistry from Yale University. After doing postdoctoral research at Washington University and teaching for a year at Hunter College of the City University of New York, he joined the chemistry department at Williams College, where he has taught since 1966.

Professor Chang has served on the American Chemical Society Examination Committee, the National Chemistry Olympiad Examination Committee, and the Graduate Record Examinations (GRE) Committee. He is an editor of *The Chemical Educator*. Professor Chang has written books on physical chemistry, industrial chemistry, and physical science. He has also coauthored books on the Chinese language, children's picture books, and a novel for juvenile readers.

For relaxation, Professor Chang maintains a forest garden; plays tennis, Ping-Pong, and the harmonica; and practices the violin.



1	Introduction to Organic Chemistry	346
2	Intermolecular Forces and Liquids and Solids	376
3	Thermal Properties of Solids	410
4	Chemical Kinetics	435
5	Chemical Equilibrium	478
6	Acids and Bases	510
7	Acid-Base Equilibria and Solubility Equilibria	553
8	Thermodynamics	583
9	Redox Reactions and Electrochemistry	620
10	The Chemistry of Coordination Compounds	667
11	Nuclear Chemistry	683
12	Organic Polymers—Synthetic and Natural	716
Appendix 1	Units for the Gas Constant	A-1
Appendix 2	Selected Thermodynamic Data at 298 and 25 °C	A-2
Appendix 3	Mathematical Operations	A-6
Appendix 4	The Elements and the Derivations of Their Names and Symbols	A-7
Index		A-11



# Brief Contents

List of Animations xvii

Preface xix

A Note to the Student xxvii

- 1 Introduction 1
  - 2 Atoms, Molecules, and Ions 28
  - 3 Stoichiometry 56
  - 4 Reactions in Aqueous Solutions 93
  - 5 Gases 130
  - 6 Energy Relationships in Chemical Reactions 168
  - 7 The Electronic Structure of Atoms 201
  - 8 The Periodic Table 239
  - 9 Chemical Bonding I: The Covalent Bond 272
  - 10 Chemical Bonding II: Molecular Geometry and Hybridization of Atomic Orbitals 299
  - 11 Introduction to Organic Chemistry 341
  - 12 Intermolecular Forces and Liquids and Solids 376
  - 13 Physical Properties of Solutions 410
  - 14 Chemical Kinetics 438
  - 15 Chemical Equilibrium 478
  - 16 Acids and Bases 510
  - 17 Acid-Base Equilibria and Solubility Equilibria 553
  - 18 Thermodynamics 588
  - 19 Redox Reactions and Electrochemistry 620
  - 20 The Chemistry of Coordination Compounds 662
  - 21 Nuclear Chemistry 685
  - 22 Organic Polymers—Synthetic and Natural 716
- Appendix 1** Units for the Gas Constant A-1
- Appendix 2** Selected Thermodynamic Data at 1 atm and 25°C A-2
- Appendix 3** Mathematical Operations A-6
- Appendix 4** The Elements and the Derivation of Their Names and Symbols A-9

Glossary G-1

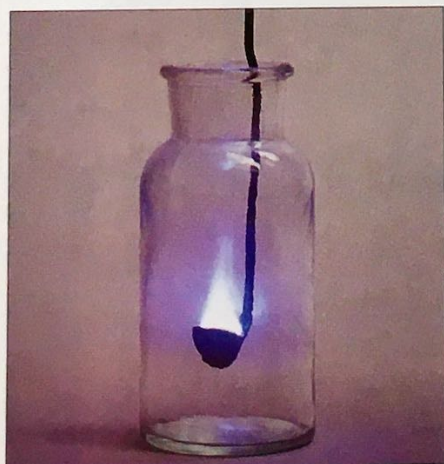
Answers to Even-Numbered Problems AP-1

Credits C-1

Index I-1



# Contents



List of Animations xvii  
Preface xix  
A Note to the Student xxvii

## Introduction 1

- 1.1 The Study of Chemistry 2
  - 1.2 The Scientific Method 2
  - 1.3 Classifications of Matter 4
  - 1.4 Physical and Chemical Properties of Matter 7
  - 1.5 Measurement 8
  - 1.6 Handling Numbers 13
  - 1.7 Dimensional Analysis in Solving Problems 18
- Summary of Facts and Concepts* 22  
*Key Words* 22  
*Questions and Problems* 22

## Atoms, Molecules, and Ions 28

- 2.1 The Atomic Theory 29
  - 2.2 The Structure of the Atom 30
  - 2.3 Atomic Number, Mass Number, and Isotopes 35
  - 2.4 The Periodic Table 36
  - 2.5 Molecules and Ions 37
  - 2.6 Chemical Formulas 39
  - 2.7 Naming Compounds 43
- Summary of Facts and Concepts* 50  
*Key Words* 51  
*Questions and Problems* 51

## Stoichiometry 56

- 3.1 Atomic Mass 57
- 3.2 Avogadro's Number and the Molar Mass of an Element 58
- 3.3 Molecular Mass 62
- 3.4 The Mass Spectrometer 65
- 3.5 Percent Composition of Compounds 66

# 1

# 2

# 3





- 3.6 Experimental Determination of Empirical Formulas 69
- 3.7 Chemical Reactions and Chemical Equations 71
- 3.8 Amounts of Reactants and Products 76
- 3.9 Limiting Reagents and Reaction Yield 80

*Summary of Facts and Concepts* 84

*Key Words* 85

*Questions and Problems* 85

## Reactions in Aqueous Solutions 93

# 4

- 4.1 General Properties of Aqueous Solutions 94
- 4.2 Precipitation Reactions 96
- 4.3 Acid-Base Reactions 100
- 4.4 Oxidation-Reduction Reactions 105
- 4.5 Concentration of Solutions 113
- 4.6 Solution Stoichiometry 117

*Summary of Facts and Concepts* 122

*Key Words* 122

*Questions and Problems* 123

## Gases 130

# 5

- 5.1 Substances That Exist as Gases 131
- 5.2 Pressure of a Gas 132
- 5.3 The Gas Laws 134
- 5.4 The Ideal Gas Equation 140
- 5.5 Dalton's Law of Partial Pressures 146
- 5.6 The Kinetic Molecular Theory of Gases 151
- 5.7 Deviation from Ideal Behavior 157

*Summary of Facts and Concepts* 160

*Key Words* 160

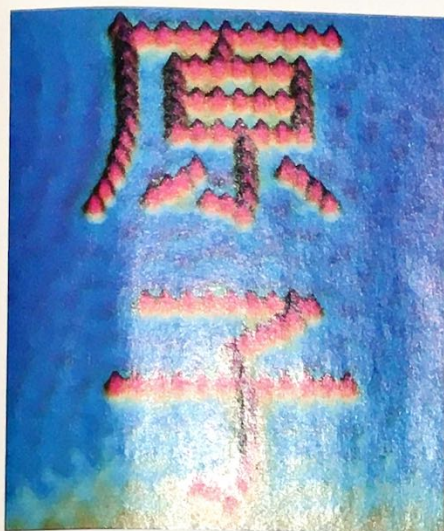
*Questions and Problems* 161

## Energy Relationships in Chemical Reactions 168

# 6

- 6.1 The Nature of Energy and Types of Energy 169
- 6.2 Energy Changes in Chemical Reactions 170
- 6.3 Introduction to Thermodynamics 171
- 6.4 Enthalpy of Chemical Reactions 177
- 6.5 Calorimetry 182





6.6 Standard Enthalpy of Formation and Reaction 188

Summary of Facts and Concepts 193

Key Words 194

Questions and Problems 194

The Electronic Structure of Atoms 201

7

7.1 From Classical Physics to Quantum Theory 202

7.2 The Photoelectric Effect 206

7.3 Bohr's Theory of the Hydrogen Atom 207

7.4 The Dual Nature of the Electron 212

7.5 Quantum Mechanics 214

7.6 Quantum Numbers 216

7.7 Atomic Orbitals 217

7.8 Electron Configuration 222

7.9 The Building-Up Principle 228

Summary of Facts and Concepts 232

Key Words 233

Questions and Problems 233

The Periodic Table 239

8

8.1 Development of the Periodic Table 240

8.2 Periodic Classification of the Elements 241

8.3 Periodic Variation in Physical Properties 244

8.4 Ionization Energy 250

8.5 Electron Affinity 253

8.6 Variation in Chemical Properties of the Representative Elements 255

Summary of Facts and Concepts 266

Key Words 266

Questions and Problems 266

Chemical Bonding I: The Covalent Bond 272

9

9.1 Lewis Dot Symbols 273

9.2 The Covalent Bond 274

9.3 Electronegativity 275

9.4 Writing Lewis Structures 279

9.5 Formal Charge and Lewis Structures 281

ELEMENTS		
Hydrogen	Strontian	40
Nitrogen	Barytes	68
Carbon	Iron	56
Oxygen	Zinc	56
Phosphorus	Copper	56
Sulphur	Lead	90
Magnesia	Silver	190
Lime	Gold	190
Soda	Platina	190
Potash	Mercury	167

