

**Raymond Chang**

# **CHEMISTRY**

**Fifth Edition**

INTERNATIONAL EDITION



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# CHEMISTRY

FIFTH EDITION

**Raymond Chang**

WILLIAMS COLLEGE

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## CHEMISTRY

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This book was set in Times Roman by York Graphic Services, Inc. The editors were Jennifer Speer, Judith Kromm, and Jack Maisel; the designer was Hermann Strohbach; the production supervisor was Janelle S. Travers. The photo researcher was Mira Schachne. The photo editor was Kathy Bendo. Von Hoffmann Press, Inc., was printer and binder.

The cover photo shows a piece of platinum strip moistened with a lithium salt solution which shows the characteristic crimson flame color of lithium. Cover photo by Ken Karp. p. i Dry ice (solid carbon dioxide) sublimates under atmospheric conditions. p. iii Dry ice is added to a beaker of water containing a few drops of an acid-base indicator (bromothymol blue). The carbonic acid formed by the reaction of dry ice and water turns the color of the indicator from blue to yellow. p. xxvii The color of the bromothymol blue indicator is yellow in the presence of a high concentration of carbonic acid. All, McGraw-Hill photos by Ken Karp.

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| 3                | 3B                | 4                 | 4B                | 5                | 5B                | 6                 | 6B                | 7                 | 7B                | 8                 | 8B                | 9                 | 10                | 11                | 12                | 13                | 14                | 15                | 16                | 17               | 18                |                   |                   |                  |                   |                   |                   |                   |                   |                   |                   |                   |                   |                  |                   |                   |                   |                   |                   |                   |                  |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                     |                     |                     |                     |                     |                     |
| 19<br>K<br>39.10 | 20<br>Ca<br>40.08 | 21<br>Sc<br>44.96 | 22<br>Ti<br>47.88 | 23<br>V<br>50.94 | 24<br>Cr<br>52.00 | 25<br>Mn<br>54.94 | 26<br>Fe<br>55.85 | 27<br>Co<br>58.93 | 28<br>Ni<br>58.69 | 29<br>Cu<br>63.55 | 30<br>Zn<br>65.39 | 31<br>Ga<br>69.72 | 32<br>Ge<br>72.59 | 33<br>As<br>74.92 | 34<br>Se<br>78.96 | 35<br>Br<br>79.90 | 36<br>Kr<br>83.80 | 37<br>Rb<br>85.47 | 38<br>Sr<br>87.62 | 39<br>Y<br>88.91 | 40<br>Zr<br>91.22 | 41<br>Nb<br>92.91 | 42<br>Mo<br>95.94 | 43<br>Tc<br>(98) | 44<br>Ru<br>101.1 | 45<br>Rh<br>102.9 | 46<br>Pd<br>106.4 | 47<br>Ag<br>107.9 | 48<br>Cd<br>112.4 | 49<br>In<br>114.8 | 50<br>Sn<br>118.7 | 51<br>Sb<br>121.8 | 52<br>Te<br>127.6 | 53<br>I<br>126.9 | 54<br>Xe<br>131.3 | 55<br>Cs<br>132.9 | 56<br>Ba<br>137.3 | 57<br>La<br>138.9 | 72<br>Hf<br>178.5 | 73<br>Ta<br>180.9 | 74<br>W<br>183.9 | 75<br>Re<br>186.2 | 76<br>Os<br>190.2 | 77<br>Ir<br>192.2 | 78<br>Pt<br>195.1 | 79<br>Au<br>197.0 | 80<br>Hg<br>200.6 | 81<br>Tl<br>204.4 | 82<br>Pb<br>207.2 | 83<br>Bi<br>209.0 | 84<br>Po<br>(210) | 85<br>At<br>(210) | 86<br>Rn<br>(222) | 87<br>Fr<br>(223) | 88<br>Ra<br>(226) | 89<br>Ac<br>(227) | 104<br>Uuq<br>(257) | 105<br>Uup<br>(260) | 106<br>Uuh<br>(263) | 107<br>Uus<br>(262) | 108<br>Uuo<br>(265) | 109<br>Uue<br>(266) |

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| 58<br>Ce<br>140.1 | 59<br>Pr<br>140.9 | 60<br>Nd<br>144.2 | 61<br>Pm<br>(147) | 62<br>Sm<br>150.4 | 63<br>Eu<br>152.0 | 64<br>Gd<br>157.3 | 65<br>Tb<br>158.9 | 66<br>Dy<br>162.5 | 67<br>Ho<br>164.9 | 68<br>Er<br>167.3 | 69<br>Tm<br>168.9 | 70<br>Yb<br>173.0 | 71<br>Lu<br>175.0 | 90<br>Th<br>232.0 | 91<br>Pa<br>(231) | 92<br>U<br>238.0 | 93<br>Np<br>(237) | 94<br>Pu<br>(242) | 95<br>Am<br>(243) | 96<br>Cm<br>(247) | 97<br>Bk<br>(247) | 98<br>Cf<br>(249) | 99<br>Es<br>(254) | 100<br>Fm<br>(253) | 101<br>Md<br>(256) | 102<br>No<br>(254) | 103<br>Lr<br>(257) |
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The 1-18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text we use the standard U.S. notation for group numbers (1A-8A and 1B-8B).

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

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

\* 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.

# CHEMISTRY



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## **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, he joined the chemistry department at Williams College, where he has taught since 1968. Professor Chang has written books on spectroscopy, physical chemistry, and industrial chemistry and has coauthored books on the Chinese language and a novel for juvenile readers.

For relaxation, Professor Chang maintains a forest garden, plays tennis, and practices the violin.



# Preface

The goal of a full-year general chemistry course is to provide a firm foundation in chemical concepts and principles and to instill in students an appreciation of the vital part chemistry plays in our daily life. It is the responsibility of the textbook author to assist both instructors and students in their pursuit of this objective by presenting a broad range of topics in a clear, logical manner. In this text, I have tried to strike a balance between theory and application, to illustrate basic principles with everyday examples whenever possible, and to show that there is more to chemistry than numbers, formulas, and abstract theories. The encouraging feedback I have received from instructors and students who used previous editions has convinced me that this approach is effective.

The main features of the text are described below.

## Content and Organization

Learning chemistry is a cumulative process that begins most comfortably in familiar surroundings. Thus, this text opens with a scientific look at the macroscopic world and proceeds with an examination of the microscopic realm of atoms and molecules, which opens the way for the discussion of chemical properties and relationships and the mechanisms of chemical change. This sequence is fairly conventional and corresponds well with most syllabuses. Where differences exist, they reflect the experience of myself and many other instructors who have used previous editions of *Chemistry*. For example, discussing gases (Chapter 5) before thermochemistry (Chapter 6) makes it easier to understand thermochemical processes involving gases. Likewise, it is advantageous to introduce precipitation, acid-base, and oxidation-reduction reactions together in Chapters 3 and 4, where the relevant vocabulary is presented; it also benefits students who are taking chemistry lab concurrently. And the inclusion of the first law of thermodynamics in Chapter 6 helps to clarify for students the often ambiguous topics of heat and enthalpy. Acknowledging, however, that what works for some does not necessarily work for all, I have written these sections so that they can be covered in a different sequence without loss of continuity. Thus, an instructor who prefers to discuss the first law in conjunction with thermodynamics has the option to do so.

Typically, a general chemistry course emphasizes the content presented in Chapters 1–17, 19, and 20 of this text. A new addition to the book, Chapter 18, is one that I hope will join the group of core chapters chosen for study. This chapter on chemistry in the atmosphere focuses on the structure and composition of Earth's atmosphere, as well as on important chemical processes that occur there. It can be studied as a unit or used to supplement other chapters. Either way, topics such as indoor pollution and the disap-

pearance of the ozone layer should stimulate lively debate and interest in the growing field of environmental chemistry.

Because it is exceedingly difficult to cover all of the chapters in an introductory text in the time available, instructors sometimes skip chapters on descriptive chemistry in favor of topics of greater interest. Although this decision is understandable, it is regrettable because students consequently do not get to see how chemical principles are put into practice. Therefore, in addition to having three descriptive chapters, this text integrates a generous amount of descriptive chemistry into principles discussions. In particular, Chapters 3, 4, 8, and 18 have a strong descriptive orientation.

## Balance of Theory and Application

Seeing how chemical principles can be applied is one of the rewards of studying chemistry. Throughout the book, applications are used to reinforce students' grasp of concepts and principles. In addition, Chemistry in Action essays—a popular feature in all editions of *Chemistry*—emphasize the relevance of chemistry to biology, medicine, technology, engineering, and even current events. New essays discuss the mining of metal from the sea, buckminsterfullerene (or “buckyball”), nano-sized galvanic cells, and DNA fingerprinting. I have revised and updated a number of others.

Applied Chemistry Examples focus on key industrial chemicals, drugs, and technological advances in chemistry. Placed at the end of a number of chapters, they also serve as summarizing examples.

## Problem-Solving Approach

As an experimental science, chemistry requires quantification. It is this aspect of the general chemistry course that represents the greatest challenge for many students. The development of problem-solving skills has always been a major objective of this text, and this edition provides many opportunities to hone those skills. Not only are problem-solving strategies presented in the text, but there are also approximately 250 worked examples illustrating their use. Most are preceded by a statement describing the concept, technique, or calculation that the example demonstrates and placing the problem in context. A practice exercise (with answer) accompanies each example so that students can immediately check their understanding of the procedure used to solve the example. Additionally, marginal references enable students to apply new skills to other, similar problems at the end of the chapter.

## End-of-Chapter Review

At the end of each chapter you will find a list of key terms with page references so that students can review definitions in context, plus review questions and problems. Approximately 2400 review questions and problems, including a number of new ones, are grouped together by topics and concepts presented in the chapter.

Review questions deal with concepts explained in the chapter—the “why” of chemistry. The problems emphasize the quantitative, experimental “how” of chemistry. They test the ability to apply conceptual logic and perform specific calculations. In the

category labeled “miscellaneous problems” are more challenging and multiconcept exercises, which provide practice in identifying different types of problems and applying the concepts and techniques necessary to solve them; in short, they are helpful in preparing for an exam.

## **Design and Illustrations**

One feature of past editions of *Chemistry* that has consistently drawn praise is its design. In particular, the color background highlighting worked examples and Chemistry in Action essays clearly indicates the beginning and end of these sections, but it is subtle enough not to be distracting.

While certain elements of the design have been retained in this edition, a major change can be seen in the illustrations. The photo program has been expanded to show additional substances and reactions described in the text and everyday examples of chemical principles and concepts. But more significantly, virtually all of the diagrams in the book have been rendered anew. Advances in drafting technology made it possible to create a more contemporary, less schematic style of art that is also more effective pedagogically. I believe you will find that this three-dimensional looking, easy-to-interpret illustration program invites close study and reinforces the text presentation.

The supplements available for use with this text are:

### **Student Solutions Manual by Jerry L. Mills and Raymond Chang**

This supplement contains detailed solutions and explanations for all even-numbered problems and selected odd-numbered problems in the main text. Solutions and explanations are also given for some of the Review Questions. The authors' emphasis is on problem-solving through a three-pronged approach. The first part of each solution is an introductory discussion with text references, comments, and hints. The second part includes questions that test the student's understanding of the logic behind the problem solution. The third part contains afterthoughts on the problem and additional questions to help students deal with similar kinds of problems.

### **Microscale and Macroscale Experiments for General Chemistry by Jerry L. Mills and Michael D. Hampton**

The manual contains over 40 general chemistry experiments based on both microscale and macroscale laboratory techniques. Special attention is given to the cost and safety of experiments and to the safe disposal of wastes. A version of the manual containing only 25 microscale experiments is also available.

### **Study Guide by Kenneth W. Watkins**

This valuable ancillary contains material to help the student organize his/her study time, practice problem-solving skills, and complete self-tests. Each chapter section lists study objectives and a summary of the corresponding section of the main text. After each summary there are example problems with detailed solutions. Each chapter has true/false questions and a self-test, with all answers provided at the end of the chapter.

**Instructor's Manual by Raymond Chang and Jerry L. Mills**

This manual contains for each chapter a brief explanation of the chapter contents, the general goals of the chapter, and references to background concepts in earlier chapters. Following this material is a complete listing of the more challenging problems in the chapter, the problems for which answers are given in the back of the textbook, and the problems that are worked out in detail in the Student Solutions Manual. The solutions to all the end-of-chapter problems are then given, including those which are in the Student Solutions Manual. A few, but not all, of the end-of-chapter Review Questions are also answered. New to this edition are "How Do We Know?" sections.

**Print Test Bank by Kenneth W. Watkins**

This updated print test file contains over 2,000 exam questions in both multiple choice and short-answer formats.

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**Chemistry at Work Videodisc**

This valuable teaching tool provides instant access to tables, illustrations, and photos from the text, plus 50 live laboratory demonstrations.

**MicroGuide Computerized Tutorial by Robert Holwerda**

Tutorial software for both IBM and Macintosh computers, specifically correlated to the text. Each chapter contains a chapter table of contents, learning objectives and a practice quiz. Students can choose a number of questions on the quiz, and questions can be pulled from more than one chapter. Students receive feedback screens on both correct and incorrect answers, including specific page references for further information. MicroGuide contains a word-processing system so that students can take notes as they work through the quizzes. Students' results are graded by the computer both throughout and at the end of the session. MicroGuide has full print capabilities. The new edition also includes Review Sections and Key Terms for each chapter.

## Algorithmic Test Bank

This state-of-the-art test allows the user to generate hundreds of unique questions for each chapter in the text. This supplement enables the user to: combine standard and algorithm-generated questions on the same test, create an unlimited number of similar but unique tests, select questions by level of difficulty, make tests corresponding to specific learning objectives in the text, customize the printed format of tests to meet personal specifications, add his/her own questions, and add existing ones. Available in IBM PC and Macintosh versions.

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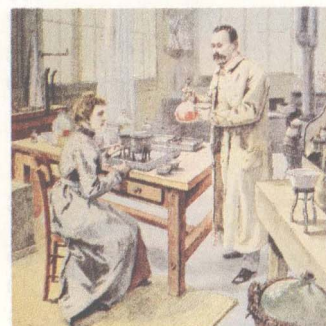
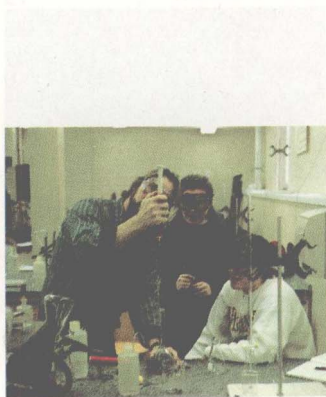
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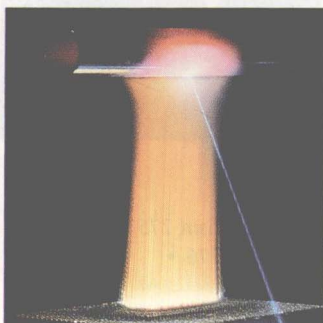
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