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General Chemistry

ELEVENTH EDITION

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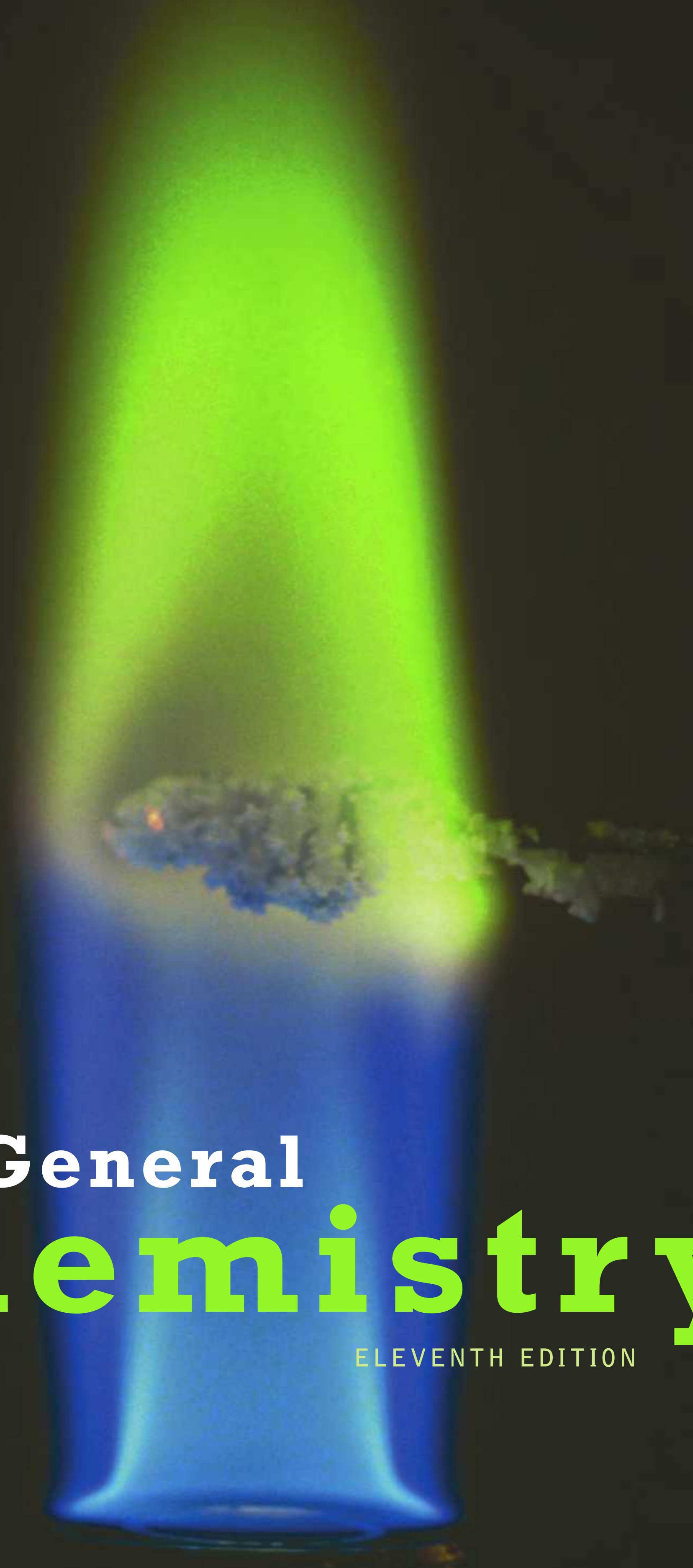

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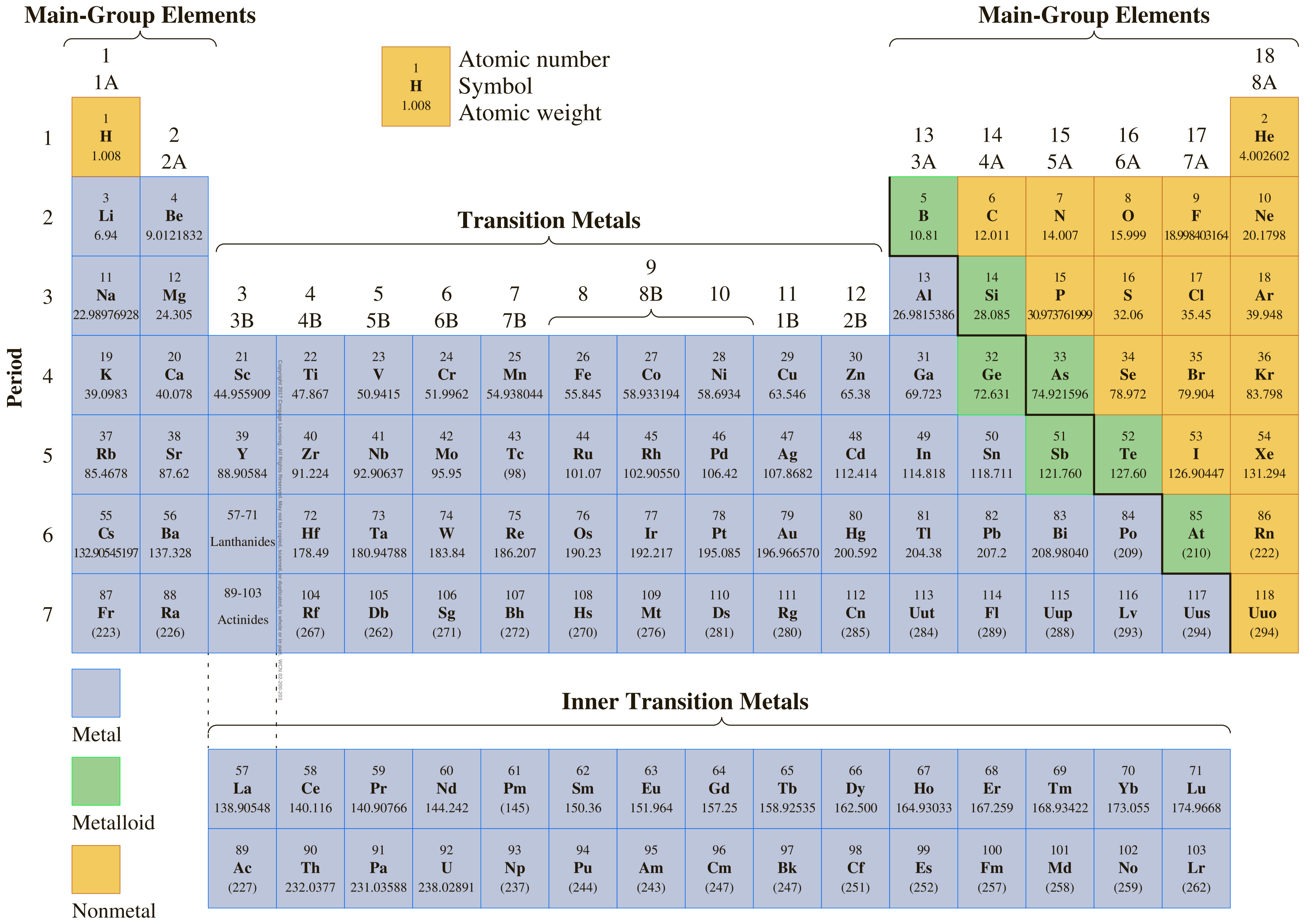
PERIODIC TABLE OF THE ELEMENTS



1 **H** 1.008	
1	Atomic number
H	Symbol
1.008	Atomic weight

Main-Group Elements

Transition Metals

Main-Group Elements

Period	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** 1.008																	2 **He** 4.002602
2	3 **Li** 6.94	4 **Be** 9.0121832											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998403164	10 **Ne** 20.1798
3	11 **Na** 22.98976928	12 **Mg** 24.305											13 **Al** 26.9815386	14 **Si** 28.085	15 **P** 30.973761999	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.955909	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9962	25 **Mn** 54.938044	26 **Fe** 55.845	27 **Co** 58.933194	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.631	33 **As** 74.921596	34 **Se** 78.972	35 **Br** 79.904	36 **Kr** 83.798
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90584	40 **Zr** 91.224	41 **Nb** 92.90637	42 **Mo** 95.95	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.414	49 **In** 114.818	50 **Sn** 118.711	51 **Sb** 121.760	52 **Te** 127.60	53 **I** 126.90447	54 **Xe** 131.294
6	55 **Cs** 132.90545197	56 **Ba** 137.328	57-71 Lanthanides	72 **Hf** 178.49	73 **Ta** 180.94788	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.085	79 **Au** 196.966570	80 **Hg** 200.592	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98040	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89-103 Actinides	104 **Rf** (267)	105 **Db** (262)	106 **Sg** (271)	107 **Bh** (272)	108 **Hs** (270)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **Uut** (284)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

Inner Transition Metals

57 **La** 138.90548	58 **Ce** 140.116	59 **Pr** 140.90766	60 **Nd** 144.242	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.964	64 **Gd** 157.25	65 **Tb** 158.92535	66 **Dy** 162.500	67 **Ho** 164.93033	68 **Er** 167.259	69 **Tm** 168.93422	70 **Yb** 173.055	71 **Lu** 174.9668
89 **Ac** (227)	90 **Th** 232.0377	91 **Pa** 231.03588	92 **U** 238.02891	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

🟦 Metal

🟩 Metalloid

🟨 Nonmetal

The 1–18 group labels are recommended by the International Union of Pure and Applied Chemistry (IUPAC). The group labels below those with numerals and letters (1A, 2A, etc.) follow the common North American convention, as we do in this text.

A value in parentheses is the mass number of the isotope of the longest half-life.

Permanent names are not yet assigned for elements 113, 115, 117, and 118. These elements are assigned temporary names based on their atomic numbers. See www.webelements.com for more information.

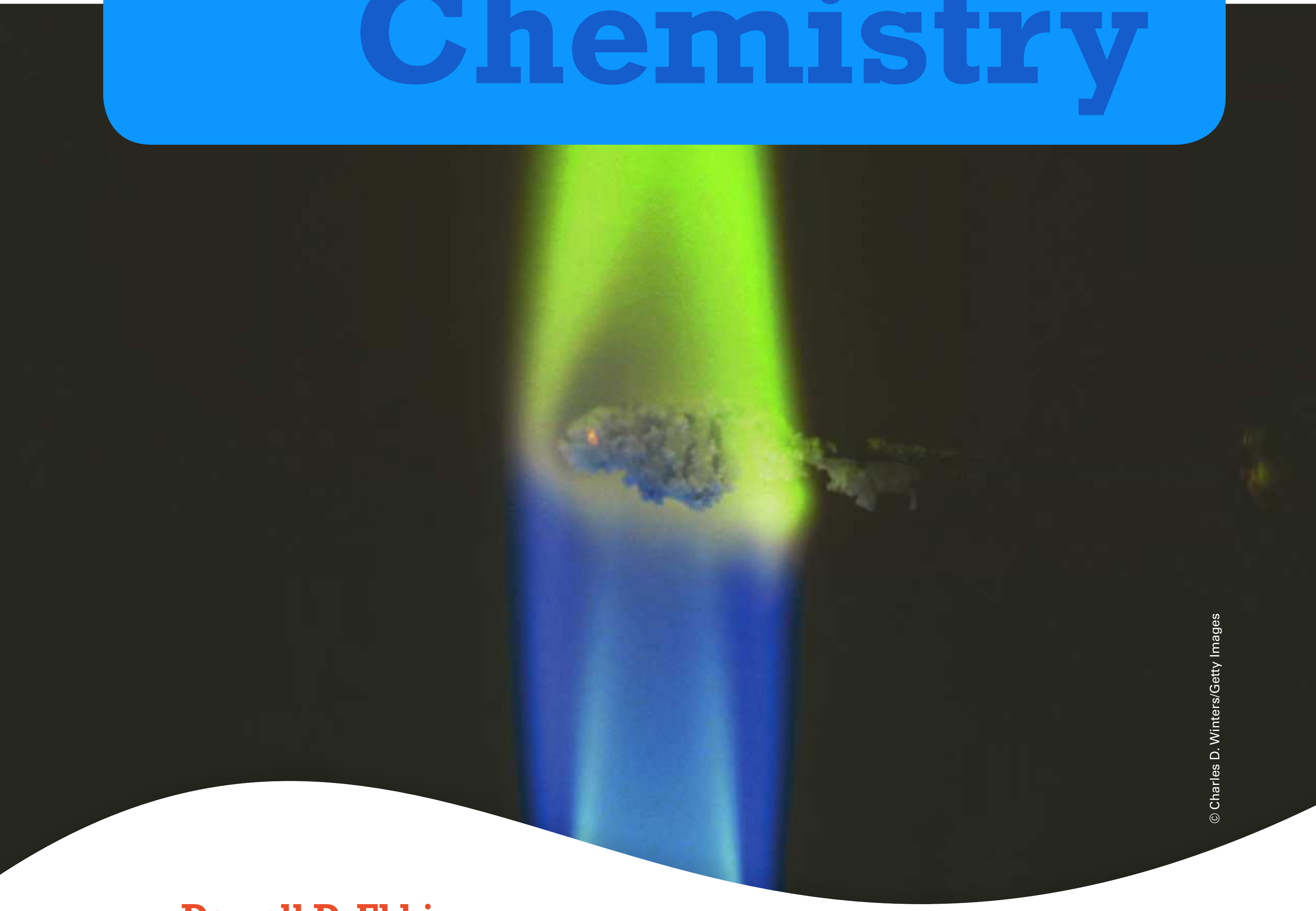
TABLE OF ATOMIC NUMBERS AND ATOMIC WEIGHTS

Name	Symbol	Atomic Numbe	Atomic Weight
Actinium	Ac	89	(227)
Aluminum	Al	13	26.9815386
Americium	Am	95	(243)
Antimony	Sb	51	121.760
Argon	Ar	18	39.948
Arsenic	As	33	74.921596
Astatine	At	85	(210)
Barium	Ba	56	137.328
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.0121832
Bismuth	Bi	83	208.98040
Bohrium	Bh	107	(272)
Boron	B	5	10.81
Bromine	Br	35	79.904
Cadmium	Cd	48	112.414
Calcium	Ca	20	40.078
Californium	Cf	98	(251)
Carbon	C	6	12.011
Cerium	Ce	58	140.116
Cesium	Cs	55	132.90545197
Chlorine	Cl	17	35.45
Chromium	Cr	24	51.9962
Cobalt	Co	27	58.933194
Copernicum	Cn	112	(285)
Copper	Cu	29	63.546
Curium	Cm	96	(247)
Darmstadtium	Ds	110	(281)
Dubnium	Db	105	(262)
Dysprosium	Dy	66	162.500
Einsteinium	Es	99	(252)
Erbium	Er	68	167.259
Europium	Eu	63	151.964
Fermium	Fm	100	(257)
Flerovium	Fl	114	(289)
Fluorine	F	9	18.998403164
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.723
Germanium	Ge	32	72.631
Gold	Au	79	196.966570
Hafnium	Hf	72	178.49
Hassium	Hs	108	(270)
Helium	He	2	4.002602
Holmium	Ho	67	164.93033
Hydrogen	H	1	1.008
Indium	In	49	114.818
Iodine	I	53	126.90447
Iridium	Ir	77	192.217
Iron	Fe	26	55.845
Krypton	Kr	36	83.798
Lanthanum	La	57	138.90548
Lawrencium	Lr	103	(262)
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Livermorium	Lv	116	(293)
Lutetium	Lu	71	174.9668
Magnesium	Mg	12	24.305
Manganese	Mn	25	54.938044
Meitnerium	Mt	109	(276)
Mendelevium	Md	101	(258)
Mercury	Hg	80	200.592
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.242
Neon	Ne	10	20.1798
Neptunium	Np	93	(237)
Nickel	Ni	28	58.6934
Niobium	Nb	41	92.90637
Nitrogen	N	7	14.007
Nobelium	No	102	(259)
Osmium	Os	76	190.23
Oxygen	O	8	15.999
Palladium	Pd	46	106.42
Phosphorus	P	15	30.973761999
Platinum	Pt	78	195.085
Plutonium	Pu	94	(244)
Polonium	Po	84	(209)
Potassium	K	19	39.0983
Praseodymium	Pr	59	140.90766
Promethium	Pm	61	(145)
Protactinium	Pa	91	231.03588
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.207
Rhodium	Rh	45	102.90550
Roentgenium	Rg	111	(280)
Rubidium	Rb	37	85.4678
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	(267)
Samarium	Sm	62	150.36
Scandium	Sc	21	44.955909
Seaborgium	Sg	106	(271)
Selenium	Se	34	78.972
Silicon	Si	14	28.085
Silver	Ag	47	107.8682
Sodium	Na	11	22.98976928
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.94788
Technetium	Tc	43	(98)
Tellurium	Te	52	127.60
Terbium	Tb	65	158.92535
Thallium	Tl	81	204.38
Thorium	Th	90	232.0377
Thulium	Tm	69	168.93422
Tin	Sn	50	118.711
Titanium	Ti	22	47.867
Tungsten	W	74	183.84
Ununoctium	Uuo	118	(294)
Ununpentium	Uup	115	(288)
Ununseptium	Uus	117	(294)
Ununtrium	Uut	113	(284)
Uranium	U	92	238.02891
Vanadium	V	23	50.9415
Xenon	Xe	54	131.294
Ytterbium	Yb	70	173.055
Yttrium	Y	39	88.90584
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.224

A value in parentheses is the mass number of the isotope of longest half-life.

ELEVENTH EDITION

General Chemistry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Brief Contents

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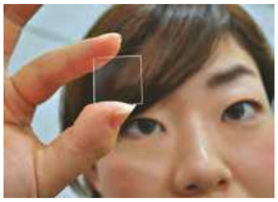

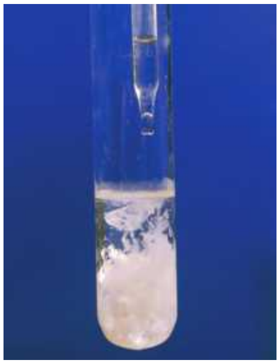

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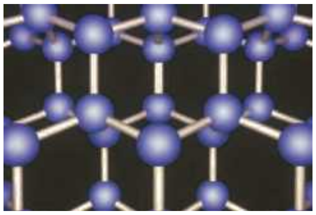

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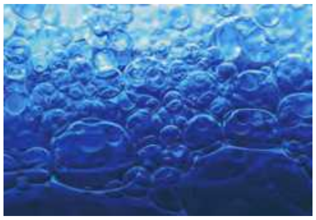

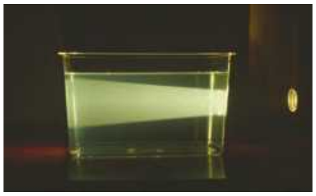

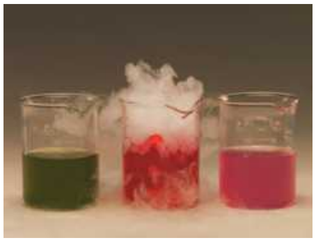

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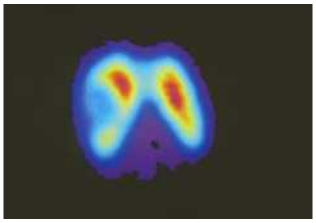

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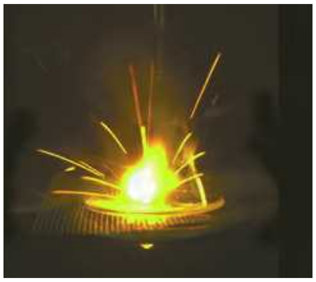

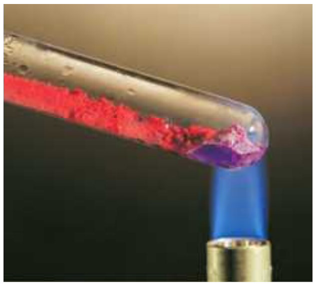

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Essays

A CHEMIST LOOKS AT . . .

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INSTRUMENTAL METHODS

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Preface

In the preface to the first edition, we wrote, “Scientists delve into the molecular machinery of the biological cell and examine bits of material from the planets of the solar system. The challenge for the instructors of introductory chemistry is to capture the excitement of these discoveries [of chemistry] while giving students a solid understanding of the basic principles and facts. The challenge for the students is to be receptive to a new way of thinking, which will allow them to be caught up in the excitement of discovery.” From the very first edition of this text, our aims have always been to help instructors capture the excitement of chemistry and to teach students to “think chemistry.” Here are some of the features of the text that we feel are especially important in achieving these goals.

Clear, Lucid Explanations of Chemical Concepts

We have always placed the highest priority on writing clear, lucid explanations of chemical concepts. We have strived to relate abstract concepts to specific real-world events and have presented topics in a logical, yet flexible, order. With succeeding editions we have refined the writing, incorporating suggestions from instructors and students.

Coherent Problem-Solving Approach

With the first edition, we presented a coherent problem-solving approach that involved worked-out *Examples* coupled with in-chapter *Exercises* and corresponding end-of-chapter *Problems.* This approach received an enormously positive response, and we have continued to refine the pedagogical and conceptual elements in each subsequent edition.

In the ninth edition, we revised every Example, dividing the problem-solving process into a *Problem Strategy*, a *Solution*, and an *Answer Check*. By doing this, we hoped to help students develop their problem-solving skills: *think* how to proceed, *solve* the problem, and *check* the answer. This last step is one that is often overlooked by students, but it is critical if one is to obtain consistently reliable results.

In the tenth edition, we added yet another level of support for students in this problem-solving process. In every Example, we added what we call the *Gaining Mastery Toolbox*. We based this Toolbox on how we as instructors might help a student who is having trouble with a particular problem. We imagine a student coming to our office because of difficulty with a particular problem. We begin the help session by pointing out to the student the “big idea” that one needs to solve the problem. We call this the *Critical Concept*. But suppose the student is still having difficulty with the problem. We now ask the student about his or her knowledge of prior topics that will be needed to approach the problem. We call these needed prior topics the *Solution Essentials*. Each Gaining Mastery Toolbox that we have added to an Example begins by pointing out the Critical Concept involved in solving the problem posed in that Example. Then, under the heading of Solution Essentials, we list the topics the student needs to have mastered to solve this problem. We hope the Gaining Mastery Toolbox helps the student in much the way that an individual office visit can. Over several Examples, these Toolboxes should help the student develop the habit of focusing on the Critical Concept and the Solution Essentials while engaged in general problem solving.

While we believe in the importance of this coherent example/exercise approach, we also think it is necessary to have students expand their understanding of the concepts. For this purpose, we have a second type of in-chapter problem, *Concept Checks.* We have written these to force students to think about the concepts involved, rather than to focus on the final result or numerical answer—or to try to fit the problem to a memorized algorithm. We want students to begin each problem by asking, "What are the chemical concepts that apply here?" Many of these problems involve visualizing a molecular situation, since visualization is such a critical part of learning and understanding modern chemistry. Similar types of end-of-chapter problems, the *Conceptual Problems,* are provided for additional practice.

A major focus of this edition was to perform a thorough integration of the text with the host of digital instructional materials available from Cengage Learning, including the MindTap digital version and the OWLv2 online learning solution. However, of particular note for this edition is a revision to how each of the Example Problems have been formatted to provide a clearer path for student learning. Additionally, new Capstone Problems have been added to a number of chapters. Essays have been added, updated, and revised to reflect our current understanding of a variety of relevant topics.

Extensive Conceptual Focus

A primary goal of recent editions has been to strengthen the conceptual focus of the text. To that end we have three types of end-of-chapter problems, *Concept Explorations*, *Strategy Problems*, and *Self-Assessment Questions*. While we have included them in the end-of-chapter material, *Concept Explorations* are unlike any of the other end-of-chapter problems. These multipart, multistep problems are structured activities developed to help students explore important chemical concepts—the key ideas in general chemistry—and confront common misconceptions or gaps in learning. Often deceptively simple, *Concept Explorations* ask probing questions to test student's understanding. Because we feel strongly that in order to develop a lasting conceptual understanding, students must think about the question without jumping quickly to formulas or algorithms (or even a calculator); we have purposely not included their answers in the *Student Solutions Manual.* As *Concept Explorations* are ideally used in an interactive classroom situation, we have reformatted them into workbook style in-class handouts with space for written answers and drawings to facilitate their use in small groups. In the *Instructor's Resource Manual*, we provide additional background on the literature and theories behind their development, information on how Steve Gammon has implemented them into his classroom and suggestions for integration, and a listing of the concepts (and common misconceptions thereof) that each *Concept Exploration* addresses.

We recognize a need to challenge students to build a conceptual understanding rather than simply memorizing the algorithm from the matched pair and then applying it to a similar problem to get a solution. The *Strategy Problems* were written to extend students' problem-solving skills beyond those developed in the *Practice* and *General Problems.* With this edition, we have nearly doubled the number of these problems. To work a *Strategy Problem,* students will need to think about the problem (which might involve several concepts or problem-solving skills from the chapter), then solve it on their own without a similar problem from which to model their answer. For this reason, we have explicitly chosen not to include their answers in the *Student Solutions Manual.*

On the basis of student feedback, we developed conceptually focused multiple-choice questions to provide students with a quick opportunity for self-assessment. As they are intended primarily for self-study, these questions have been included with the Review Questions, in the retitled *Self-Assessment and Review Questions* section. As an instructor, you know that a student may answer a multiple-choice question correctly but still use incorrect reasoning to arrive at the answer. You would certainly like to know whether the student has used correct reasoning. In this edition, we have explored using *two-tier questions* to address whether the student's learning of a concept has depth or is superficial. The first tier of a question might be fairly straightforward. For example, we might begin a question by listing a number of formulas of compounds and ask the student to classify each one as an ionic compound or a molecular compound. The student might give correct answers, but we want to draw him or her out as to the reasoning used by adding a further question (the second tier), such as, "Which of the following is the best statement regarding molecular compounds?" By seeing how the student answers the second tier of a two-tier question, we can learn whether he or she may have a misconception of the material. In other words, we learn whether the student has a complete and correct understanding of an important concept.

An Illustration Program with an Emphasis on Molecular Concepts

Most of us (and our students) are highly visual in our learning. When we see something, we tend to remember it. As in the previous edition, we went over each piece of art, asking how it might be improved or where art could be added to improve student comprehension. We continue to focus on the presentation of chemistry at the molecular level. The molecular "story" starts in Chapter 1, and by Chapter 2, we have developed the molecular view and have integrated it into the problem-solving apparatus as well as into the text discussions. The following chapters continue to use the molecular view to strengthen chemical concepts. We have introduced electrostatic potential maps where pedagogically relevant to show how electron density changes across a molecule. This is especially helpful for visually demonstrating such things as bond and molecular polarity and acid–base behavior.

Chapter Essays Showcasing Chemistry as a Modern, Applicable Science

We continue our *A Chemist Looks at . . .* essays, which cover up-to-date issues of science and technology. We have chosen topics that will engage students' interest while at the same time highlight the chemistry involved. Icons are used to describe the content area (materials, environment, daily life, frontiers, and life science) being discussed. The essays show students that chemistry is a vibrant, constantly changing science that has relevance for our modern world. The essay "Gecko Toes, Sticky But Not Tacky," for example, describes the van der Waals forces used by gecko toes and their possible applications to the development of infinitely reusable tape or robots that can climb walls!

Also, with this edition, we continue our *Instrumental Methods* essays. These essays demonstrate the importance of sophisticated instruments for modern chemistry by focusing on an instrumental method used by research chemists, such as mass spectroscopy or nuclear magnetic resonance. Although short, these essays provide students with a level of detail to pique the students' interest in this subject.

We recognize that classroom and study times are very limited and that it can be difficult to integrate this material into the course. For that reason, we include end-of-chapter essay questions based on each *A Chemist Looks at . . .* and *Instrumental Methods* essay. These questions promote the development of scientific writing skills, another area that often gets neglected in packed general chemistry courses. It is our hope that having brief essay questions ready to assign will allow both students and instructors to value the importance of this content and make it easier to incorporate into their curriculums.

Additions and Changes Made in This Edition

- Changed formatting of Example Problems to facilitate student learning.
- Throughout the text, we adopted the terms atomic weight, molecular weight, and formula weight in place of corresponding terms atomic mass, and so on.

- Throughout the text, we adopted IUPAC periodic table conventions.
- Revisions throughout reflect recent work showing that the *d* hybrid orbitals are not dominant in bonding.
- Several "A Chemist Looks At" essays, including "Carbon Dioxide Gas and the Greenhouse Effect," "Nuclear Magnetic Resonance (NMR)," "Acid Rain," "Limestone Caves," and "Superconductivity," were updated. New essays on "The Discovery of New Elements" and "Lithium-Ion Batteries" were added.
- The mass spectrometer was added to Figure 3.8.
- In Chapter 6, the explanation of conversion factors used in stoichiometry calculations was clarified and the discussion of the NASA space program updated.
- In Chapter 7, figures relating to the electron microscope and scanning tunneling microscope were updated.
- In Chapter 8, the discussion on main-group elements was updated.

- In Chapter 9, we improved the discussion of electrostatic potential maps and the application of formal charge.
- In Chapter 10, a new subsection was added explaining the modern view of bonding in central atoms having more than eight valence electrons.
- The discussion of graphite in Chapter 11 was updated to include the recent discovery of graphene, the Nobel Prize for its discovery, and the lubricating ability of graphite by adsorption of water molecules to the layer structure.
- Chapter 18 was revised in several areas to clarify the discussion of the laws of thermodynamics.
- In Chapter 19, major revisions were made to the discussion of commercial voltaic cells to include modern battery types.
- In Chapter 23, a mention of the "E-Z system" for naming geometric isomers was added.

Supporting Materials

Please visit **www.cengage.com/chemistry/ebbing/generalchemistry11e** for information about student and instructor resources for this text.

Acknowledgments

The successful revision of a text depends upon the knowledge, skills, and dedication of a large number of individuals at Cengage Learning. This revision was initiated and led by Lisa Lockwood. Content developers provide invaluable guidance in performing the revision. Alyssa White and Peter McGahey were invaluable in this role. Our content product manager, Teresa Trego, ensured that we had the perfect content asset to meet our instructional needs. Art direction was provide by Sarah Cole. Her work created the new interior and cover designs. Ensuring that the 11th edition gets into the hands of students is our marketing manager, Janet Del Mundo. Product assistance was provided by Margaret O'Neil. Margaret prepared all of our permission and art logs. The media developer is Lisa Weber. Lisa works with content developers and vendors to ensure the seamless integration of technology with the text. Christine Myakovsky, permissions specialist, worked tirelessly to acquire photo permissions, kept us on track with the photo budget, and led the photo research team. Our IP project manager, Farah Fard, managed the photo researcher in order to provide the best possible photographic choices.

In addition to those people at Cengage, a number of people from other vendors were key players in this revision. These include Lynn Lustberg, at MPS Limited. Lynn was the production manager who ensured that everything came together when preparing the final product. Vikram Jayabala, at Lumina Datamatics, performed all of the photo research and permissioning. Our new chemistry photographs were due to the work of Jean Smolen (chemist) and Melissa Kelly (photographer) at St. Joseph's University.

David Shinn, at the U.S. Merchant Marine Academy, performed the revisions to end-of-chapter problems and provided new problems. Accuracy reviews and pre-revision reviews were performed by Don Neu at St. Cloud State University. Over the numerous editions of the text, we have been grateful for the insights and suggestions of the reviewers. They have played a critical role in the continuous improvements that are a hallmark of this text. For this edition, we would like to give a special thank you to Mark Blankenbuehler at Morehead State University and Mathilda Doorley at Southwest Tennessee Community College, who played the most critical role in the current revision.

Darrell wishes to thank his wife Jean and their children, Julie, Linda, and Russell, for their continued support and encouragement over many years of writing. Steve thanks his wife Jodi and their two children, Katie and Andrew, and his parents, Judy and Dick, for their support and for helping him keep a perspective on the important things in life.

A Note to Students

Having studied and taught chemistry for some years, we are well aware of the problems students encounter. We also know that students don't always read the Preface, so we wanted to remind you of all the resources available to help you master general chemistry.

Read the book

Each individual learns in a different way. We have incorporated a number of features into the text to help you tailor a study program that meets your particular needs and learning style.

Practice, practice, practice

Problem solving is an important part of chemistry, and it only becomes easier with practice. We worked hard to create a consistent three-part problem-solving approach (*Problem Strategy, Solution,* and *Answer Check*) in each in-chapter *Example*. Try the related *Exercise* on your own, and use the corresponding end-of-chapter *Practice Problems* to gain mastery of your problem-solving skills.

In every Example, we have also added what we call the *Gaining Mastery Toolbox*. We based this Toolbox on how we as instructors might help a student who is having trouble with a particular problem. We imagine a student coming to our office because of difficulty with a particular problem. We begin the help session by pointing out to the student the "big idea" that one needs to solve the problem. We call this the *Critical Concept*. But suppose the student is still having difficulty with the problem. We now ask the student about his or her knowledge of prior topics that will be needed to approach the problem. We call these needed prior topics the *Solution Essentials*. Each Gaining Mastery Toolbox that we have added to an Example begins by pointing out the Critical Concept involved in solving the problem posed in that Example. Then, under the heading of Solution Essentials, we list the topics the student needs to have mastered to solve this problem. We hope the Gaining Mastery Toolbox helps the student in much the way that an individual office visit can. Over several Examples, these Toolboxes should help the student develop the habit of focusing on the Critical Concept and the Solution Essentials while engaged in general problem solving.

Get help when you need it

Don't hesitate to ask your instructor or teaching assistant for help. You can also take advantage of the following helpful aids available at your school bookstore or at **www.cengagebrain.com**:

- The **Student Solutions Manual** contains detailed solutions to textbook problems.
- The **Study Guide** reinforces concepts and further builds problem-solving skills.

We have put a lot of time and thought into how to help you succeed. We hope you take advantage of all the technology and resources available with *General Chemistry,* Eleventh Edition. Best of luck in your study!

Darrell D. Ebbing
Steven D. Gammon

About the Authors

DARRELL D. EBBING

Darrell Ebbing became interested in chemistry at a young age when he tried his hand at doing magic tricks for friends, such as turning water to wine and having (nitrated) handkerchiefs disappear in a poof. Soon, however, his interests turned to the chemistry behind the magic and he even set up a home laboratory. After briefly becoming interested in botany in high school (having gathered several hundred plant specimens), his interest in chemistry was especially piqued when he managed to isolate white crystals of caffeine from tea. From that point, he knew he would go on to major in chemistry. During college, he helped pay his expenses by working at the USDA lab in Peoria, Illinois, as an assistant to a carbohydrate chemist, where he worked on derivatives of starch. As a graduate student at Indiana University, his interests gravitated to the theoretical—to understand the basis of chemistry—and he pursued a PhD in physical chemistry in the area of quantum chemistry.

Professor Ebbing began his professional career at Wayne State University where he taught courses at the undergraduate and graduate level and was for several years the Head of the Physical Chemistry Division. He soon became especially involved in teaching general chemistry, taking the position of Coordinator of General Chemistry. In his teaching, he used his knowledge of "chemical magic" to do frequent lecture demonstrations. He has written a book for introductory chemistry as well as this one for general chemistry (where you will see many of those lecture demonstrations). Although retired from active teaching, he retains a keen interest in frontier topics of science and in the history and philosophy of physical science, interests he hopes to turn into another book.

Having grown up in farm country, surrounded by fields and woods, Professor Ebbing has always maintained a strong interest in the great outdoors. He enjoys seeing nature up close through hiking and birding. His interests also include concerts and theater, as well as world travel.

STEVEN D. GAMMON

Steve Gammon started on his path to becoming a chemist and science educator in high school where he was captivated by a great instructor. After receiving a PhD in inorganic chemistry and chemical education from the University of Illinois-Urbana, he worked for two years at the University of Wisconsin-Madison, serving as the General Chemistry Laboratory Coordinator and becoming immersed in the field of chemical education. Professor Gammon then went on to join the faculty at the University of Idaho as the Coordinator of General Chemistry. In this role, he taught thousands of students, published instructional software, directed federally funded projects involving K-12 teachers, and began his work on *General Chemistry* (then going into its sixth edition). During his 11 years at the University of Idaho, he was honored with both university and national (Carnegie Foundation) teaching awards.

Throughout his career, while working at a number of colleges and universities, Professor Gammon has been involved with science education and has maintained a keen interest in the learning and teaching of introductory chemistry. In all of his endeavors, his desire is to create materials and methods that inspire his students to be excited about learning chemistry and science.

When Professor Gammon isn't thinking about the teaching and learning of chemistry, he enjoys doing a variety of activities with his family, including outdoor pursuits such as hiking, biking, camping, gold panning, and fishing. Scattered throughout the text you might find some examples of where his passion for these activities is used to make connections between chemistry and everyday living.

1

Chemistry and Measurement

A plate made of quartz (SiO_2) that can be used for data storage. Laser beams are used to write data inside the glass. Unlike most data storage in use today that have lifespans measured in decades or centuries, these plates can be used to preserve data for hundreds of millions of years.

YOSHIKAZUTSUNO/Getty Images

CONTENTS AND CONCEPTS

An Introduction to Chemistry

We start by defining the science called chemistry and introducing some fundamental concepts.

Physical Measurements

Making and recording measurements of the properties and chemical behavior of matter is the foundation of chemistry.

In 1964 Barnett Rosenberg and his coworkers at Michigan State University were studying the effects of electricity on bacterial growth. They inserted platinum wire electrodes into a live bacterial culture and allowed an electric current to pass. After 1 to 2 hours, they noted that cell division in the bacteria stopped. The researchers were very surprised by this result, but even more surprised by the explanation. They were able to show that cell division was inhibited by a substance containing platinum, produced from the platinum electrodes by the electric current. A substance such as this one, the researchers thought, might be useful as an anticancer drug, because cancer involves runaway cell division. Later research confirmed this view, and the platinum-containing substances, *cisplatin, carboplatin*, and *oxaliplatin* are all current anticancer drugs. (Figure 1.1).

This story illustrates three significant reasons to study chemistry. First, chemistry has important practical applications. The development of lifesaving drugs is one, and a complete list would touch upon most areas of modern technology.

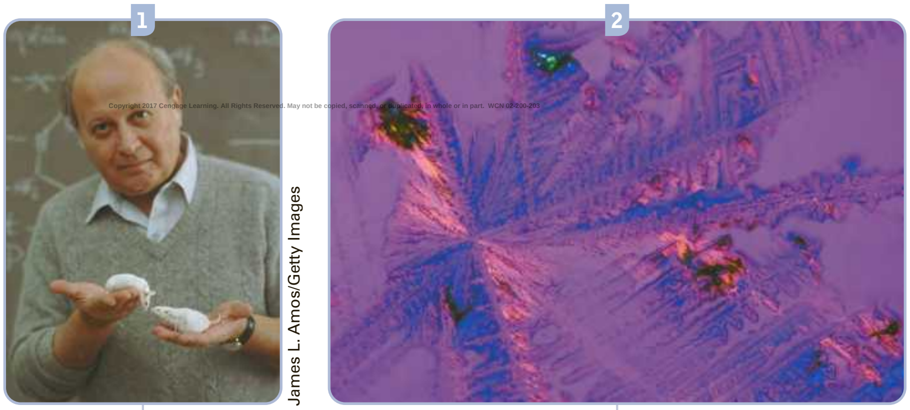
Second, chemistry is an intellectual enterprise, a way of explaining our material world. When Rosenberg and his coworkers saw that cell division in the bacteria had ceased, they systematically looked for the chemical substance that caused it to cease. They sought a chemical explanation for the occurrence.

Finally, chemistry figures prominently in other fields. Rosenberg's experiment began as a problem in biology; through the application of chemistry, it led to an advance in medicine. Whatever your career plans, you will find that your knowledge of chemistry is a useful intellectual tool for making important decisions.

▶ An Introduction to Chemistry

All of the objects around you—this book, your pen or pencil, and the things of nature such as rocks, water, and plant and animal substances—constitute the *matter* of the universe. Each of the particular kinds of matter, such as a certain kind of paper or plastic or metal, is referred to as a *material.* We can define chemistry as the science of the composition and structure of materials and of the changes that materials undergo.

One chemist may hope that by understanding certain materials, he or she will be able to find a cure for a disease or a solution for an environmental ill. Another chemist may simply want to understand a phenomenon. Because chemistry deals with all materials, it is a subject of enormous breadth. It would be difficult to exaggerate the influence of chemistry on modern science and technology or on our ideas about our planet and the universe. In the section that follows, we will take a brief glimpse at modern chemistry and see some of the ways it has influenced technology, science, and modern thought.



James L. Amos/Getty Images

Science sources

Figure 1.1 ▶

Barnett Rosenberg and Cisplatin

1 Photo of the discoverer of the anti-cancer activity of Cisplatin.

2 Photo of Cisplatin crystals as seen with a microscope.

1.1 Modern Chemistry: A Brief Glimpse

For thousands of years, human beings have fashioned natural materials into useful products. Modern chemistry certainly has its roots in this endeavor. After the discovery of fire, people began to notice changes in certain rocks and minerals exposed to high temperatures. From these observations came the development of ceramics, glass, and metals, which today are among our most useful materials. Dyes and medicines were other early products obtained from natural substances. For example, the ancient Phoenicians extracted a bright purple dye, known as Tyrian purple, from a species of sea snail. One ounce of Tyrian purple required over 200,000 snails. Because of its brilliant hue and scarcity, the dye became the choice of royalty.

Although chemistry has its roots in early technology, chemistry as a field of study based on scientific principles came into being only in the latter part of the eighteenth century. Chemists began to look at the precise quantities of substances they used in their experiments. From this work came the central principle of modern chemistry: the materials around us are composed of exceedingly small particles called *atoms,* and the precise arrangement of these atoms into *molecules* or more complicated structures accounts for the many different characteristics of materials. Once chemists understood this central principle, they could begin to fashion molecules to order. They could *synthesize* molecules; that is, they could build large molecules from small ones. Tyrian purple, for example, was eventually synthesized from the simpler molecule aniline; see Figure 1.2. Chemists could also correlate molecular structure with the characteristics of materials and so begin to fashion materials with special characteristics.

The liquid-crystal displays (LCDs) that are used on everything from watches and cell phones to computer monitors and televisions are an example of an application that depends on the special characteristics of materials (Figure 1.3). The liquid crystals used in these displays are a form of matter intermediate in characteristics between those of liquids and those of solid crystals—hence the name. Many of these liquid crystals are composed of rodlike molecules that tend to align themselves something like the wood matches in a matchbox. The liquid crystals are held in alignment in layers by plates that have microscopic grooves. The molecules are attached to small electrodes or transistors. When the molecules are subjected to an electric charge from the transistor or electrode, they change alignment to point in a new direction. When they change direction, they change how light passes through their layer. When the liquid-crystal layer is combined with a light source and color filters, incremental changes of alignment of the molecules throughout the display allow for images that have high contrast and millions of colors. ▶ Figure 1.4 shows a model of one of the molecules that forms a liquid crystal; note the rodlike shape

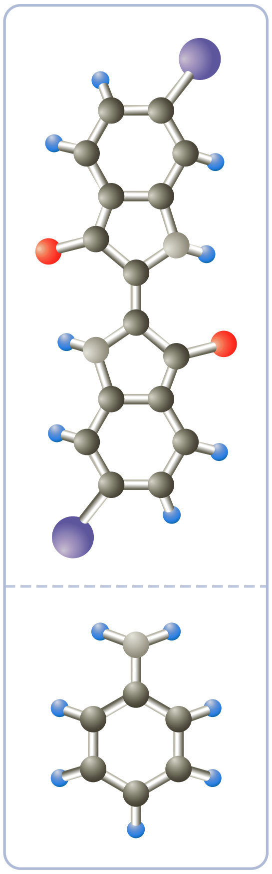

Science sources

Figure 1.2 ▲

Molecular models of Tyrian purple and aniline Tyrian purple (*top*) is a dye that was obtained by the early phoenicians from a species of sea snail. The dye was eventually synthesized from aniline (*bottom*). In molecular models the balls represent atoms; each element is represented by a particular color. The lines between the balls indicate that there is a connection holding the atoms together.

Liquid crystals and liquid-crystal displays are described in the essay at the end of Section 11.7.

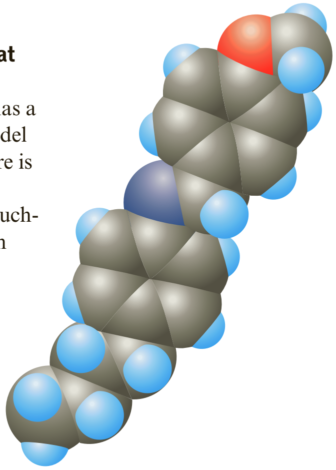
Figure 1.3 ▶

An iPad© that uses a liquid-crystal display These liquid-crystal displays are used in a variety of electronic devices.


Denys Prykhodov/Shutterstock

Figure 1.4 ▶

Model of a molecule that forms a liquid crystal Note that the molecule has a rodlike shape. In this model each atom in the structure is represented by a colored shape. Atoms that are touching are connected to each other.



of the molecule. Chemists have designed many similar molecules for liquid-crystal applications.


Henrik5000/iStockphoto.com

Figure 1.5 ▲

Optical fibers A bundle of optical fibers that can be used to transmit data via pulses of light.

Chemists continue to develop new materials and to discover new properties of old ones. Electronics and communications, for example, have been completely transformed by technological advances in materials. Optical-fiber cables have replaced long-distance telephone cables made of copper wire. Optical fibers are fine threads of extremely pure glass. Because of their purity, these fibers can transmit laser light pulses for miles compared with only a few inches in ordinary glass. Not only is optical-fiber cable cheaper and less bulky than copper cable carrying the same information, but through the use of different colors of light, optical-fiber cable can carry voice, data, and video information at the same time (Figure 1.5). At the ends of an optical-fiber cable, devices using other new materials convert the light pulses to electrical signals and back, while computer chips constructed from still other materials process the signals.

Chemistry has also affected the way we think of the world around us. For example, biochemists and molecular biologists—scientists who study the molecular basis of living organisms—have made a remarkable finding: all forms of life appear to share many of the same molecules and molecular processes. Consider the information of inheritance, the genetic information that is passed on from one generation of organism to the next. Individual organisms, whether bacteria or human beings, store this information in a particular kind of molecule called deoxyribonucleic acid, or DNA (Figure 1.6).

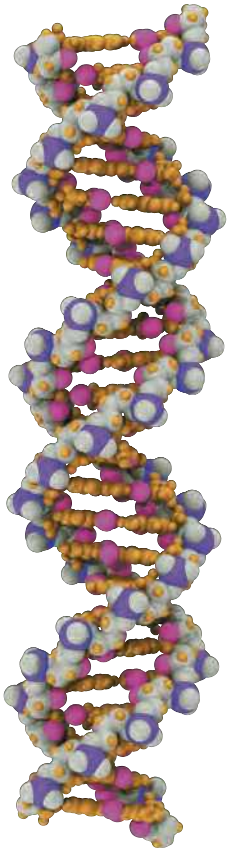

Scott Camazine/Alamy

Figure 1.6 ▲

A side view of a fragment of a DNA molecule DNA contains the hereditary information of an organism that is passed on from one generation to the next.

DNA consists of two intertwined molecular chains; each chain consists of links of four different types of molecular pieces, or bases. Just as you record information on a page by stringing together characters (letters, numbers, spaces, and so on), an organism stores the information for reproducing itself in the order of these bases in its DNA. In a multicellular organism, such as a human being, every cell contains the same DNA.

One of our first projects will be to look at this central concept of chemistry, the atomic theory of matter. We will do that in the next chapter, but first we must lay the groundwork for this discussion. We will need some basic vocabulary to talk about science and to describe materials; then we will need to discuss measurement and units, because measurement is critical for quantitative work.

1.2 Experiment and Explanation

Experiment and explanation are the heart of chemical research. A chemist makes observations under circumstances in which variables, such as temperature and amounts of substances, can be controlled. An **experiment** is *an observation of natural phenomena carried out in a controlled manner so that the results can be duplicated and rational conclusions made.* In the chapter opening, it was mentioned that Rosenberg studied the effects of electricity on bacterial growth. Temperature and amounts of nutrients in a given volume of bacterial medium are important variables in such experiments. Unless these variables are controlled, the work cannot be duplicated, nor can any reasonable conclusion be drawn.

After a series of experiments, perhaps a researcher sees some relationship or regularity in the results. For instance, Rosenberg noted that in each experiment in which an electric current was passed through a bacterial culture by means of platinum wire electrodes, the bacteria ceased dividing. If the regularity or relationship is fundamental and we can state it simply, we call it a law. A **law** is *a concise statement or mathematical equation about a fundamental relationship or regularity of nature.* An example is the law of conservation of mass, which says that the mass, or quantity of matter, remains constant during any chemical change.

At some point in a research project, a scientist tries to make sense of the results by devising an explanation. Explanations help us organize knowledge and predict future events. A **hypothesis** is *a tentative explanation of some regularity of nature.* Having seen that bacteria ceased to divide when an electric current from platinum wire electrodes passed through the culture, Rosenberg was eventually able to propose the hypothesis that certain platinum compounds were responsible. If a hypothesis

Daily Life

A **CHEMIST** Looks at . . .

The Birth of the Post-it Note®

Have you ever used a Post-it and wondered where the idea for those little sticky notes came from? You have a chemist to thank for their invention. The story of the Post-it Note illustrates how the creativity and insights of a scientist can result in a product that is as common in the office as the stapler or pen.

In the early 1970s, Art Fry, a 3M scientist, was standing in the choir at his church trying to keep track of all the little bits of paper that marked the music selections for the service. During the service, a number of the markers fell out of the music, making him lose his place. While standing in front of the congregation, he realized that he needed a bookmark that would stick to the book, wouldn't hurt the book, and could be easily detached. To make his plan work, he required an adhesive that would not *permanently* stick things together. Finding the appropriate adhesive was not as simple as it may seem, because most adhesives at that time were created to stick things together permanently.

Still thinking about his problem the next day, Fry consulted a colleague, Spencer Silver, who was studying adhesives at the 3M research labs. That study consisted of conducting a series of tests on a range of adhesives to determine the strength of the bond they formed. One of the adhesives that Silver created for the study was an adhesive that always remained sticky. Fry recognized that this adhesive was just what he needed for his bookmark. His first bookmark, invented the day after the initial idea, consisted of a strip of Silver's tacky adhesive applied to the edge of a piece of paper.

Part of Fry's job description at 3M was to spend time working on creative ideas such as his bookmark. As a result, he continued to experiment with the bookmark to improve its properties of sticking, detaching, and not hurting the surface to which it was attached. One day, while doing some paperwork, he wrote a question on one of his experimental strips of paper and sent it to his boss stuck to the top of a file folder. His boss then answered the question on the note and returned it attached to some other documents. During a later discussion over coffee, Fry and his boss realized that they had invented a new way for people to communicate: the Post-it Note was born. Today the Post-it Note is one of the top-selling office products in the United States.

■ See Problems 1.143 and 1.144.

is to be useful, it should suggest new experiments that become tests of the hypothesis. Rosenberg could test his hypothesis by looking for the platinum compound and testing for its ability to inhibit cell division.

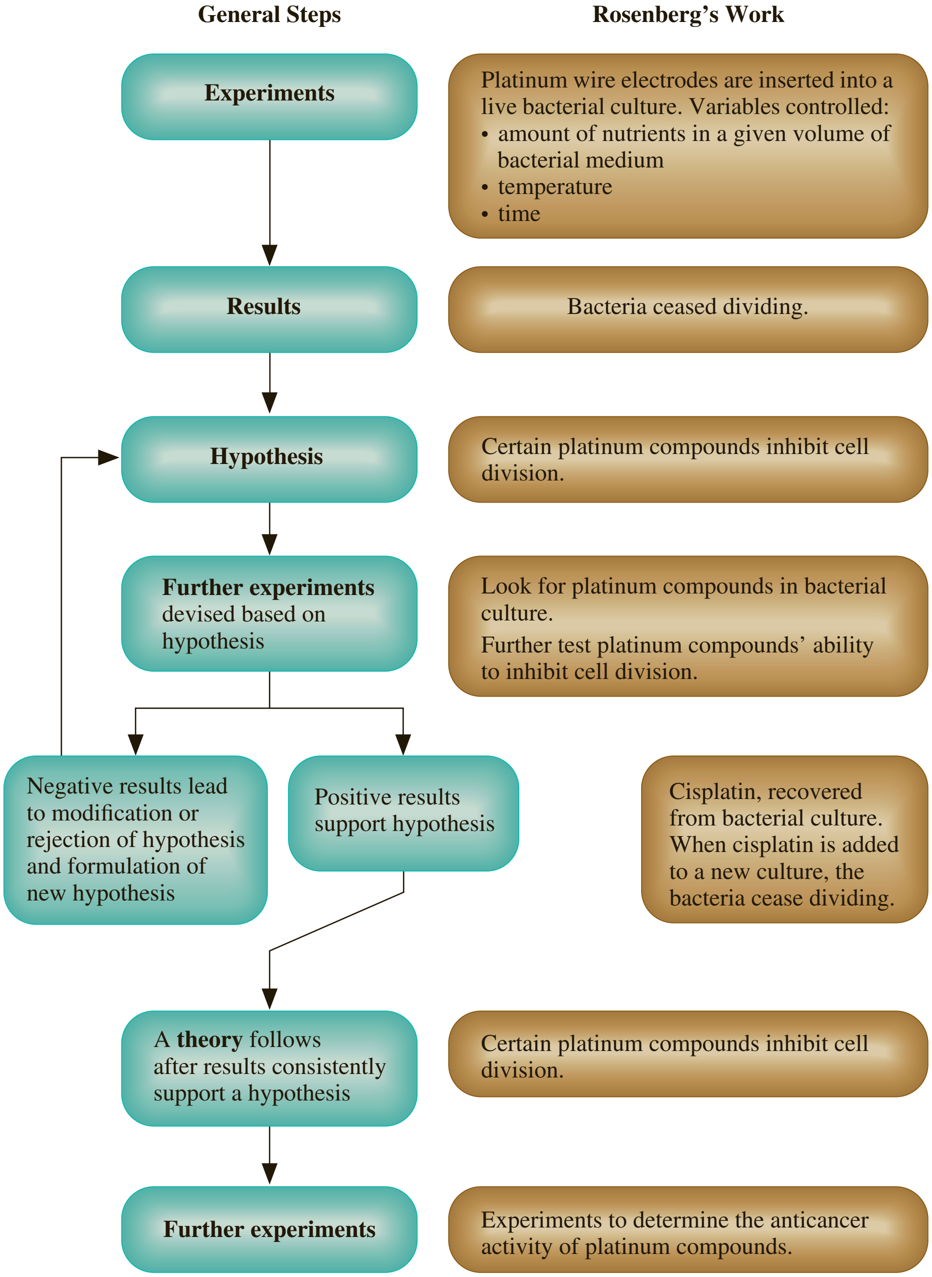
If a hypothesis successfully passes many tests, it becomes known as a theory. A **theory** is *a tested explanation of basic natural phenomena.* An example is the molecular theory of gases—the theory that all gases are composed of very small particles called molecules. This theory has withstood many tests and has been fruitful in suggesting many experiments. Note that we cannot prove a theory absolutely. It is always possible that further experiments will show the theory to be limited or that someone will develop a better theory. For example, the physics of the motion of objects devised by Isaac Newton withstood experimental tests for more than two centuries, until physicists discovered that the equations do not hold for objects moving near the speed of light. Later physicists showed that very small objects also do not follow Newton's equations. Both discoveries resulted in revolutionary developments in physics. The first led to the theory of relativity, the second to quantum mechanics, which has had an immense impact on chemistry.

The two aspects of science, experiment and explanation, are closely related. A scientist performs experiments and observes some regularity; someone explains this regularity and proposes more experiments; and so on. From his experiments, Rosenberg explained that certain platinum compounds inhibit cell division. This explanation led him to do new experiments on the anticancer activity of these compounds.

The *general* process of advancing scientific knowledge through observation; the framing of laws, hypotheses, or theories; and the conducting of more experiments

Figure 1.7 ▶

A representation of the scientific method This flow diagram shows the general steps in the scientific method. At the right, Rosenberg's work on the development of an anticancer drug illustrates the steps.




Martin Shields/Alamy

Figure 1.8 ▲

Laboratory balance A modern single-pan balance. The mass of the material on the pan appears on the digital readout.

is called the *scientific method* (Figure 1.7). It is not a method for carrying out a *specific* research program, because the design of experiments and the explanation of results draw on the creativity and individuality of a researcher.

1.3 Law of Conservation of Mass

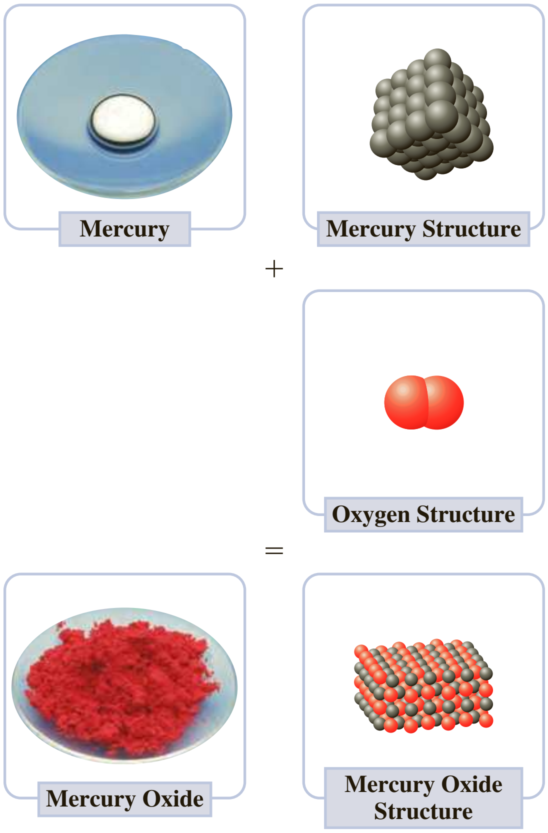
Modern chemistry emerged in the eighteenth century, when chemists began to use the balance systematically as a tool in research. Balances measure **mass**, which is *the quantity of matter in a material* (Figure 1.8). **Matter** is the general term for the material things around us; we can define it as *whatever occupies space and can be perceived by our senses.*

Antoine Lavoisier (1743–1794), a French chemist, was one of the first to insist on the use of the balance in chemical research. By weighing substances before and after chemical change, he demonstrated the **law of conservation of mass**, which states that *the total mass remains constant during a chemical change (chemical reaction).* ◀

Chemical reactions may involve a gain or loss of heat and other forms of energy. According to Einstein, mass and energy are equivalent. Thus, when energy is lost as heat, mass is also lost, but such small changes in mass in chemical reactions (billionths of a gram) are too small to detect.

Figure 1.9 ▶

Heating mercury metal in air Mercury metal reacts with oxygen to yield mercury(II) oxide. The color of the oxide varies from red to yellow, depending on the particle size.



Charles D Winters/Getty Images; Charles D. Winters/Science Source

In a series of experiments, Lavoisier applied the law of conservation of mass to clarify the phenomenon of burning, or combustion. He showed that when a material burns, a component of air (which he called oxygen) combines chemically with the material. For example, when the liquid metal mercury is heated in air, it burns or combines with oxygen to give a red-orange substance, whose modern name is mercury(II) oxide. We can represent the chemical change as follows:

$$\text{Mercury} + \text{oxygen} \longrightarrow \text{mercury(II) oxide}$$

The arrow means "is changed to." See Figure 1.9.

By strongly heating the red-orange substance, Lavoisier was able to decompose it to yield the original mercury and oxygen gas (Figure 1.10). The following example illustrates how the law of conservation of mass can be used to study this reaction.

© Cengage Learning

Figure 1.10 ▲

Heated mercury(II) oxide When you heat mercury(II) oxide, it decomposes to mercury and oxygen gas.

Example 1.1 Using the Law of Conservation of Mass

Gaining Mastery Toolbox

Critical Concept 1.1
The law of conservation of mass applies to chemical reactions. Whenever a chemical reaction occurs, the mass of the substances before the reaction (reactants) is identical to the mass of the newly formed substances after the reaction (products).

Solution Essentials:
- Definition of mass
- Definition of matter
- Law of conservation of mass

You heat 2.53 grams of metallic mercury in air, which produces 2.73 grams of a red-orange residue. Assume that the chemical change is the reaction of the metal with oxygen in air.

$$\text{Mercury} + \text{oxygen} \longrightarrow \text{red-orange residue}$$

What is the mass of oxygen that reacts? When you strongly heat the red-orange residue, it decomposes to give back the mercury and release the oxygen, which you collect. What is the mass of oxygen you collect?

Problem Strategy You apply the law of conservation of mass to the reaction. According to this law, the total mass remains constant during a chemical reaction; that is,

$$\begin{array}{c}\text{Mass of substances}\\ \text{before reaction}\end{array} = \begin{array}{c}\text{mass of substances}\\ \text{after reaction}\end{array}$$

(continued)

Example 1.1 *(continued)*

Solution From the law of conservation of mass,

$$\text{Mass of mercury + mass of oxygen} = \text{mass of red-orange residue}$$

Substituting, you obtain

$$2.53 \text{ grams} + \text{mass of oxygen} = 2.73 \text{ grams}$$

or

$$\text{Mass of oxygen} = (2.73 - 2.53) \text{ grams} = \mathbf{0.20 \text{ grams}}$$

The mass of oxygen collected when the red-orange residue decomposes equals the mass of oxygen that originally reacted **(0.20 grams)**.

Answer Check Arithmetic errors account for many mistakes. You should always check your arithmetic, either by carefully redoing the calculation or, if possible, by doing the arithmetic in a slightly different way. Here, you obtained the answer by subtracting numbers. You can check the result by addition: the sum of the masses of mercury and oxygen, 2.53 + 0.20 grams, should equal the mass of the residue, 2.73 grams.

Exercise 1.1 You place 1.85 grams of wood in a vessel with 9.45 grams of air and seal the vessel. Then you heat the vessel strongly so that the wood burns. In burning, the wood yields ash and gases. After the experiment, you weigh the ash and find that its mass is 0.28 gram. What is the mass of the gases in the vessel at the end of the experiment?

See Problems 1.37, 1.38, 1.39, and 1.40.

Lavoisier set out his views on chemistry in his *Traité Élémentaire de Chimie* (*Basic Treatise on Chemistry*) in 1789. The book was very influential, especially among younger chemists, and set the stage for modern chemistry.

Before leaving this section, you should note the distinction between the terms *mass* and *weight* in precise usage. The weight of an object is the force of gravity exerted on it. The weight is proportional to the mass of the object divided by the square of the distance between the center of mass of the object and that of the earth. ◀ Because the earth is slightly flattened at the poles, an object weighs more at the North Pole, where it is closer to the center of the earth, than at the equator. The mass of an object is the same wherever it is measured.

The force of gravity F between objects whose masses are m_1 and m_2 is Gm_1m_2/r^2, where G is the gravitational constant and r is the distance between the centers of mass of the two objects.

1.4 Matter: Physical State and Chemical Composition

We describe iron as a silvery-colored metal that melts at 1535°C (2795°F). Once we have collected enough descriptive information about many different kinds of matter, patterns emerge that suggest ways of classifying it. There are two principal ways of classifying matter: by its physical state as a solid, liquid, or gas, and by its chemical composition as an element, compound, or mixture.

Solids, Liquids, and Gases

Commonly, a given kind of matter exists in different physical forms under different conditions. Water, for example, exists as ice (solid water), as liquid water, and as steam (gaseous water) (Figure 1.11). The main identifying characteristic of solids is their rigidity: they tend to maintain their shapes when subjected to outside forces. Liquids and gases, however, are *fluids;* that is, they flow easily and change their shapes in response to slight outside forces.

What distinguishes a gas from a liquid is the characteristic of *compressibility* (and its opposite, *expansibility*). A gas is easily compressible, whereas a liquid is not. You can put more and more air into a tire, which increases only slightly in volume. In fact, a given quantity of gas can fill a container of almost any size. A small quantity would expand to fill the container; a larger quantity could be compressed to fill the same space. By contrast, if you were to try to force more liquid water into a closed glass bottle that was already full of water, it would burst.

These two characteristics, rigidity (or fluidity) and compressibility (or expansibility), can be used to frame definitions of the three common states of matter:

solid *the form of matter characterized by rigidity;* a solid is relatively incompressible and has fixed shape and volume.

liquid *the form of matter that is a relatively incompressible fluid;* a liquid has a fixed volume but no fixed shape.

gas *the form of matter that is an easily compressible fluid;* a given quantity of gas will fit into a container of almost any size and shape.

The term *vapor* is often used to refer to the gaseous state of any kind of matter that normally exists as a liquid or a solid.

These three forms of matter—solid, liquid, gas—comprise the common **states of matter**.

Elements, Compounds, and Mixtures

To understand how matter is classified by its chemical composition, we must first distinguish between physical and chemical changes and between physical and chemical properties. A **physical change** is *a change in the form of matter but not in its chemical identity.* Changes of physical state are examples of physical changes. The process of dissolving one material in another is a further example of a physical change. For instance, you can dissolve sodium chloride (table salt) in water. The result is a clear liquid, like pure water, though many of its other characteristics are different from those of pure water. The water and sodium chloride in this liquid retain their chemical identities and can be separated by some method that depends on physical changes.

Distillation is one way to separate the sodium chloride and water components of this liquid. You place the liquid in a flask to which a device called a *condenser* is attached (see Figure 1.12). The liquid in the

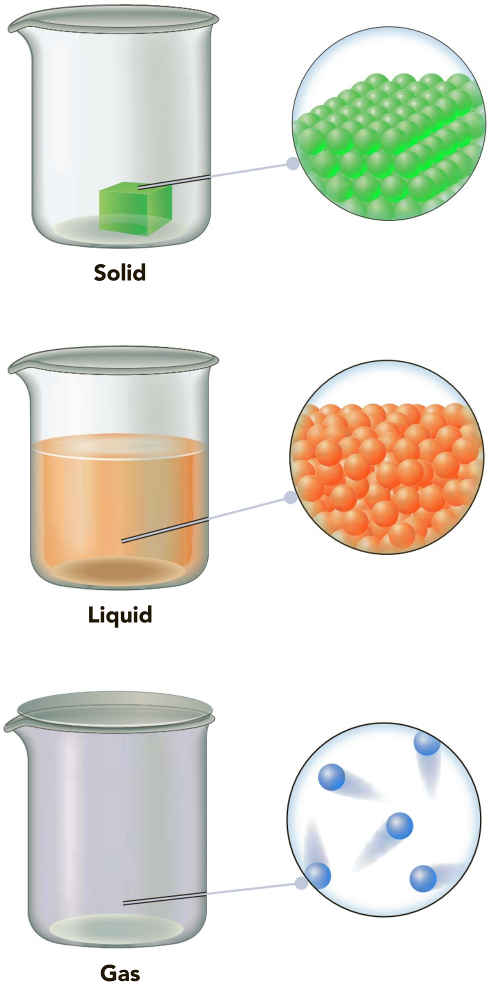


Figure 1.11 ▲

Molecular representations of solid, liquid, and gas The top beaker contains a solid with a molecular view of the solid; the molecular view depicts the closely packed, immobile atoms that make up the solid structure. The middle beaker contains a liquid with a molecular view of the liquid; the molecular view depicts atoms that are close together but moving freely. The bottom beaker contains a gas with a molecular view of the gas; the molecular view depicts atoms that are far apart and moving freely.

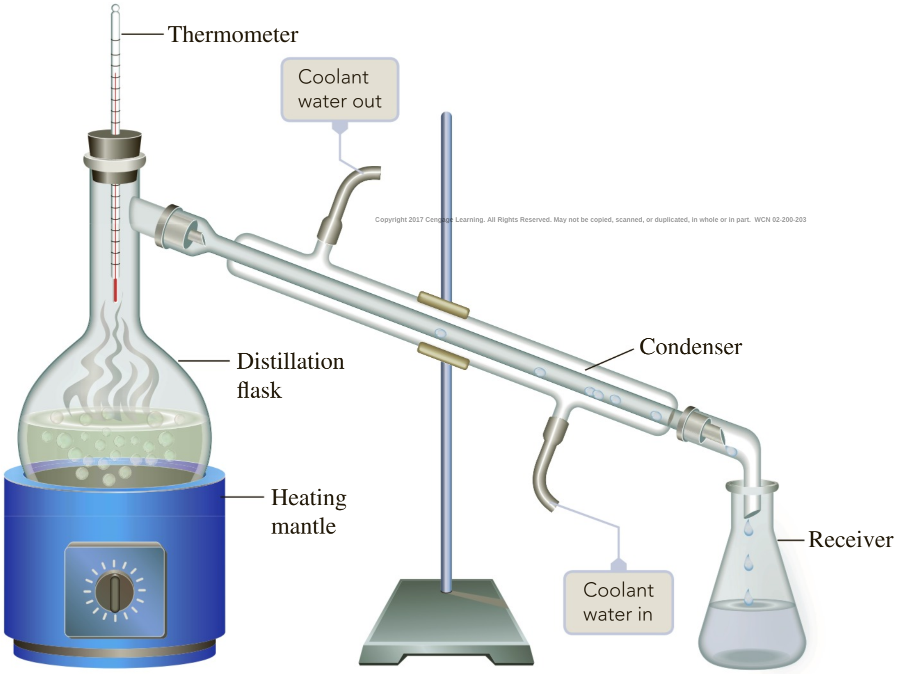


Figure 1.12 ◀

Separation by distillation You can separate an easily vaporized liquid from another substance by distillation.