



7th
Edition

JESPERSEN • HYSLOP

Chemistry

The Molecular Nature of Matter

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Periodic Table of the Elements

	Alkali metals (except H)		Alkaline earth metals		Group designation										Halogens		Noble gases	
	1A (1)		2A (2)		8B										7A (17)		8A (18)	
	1		2		3										4		5	
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
6	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
7	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
	Atomic number		Atomic mass															

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
140.12	140.91	144.24	[145]	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05	174.97

Lanthanides

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]	[262]

Actinides

ATOMIC MASSES OF THE ELEMENTS

This table is based on the 2007 table at *Pure Appl. Chem.*, **81**, 2131–2156 (2009) with changes to the values for lutetium, molybdenum, nickel, ytterbium and zinc from the 2005 table, and additions from IUPAC 2011 Periodic Table of the Elements for flerovium and livermorium. Mass number of the longest-lived isotope of hassium from *Phys. Rev. Lett.*, **97** 242501 (2006). The number in parentheses following the atomic mass is the estimated uncertainty in the last digit.

At No	Symbol	Name	Atomic Mass	Notes	At No	Symbol	Name	Atomic Mass	Notes
89	Ac	Actinium	[227]	5	101	Md	Mendelevium	[258]	5
13	Al	Aluminium	26.9815386(8)		80	Hg	Mercury	200.59(2)	
95	Am	Americium	[243]	5	42	Mo	Molybdenum	95.96(2)	1
51	Sb	Antimony	121.760(1)	1	60	Nd	Neodymium	144.242(3)	1
18	Ar	Argon	39.948(1)	1, 2	10	Ne	Neon	20.1797(6)	1, 3
33	As	Arsenic	74.92160(2)		93	Np	Neptunium	[237]	5
85	At	Astatine	[210]	5	28	Ni	Nickel	58.6934(4)	
56	Ba	Barium	137.327(7)		41	Nb	Niobium	92.90638(2)	
97	Bk	Berkelium	[247]	5	7	N	Nitrogen	14.0067(2)	1, 2, 4
4	Be	Beryllium	9.012182(3)		102	No	Nobelium	[259]	5
83	Bi	Bismuth	208.98040(1)		76	Os	Osmium	190.23(3)	1
107	Bh	Bohrium	[272]	5	8	O	Oxygen	15.9994(3)	1, 2, 4
5	B	Boron	10.811(7)	1, 2, 3, 4	46	Pd	Palladium	106.42(1)	1
35	Br	Bromine	79.904(1)	4	15	P	Phosphorus	30.973762(2)	
48	Cd	Cadmium	112.411(8)	1	78	Pt	Platinum	195.084(9)	
55	Cs	Cesium	132.9054519(2)		94	Pu	Plutonium	[244]	5
20	Ca	Calcium	40.078(4)	1	84	Po	Polonium	[209]	5
98	Cf	Californium	[251]	5	19	K	Potassium	39.0983(1)	1
6	C	Carbon	12.0107(8)	1, 2, 4	59	Pr	Praseodymium	140.90765(2)	
58	Ce	Cerium	140.116(1)	1	61	Pm	Promethium	[145]	5
17	Cl	Chlorine	35.453(2)	3, 4	91	Pa	Protactinium	231.03588(2)	5
24	Cr	Chromium	51.9961(6)		88	Ra	Radium	[226]	5
27	Co	Cobalt	58.933195(5)		86	Rn	Radon	[222]	5
112	Cn	Copernicium	[285]	5	75	Re	Rhenium	186.207(1)	
29	Cu	Copper	63.546(3)	2	45	Rh	Rhodium	102.90550(2)	
96	Cm	Curium	[247]	5	111	Rg	Roentgenium	[280]	5
110	Ds	Darmstadtium	[281]	5	37	Rb	Rubidium	85.4678(3)	1
105	Db	Dubnium	[268]	5	44	Ru	Ruthenium	101.07(2)	1
66	Dy	Dysprosium	162.500(1)	1	104	Rf	Rutherfordium	[265]	5
99	Es	Einsteinium	[252]	5	62	Sm	Samarium	150.36(2)	1
68	Er	Erbium	167.259(3)	1	21	Sc	Scandium	44.955912(6)	
63	Eu	Europium	151.964(1)	1	106	Sg	Seaborgium	[271]	5
100	Fm	Fermium	[257]	5	34	Se	Selenium	78.96(3)	
114	Fl	Flerovium	[289]	5	14	Si	Silicon	28.0855(3)	2, 4
9	F	Fluorine	18.9984032(5)		47	Ag	Silver	107.8682(2)	1
87	Fr	Francium	[223]	5	11	Na	Sodium	22.98976928(2)	
64	Gd	Gadolinium	157.25(3)	1	38	Sr	Strontium	87.62(1)	1, 2
31	Ga	Gallium	69.723(1)		16	S	Sulfur	32.065(5)	1, 2, 4
32	Ge	Germanium	72.64(1)		73	Ta	Tantalum	180.94788(2)	
79	Au	Gold	196.966569(4)		43	Tc	Technetium	[98]	5
72	Hf	Hafnium	178.49(2)		52	Te	Tellurium	127.60(3)	1
108	Hs	Hassium	[270]	5	65	Tb	Terbium	158.92535(2)	
2	He	Helium	4.002602(2)	1, 2	81	Tl	Thallium	204.3833(2)	4
67	Ho	Holmium	164.93032(2)		90	Th	Thorium	232.03806(2)	1, 5
1	H	Hydrogen	1.00794(7)	1, 2, 3, 4	69	Tm	Thulium	168.93421(2)	
49	In	Indium	114.818(3)		50	Sn	Tin	118.710(7)	1
53	I	Iodine	126.90447(3)		22	Ti	Titanium	47.867(1)	
77	Ir	Iridium	192.217(3)		74	W	Tungsten	183.84(1)	
26	Fe	Iron	55.845(2)		118	Uuo	Ununoctium	[294]	5
36	Kr	Krypton	83.798(2)	1, 3	117	Uus	Ununseptium	[294]	5
57	La	Lanthanum	138.90547(7)	1	115	Uup	Ununpentium	[288]	5
103	Lr	Lawrencium	[262]	5	113	Uut	Ununtrium	[284]	5
82	Pb	Lead	207.2(1)	1, 2	92	U	Uranium	238.02891(3)	1, 3, 5
3	Li	Lithium	6.941(2)	1, 2, 3, 4	23	V	Vanadium	50.9415(1)	
116	Lv	Livermorium	[293]	5	54	Xe	Xenon	131.293(6)	1, 3
71	Lu	Lutetium	174.9668(1)	1	70	Yb	Ytterbium	173.054(5)	1
12	Mg	Magnesium	24.3050(6)	4	39	Y	Yttrium	88.90585(2)	
25	Mn	Manganese	54.938045(5)		30	Zn	Zinc	65.38(2)	
109	Mt	Meitnerium	[276]	5	40	Zr	Zirconium	91.224(2)	1

1. Geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic mass of the element in such specimens and that given in the Table may exceed the stated uncertainty.

2. Range in isotopic composition of normal terrestrial material prevents a more precise value being given; the tabulated value should be applicable to any normal material.

3. Modified isotopic compositions may be found in commercially available material because it has been subject to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic mass of the element from that given in the Table can occur.

4. IUPAC recommends a range of masses for H, Li, B, C, N, O, Mg, Si, S, Cl, Br, Tl. For simplicity we have decided to use the single masses. In On the Cutting Edge 0.3, these masses and their ranges are discussed further.

5. Element has no stable nuclides. The value enclosed in brackets, e.g. [209], indicates the mass number of the longest-lived isotope of the element. However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic mass is tabulated.

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Preface

The seventh edition of our textbook continues to emphasize the molecular nature of matter, strong problem solving, and clarity of writing that was the basis of the sixth edition of *Chemistry: The Molecular Nature of Matter* by Neil D. Jespersen and James E. Brady. The relationship between the molecular level and the observable macroscopic properties of matter is presented in increased detail to reinforce and expand this fundamental concept.

Neil Jespersen continues his role as lead author as this text evolves in the electronic age. Neil is an analytical chemist, respected educator, and award-winning teacher who spearheaded the emphasis on the connection between the microscopic view and the macroscopic properties we experience in everyday life. **Alison Hyslop** has more than proven herself as a contributing author on the previous edition, and will continue to contribute to future editions. Alison is an inorganic chemist with extensive experience teaching graduate and undergraduate inorganic chemistry as well as general chemistry. She currently chairs her department and works collaboratively to enhance the chemistry degree programs. **James Brady** has taken an advisory role in this edition. His vision and guidance formed the philosophy and organization of the book. From completely introducing all topics before they are used to never skipping steps in solving problems, his leadership has made this book accessible for all chemistry students.

Philosophy and Goals

The philosophy of the text is based on our conviction that a general chemistry course serves a variety of goals in the education of a student. First, of course, it must provide a foundation in the basic facts and concepts of chemistry upon which theoretical models can be constructed. The general chemistry course should also give the student an appreciation of the central role that chemistry plays among the sciences, as well as the importance of chemistry in society and day-to-day living. In addition, it should enable the student to develop skills in analytical thinking and problem solving. With these thoughts in mind, our aim in structuring the text was to provide a logical progression of topics arranged to provide the maximum flexibility for the teacher in organizing his or her course. In this text, we were guided by **three principal goals**. The **first** was to strengthen the connection between observations on the macroscopic scale and the behavior of atoms, molecules, and ions

at the atomic level while introducing all concepts in a logical and understandable manner. The **second** was to further enhance and streamline our approach to teaching effective problem-solving skills. This includes emphasis on estimation and answer checking. The **third** goal was to provide a seamless, total solution to the General Chemistry course by fully integrating the textbook content with online assessment, answer-specific responses, and resources delivered within **WileyPLUS**.

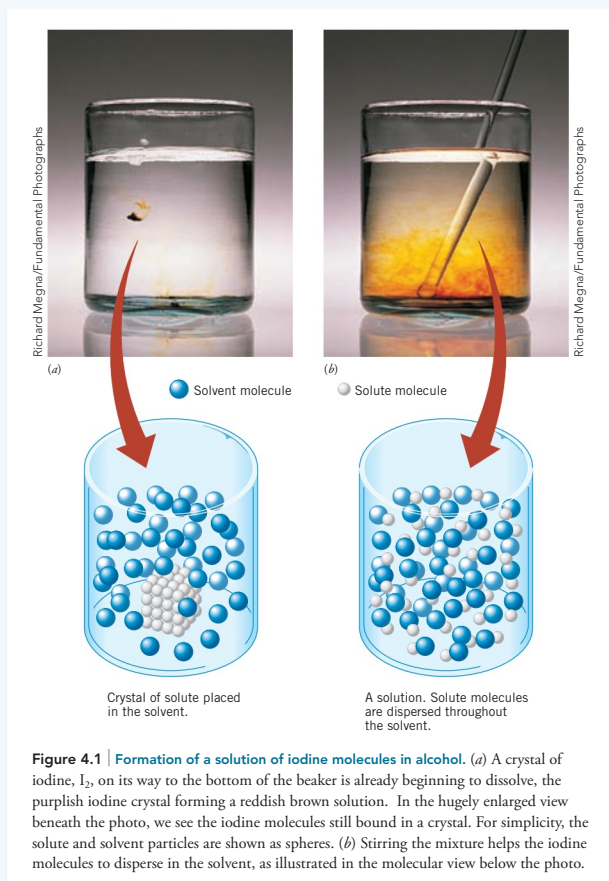
Emphasizing the Molecular View of Nature

The value of the molecular approach in teaching chemistry is well accepted and has always been a cornerstone in the approach taken by Jim Brady and his co-authors in presenting chemistry for many years. From his first text, in which novel three-dimensional computer-drawn representations of molecules and crystal structures were presented and observed using stereoscopic viewers, up through the 6th edition of this text, the atomic/molecular view has dominated the pedagogy. This new edition builds on that tradition by employing the “molecular basis of chemistry” as a powerful central theme of the text. Through this approach, the student will gain a sound appreciation of the nature of matter and how structure determines properties. Some actions we have taken to accomplish this are as follows:

Chapter Zero: A Very Brief History of Chemistry This new edition of the textbook begins with the formation of atoms from the origin of the universe. By discussing how atoms were initially formed and then moving on to the structure of the atoms through discoveries of the subatomic particles, we lay the groundwork for the atomic and molecular view of matter and outline how these concepts are used throughout the text. We provide a brief introduction to the distribution of elements throughout the earth and introduce students to the way we visualize molecules and chemical reactions.

Macro-to-Micro Illustrations To help students make the connection between the macroscopic world we see and events that take place at the molecular level, we have a substantial number of illustrations that combine both views. A photograph, for example, will show a chemical reaction as well as an artist's rendition of the chemical interpretation of what is taking place between the atoms, molecules, or ions involved.

The goal is to show how models of nature enable chemists to better understand their observations and to get students to visualize and describe events at the molecular level.



Problem Solving and the Connection between Textbook and WileyPLUS When students solve the end-of-chapter problems in *WileyPLUS*, the feedback to the answers submitted will guide the students to the correct answer. For the answers that are incorrect, the responses will give an explanation as to why the answer is wrong. In addition, we have included question and answer-specific hints and answer-specific feedback to give the students more assistance in solving problems.

Learning Objectives The learning objectives for each chapter have been explicitly stated at the beginning of each chapter. These learning objectives give the students guidance as to what they will learn after they have mastered each section. In addition, all of the end-of-chapter Questions and Problems are organized by the learning objectives and labeled by the section headers.

Developing Problem-solving Skills

We strongly believe that problem solving reinforces the learning of concepts and that assisting students in improving their skills in this area is one of the critical aspects of teaching

chemistry. We also believe that it is possible to accommodate students who come into the course with a wide range of problem-solving abilities so that they will finish the course with skill sets that will make them successful in later chemistry courses.

We continue to use a “**chemical tools**” model and approach to aid in teaching problem analysis. This approach encourages students to think of basic skills, such as converting from grams to moles, as tools that can be combined in various ways to solve more complex problems. Students and instructors have responded positively to this concept in earlier editions and we continue to employ this strategy in problem analysis. Tools are identified by an icon in the margin when they are introduced in a chapter and the tools are summarized at the end of each chapter.

TOOLS
Tools for Problem Solving The following tools were introduced in this chapter. Study them carefully so you can select the appropriate tool when needed.

Criteria for a balanced ionic equation (Section 4.3)
 To be balanced, an equation that includes the formulas of ions must satisfy two criteria: (1) the number of atoms of each kind must be the same on both sides of the equation, and (2) the net electrical charge shown on each side of the equation must be the same.

List of strong acids (Section 4.4)
 The common strong acids are perchloric acid, $HClO_4$, chloric acid, $HClO_3$, hydrochloric acid, HCl , hydrobromic acid, HBr , hydroiodic acid, HI , nitric acid, HNO_3 , and sulfuric acid, H_2SO_4 .

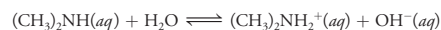
A significant strength of previous editions was the four-step problem-solving process of *Analysis, Assembling the Tools, Solution*, and asking *Is the Answer Reasonable?*, which was applied to all worked examples. Like a mechanic we perform an Analysis to understand and plan how the problem can be solved. Then the Tools needed to do the work are assembled and used to provide the Solution. This reinforces the notion that the Tools can be combined in various ways to solve complex problems. The complete solution showing every step in a logical sequence is presented. Finally, as a mechanic always tests the repair job, we show how scientists test their answers while asking “Is the Answer Reasonable?”

Example 4.3

Writing the Equation for the Ionization of a Molecular Base

Dimethylamine, $(CH_3)_2NH$, is a base that is soluble in water. It attracts boll weevils (an agricultural pest) so they can be destroyed, since this insect has caused billions in losses to cotton crops in the United States. Write an equation for the ionization of $(CH_3)_2NH$ in water.

- Analysis:** We've been told that $(CH_3)_2NH$ is a base, so it's going to react with water to form hydroxide ion. This gives us two reactants and one product. We need to determine the formula for the second product to write and balance the equation.
- Assembling the Tools:** The tool is the general equation for the ionization of a weak base with water, Equation 4.4, which we use as a template for writing the formulas of reactants and products.
- Solution:** The reactants in the equation are $(CH_3)_2NH$ and H_2O . According to Equation 4.4, when the base reacts with water it takes an H^+ from H_2O , becoming $(CH_3)_2NH_2^+$ and leaving OH^- behind. The equation for the reaction is



- Is the Answer Reasonable?** Compare the equation we've written with the general equation for reaction of a base with water. Notice that the formula for the product has one more H and a positive charge, and that the H^+ has been added to the nitrogen. Also, notice that the water has become OH^- when it loses H^+ . The equation is therefore correct.

We continue to provide at least two **Practice Exercises** following the worked examples that give the student an opportunity to apply the principles used to solve the preceding example. These have been thoroughly reviewed and in some cases expanded. The answers to all of the Practice Exercises are available to the student in Appendix B at the back of the book.

The **end-of-chapter Questions and Problems** have undergone a reworking to ensure that they provide an increasing range of difficulty, from routine drill-type problems to significantly more difficult ones, and have been organized by the learning objectives. Many problems require students to draw on knowledge acquired in earlier chapters. For example, in many of the problems in Chapter 4 and beyond, the chemical name of a compound in question is given rather than the formula, so students must apply (and review if necessary) the rules of nomenclature presented in Chapter 2.

One of the main goals of chemistry instruction is to help students develop the ability to solve problems that are more thought-provoking than typical review problems. Recognizing that students often have difficulty with solving problems that require application of several different concepts, we continue to use the Analyzing and Solving Multi-Concept Problems feature. These problems are more difficult than those in a typical worked example and require the use of concepts presented in more than one chapter. Students must combine two or more concepts before reaching a solution, and they must reduce a complex problem into a sum of simpler parts. Problems of this type first appear in Chapter 4 after students have had a chance to work on basic problem skills and after sufficient concepts have been introduced in earlier chapters to make such problems meaningful. Analyzing and Solving Multi-Concept Problems addresses instructor frustration and students' deficiencies in problem solving by teaching students how to deconstruct problems and emphasize the actual thinking that goes into solving problems.

Available in *WileyPLUS*, we include problem sets titled **Bringing it Together** that consist mostly of problems that require students to apply concepts developed in two or more of the preceding chapters. These problem sets are available for groups of four to five chapters. Problems have been selected to provide a range of difficulties so as to challenge students of varying levels of achievement.

The WileyPLUS Advantage

WileyPLUS is a research-based online environment for effective teaching and learning. *WileyPLUS* is packed with interactive study tools and resources—including the complete online textbook.

WileyPLUS addresses the needs of students, empowering them to be successful.

The 7th Edition *WileyPLUS* course that accompanies *Chemistry: The Molecular Nature of Matter* includes:

- Image Gallery that includes all line art, and tables
 - Test Bank questions
 - Classroom Response System (Clicker) questions
 - Solutions Manuals
 - A database of 3D molecules (available in *WileyPLUS*)
 - All content mapped to learning objectives
 - New visualizations of key concepts
 - End-of-chapter questions are available to be used for assessment, assignable and automatically graded
 - End-of-chapter questions that have multiple forms of assistance, available to students at the instructor's discretion. Assistance includes:
 - Question and answer-specific hints
 - Step-by-step tutorials (Go tutorials)
 - Answer-specific feedback
 - Office Hour, worked problem-solving videos
 - Links to specific sections of the textbook or other media
- In addition, *WileyPLUS* is now equipped with an adaptive learning module called ORION. Based on cognitive science, *WileyPLUS* with ORION provides students with a personal, adaptive learning experience so they can build their proficiency on concepts and use their study time effectively. *WileyPLUS* with ORION helps students learn by learning about them.
- WileyPLUS with ORION** is great as:
- An adaptive **pre-lecture tool** that assesses your students' conceptual knowledge so they come to class better prepared,
 - A **personalized study guide** that helps students understand both strengths and areas where they need to invest more time, especially in preparation for quizzes and exams.



Begin

Unique to ORION, students begin by taking a quick diagnostic for any chapter. This will determine each student's baseline proficiency on each topic in the chapter. Students see their individual diagnostic report to help them decide what to do next with the help of ORION's recommendations.



Practice

For each topic, students can either Study or Practice. **Study** directs the student to the specific topic they choose in *WileyPLUS*, where they can read from the e-textbook, or use the variety of relevant resources available there. Students can also **practice**, using questions and feedback powered by ORION's adaptive learning engine. Based on the results of their diagnostic and ongoing practice, ORION will present students with questions appropriate for their current level of understanding and will continuously adapt to each student, helping them build their proficiency.

ORION includes a number of reports and ongoing recommendations for students to help them maintain their



proficiency over time for each topic. Students can easily access ORION from multiple places within *WileyPLUS*. It does not require any additional registration, and there is no additional charge for students using this adaptive learning system.

About the Adaptive Engine

ORION includes a powerful algorithm that feeds questions to students based on their responses to the diagnostic and to the practice questions. Students who answer questions correctly at one difficulty level will soon be given questions at the next difficulty level. If students start to answer some of those questions incorrectly, the system will present questions of lower difficulty. The adaptive engine also takes into account other factors such as reported confidence levels, time spent on each question, and changes in response options before submitting answers.

The questions used for the adaptive practice are numerous and are not found in the *WileyPLUS* assignment area. This ensures that students will not be encountering questions in ORION that they may also encounter in their *WileyPLUS* assessments.

ORION also offers a number of reporting options available for instructors so that instructors can easily monitor student usage and performance.

Significant Changes in the 7th Edition

As noted earlier, our mission in developing this revision was to sharpen the focus of the text as it relates to the relationship between behavior at the molecular level and properties observed at the macroscopic level.

As much as possible, chapters are written to stand alone as instructional units, enabling instructors to modify the chapter sequence to suit the specific needs of their students. For example, if instructors wish to cover the chapter dealing with the properties of gases (Chapter 10) early in the course, they can easily do so. While we believe this chapter fits best in sequence with the chapters dealing with the other states of matter, we realize that there are other valid organizational preferences and the chapter has been written to accommodate them.

Some of the more significant changes to the organization are the following:

- Short essays addressing special topics are spread throughout the book. Those titled *Chemistry Outside the Classroom* and *Chemistry and Current Affairs* provide descriptions of real-world, practical applications of chemistry to industry, medicine, and the environment. Essays titled *On the Cutting Edge* serve to highlight chemical phenomena that are of current research interest and that have potential practical applications in the future. A list of these special topics appears at the end of the Table of Contents. In these essays we have included discussions on the IUPAC recommendations for using a range of atomic masses for

some elements and the use of these ranges in forensic science.

- **Chapter 0** is entirely new and sets the tone for the rest of the text. It provides an introduction to the important topics that we will address in this book: atomic theory, macroscopic properties rely on the microscopic properties, energy changes, and the geometric shapes of molecules. The atomic theory is introduced after a discussion of the origins of the elements from the start of the universe, through multiple supernova. A clear connection is made between observations at the macroscopic level and their interpretation at the molecular level.
- **Chapter 1** is devoted to measurements and their units. In this edition, we start with the scientific method and the classification of matter, then we move on to scientific measurements. The importance of quantitative measurements with respect to physical properties is introduced along with the concepts of intensive and extensive properties. The uncertainty of measurements is described. Significant figures are developed to provide the student with a logical method for assessing data. Finally, the method of dimensional analysis is discussed and applied to familiar calculations to develop confidence at an early stage.
- **Chapter 2** continues the discussion begun in Chapter 0 on the structure of the atom. We introduce the periodic table in this chapter as well as molecules, chemical formulas, and chemical reactions. The concepts of chemical reactions and chemical equations are presented and described by drawings of molecules and through the use of chemical symbols.
- **Chapter 3** covers the mole concept and stoichiometry. We have separated the discussion on the mole and Avogadro's number to emphasize the importance of these concepts.
- **Chapter 5** deals with redox reactions and includes a revised section on redox titrations to connect this procedure to the one introduced in Chapter 4. Redox reactions are presented in this chapter because many concomitant laboratory experiments use redox reactions.
- **Chapter 7** is a logical extension of Chapter 0 in our discussion of how our understanding of the atom has developed. The fundamentals of the quantum mechanical atom are introduced to the extent that the material is relevant to the remainder of the text. The discussion concerning orbitals has been expanded to include *f* orbitals.
- **Chapter 8** is the first of two chapters dealing with chemical bonding. We have moved the section devoted to some common kinds of organic compounds to the end of the chapter to allow for a more logical flow of concepts within the chapter. The section also serves as a brief introduction to organic chemistry for students whose major requires only one semester of chemistry. For instructors who do not wish to discuss organic compounds at this point in the course, the section is easily skipped and may be covered with Chapter 22.

- **Chapter 12** discusses the physical properties of solutions. The discussion on concentration units has been rewritten to integrate the temperature-independent concentration units with the temperature-dependent concentration units.
- **Chapter 13** covers the kinetics of chemical reactions, including mechanisms, and catalysis with the section on integrated rate laws is expanded in this new edition.
- **Chapter 20** discusses nuclear reactions and their applications. In this chapter, we have utilized the masses of the subatomic particles as defined by the National Institutes of Standards and Technology. Additional Review Problems were added that address the utilization of radioactive elements in quantitative analysis.
- **Chapter 22** provides an expanded discussion of organic chemistry with an emphasis on organic structures and functional groups. The number of Practice Exercises has been increased to give the student the opportunity to work through some examples while reading the chapter.

TEACHING AND LEARNING RESOURCES

A comprehensive package of supplements has been created to assist both the teacher and the student and includes the following:

For Students

Study Guide by Neil Jespersen of St. John's University. This guide has been written to further enhance the understanding of concepts. It is an invaluable tool for students and contains chapter overviews, additional worked-out problems giving detailed steps involved in solving them, alternate problem-solving approaches, as well as extensive review exercises. (ISBN: 978-1-118-70508-7)

Student Solutions Manual by Alison Hyslop, of St. John's University, with contributions by Duane Swank, of Pacific Lutheran University. The manual contains worked-out solutions for text problems whose answers appear in Appendix B. (ISBN: 978-1-118-70494-3)

Laboratory Manual for Principles of General Chemistry, 10th Edition, by Jo Beran of Texas A&M University, Kingsville. This comprehensive laboratory manual is for use in the general chemistry course. This manual is known for its broad selection of topics and experiments, and for its clear, user-friendly layout and design. Containing enough material for two or three terms, this lab manual emphasizes techniques, helping students learn the appropriate time and situation for their correct use. The accompanying Instructor's Manual presents the details of each experiment, including overviews, an instructor's lecture outline, teaching hints, and answers to pre-lab and laboratory questions. The Instructor's Manual also contains answers to the pre-laboratory assignment and laboratory questions. (ISBN: 978-1-118-62151-6)

For Instructors

Instructor's Manual by Scott Kirkby of East Tennessee State University. In addition to lecture outlines, alternate syllabi, and chapter overviews, this manual contains suggestions for small group active-learning projects, class discussions, tips for first-time instructors, class demonstrations, short writing projects, and relevant web links for each chapter.

Test Bank by Justin Meyer of South Dakota School of Mines and Technology. The test bank contains over 2,300 questions including: multiple-choice, true-false, short answer questions, fill in the blank questions, and critical thinking problems. A computerized version of the entire test bank is available with full editing features to help instructors customize tests.

Instructor's Solutions Manual by Alison Hyslop, of St. John's University, with contributions by Duane Swank, of Pacific Lutheran University, contains worked-out solutions to all end-of-chapter problems.

Digital Image Archive—The text web site includes downloadable files of text images in JPEG format. Instructors may use these images to customize their presentations and to provide additional visual support for quizzes and exams.

PowerPoint Lecture Slides by Mark Vitha, of Drake University and Nicholas Kingsley, of the University of Michigan – Flint, highlight key chapter concepts, contain numerous clicker questions, and include examples and illustrations that help reinforce and test students' grasp of essential topics. The slides feature images from the text that are customizable to fit your course.

PowerPoint Slides with Text Images—PPT slides containing images, tables, and figures from the text.

Personal Response Systems/"Clicker" Questions—A bank of questions is available for anyone using personal response systems technology in their classroom.

All instructor supplements can be requested from your local Wiley sales representative.

ACKNOWLEDGMENTS

In this edition it is a pleasure to welcome Alison Hyslop who contributed significantly to the sixth edition and now is a co-author for the seventh edition. She has important insights that will continually improve this text and we look forward to an on-going productive collaboration. At the same time we celebrate the tradition of excellence in chemistry teaching and lucid writing set forth by Jim Brady for many years. In his role as consultant, mentor, and friend he contributes greatly with his support and encouragement.

We express our fond thanks to our spouses, June Brady, Marilyn Jespersen, and Peter de Rege, and our children, Mark and Karen Brady, Lisa Fico and Kristen Pierce, and Nora, Alexander, and Joseph de Rege, for their constant support, understanding, and patience.

They have been, and continue to be, a constant source of inspiration for us all.

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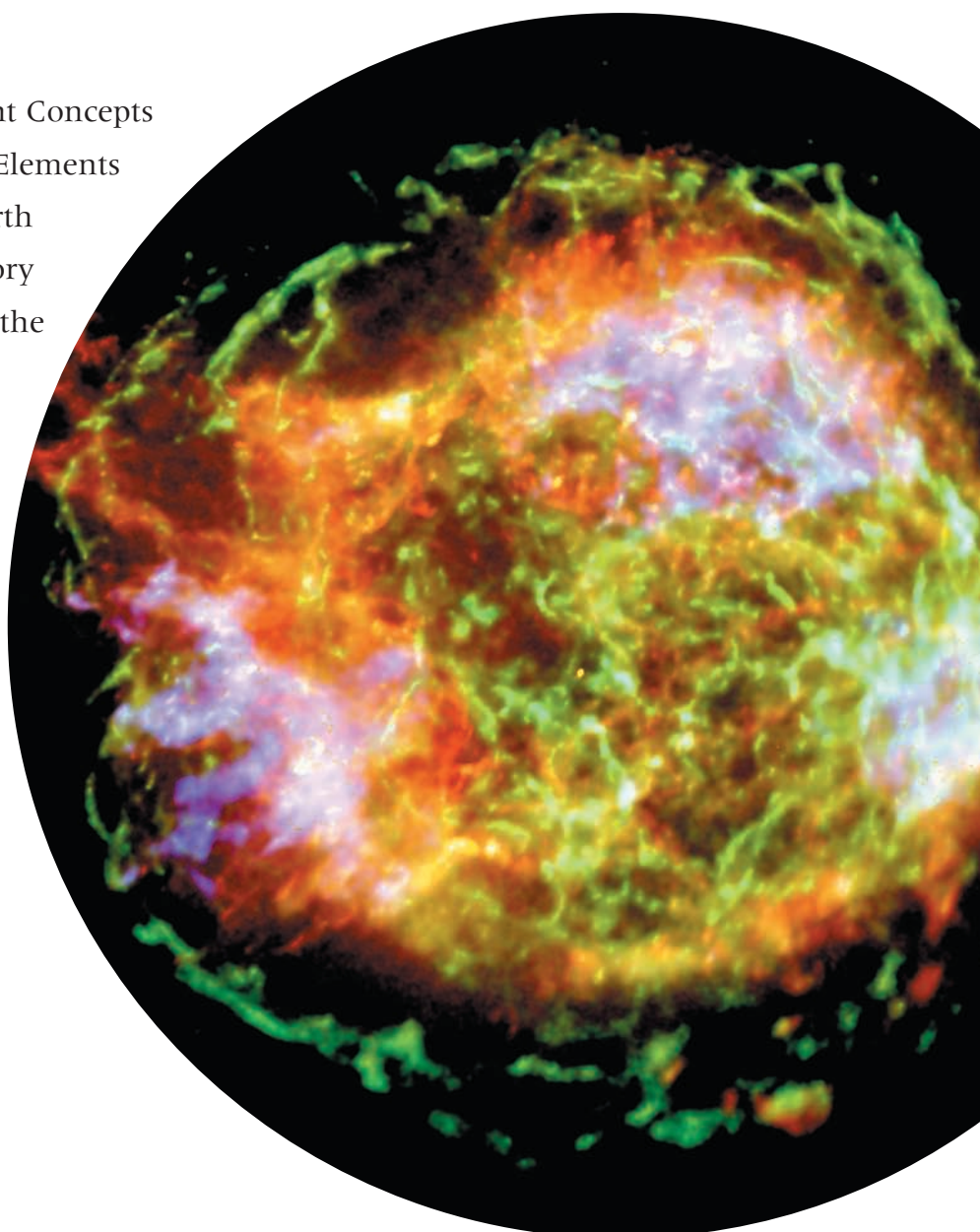
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A Very Brief History of Chemistry

Chapter Outline

- 0.1** | Chemistry's Important Concepts
- 0.2** | Supernovas and the Elements
- 0.3** | Elements and the Earth
- 0.4** | Dalton's Atomic Theory
- 0.5** | Internal Structure of the Atom



This Chapter in Context

In this introductory chapter we attempt to answer the large questions: “Where did we come from?” and “Where are we going?” In suggesting where we came from, we draw upon cosmology’s current theories about the start of the universe and the sequential synthesis of the elements. To the question of where we are going, this chapter suggests some of the “Important Concepts” that the science of chemistry uses to entice us toward the future.

These goals also set the theme on how scientists ply their trade. All of the information in this text is the result of a scientist asking a question, and then through scientific observation and research finding an answer. The same person who asks a question may not find the answer, and the time between asking and answering a question can be minutes or hundreds of years. In the end, we have an explanation of how chemists describe the physical world around us.

Advances in modern chemistry, physics, and mathematics allow us to explain our chemical surroundings with more clarity than ever. There will be more involved details to master, especially if your career plans include a significant amount of chemical work. However, you should be aware of the big picture and modern ideas. If you do that, it will certainly make the study of chemistry more meaningful for you. So, sit back and enjoy this chapter.

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- develop a sense of the scope and purpose of the chemical sciences
- learn how the elements were formed
- understand that the distribution of substances around the world is not accidental
- appreciate the powerful nature of the atomic theory
- understand how we came to know about the structure of the atom

0.1 | Chemistry’s Important Concepts

Although this seems to be a rather large and heavy textbook, and it must contain a lot of information that needs to be learned, there are a few guiding ideas that bring it all together. The intent of this section is to give an overall view of the main concepts of chemistry, and then we will fill in the details as we go along.

The *atomic theory* as explained by John Dalton in 1813 is the first of these important concepts. This theory describes atoms, the basic building blocks of our world. Dalton, in the most fundamental way, described the nature of atoms and how they interact with each other. Since then, chemists and physicists have been working out the fine details of atomic structure and chemical interactions. Many of these details are described in later chapters.

The second important concept is that we can tell a lot about what happens on the atomic scale with *careful observations on the laboratory or macroscopic scale*. In fact, until recently when instruments were developed to see, really detect, individual atoms and molecules, this was the only way that scientists could deduce what was happening.

Our third concept is that knowledge of *energy changes* and the probability of different arrangements of atoms help scientists predict how atoms interact. All energy of atoms can be classified as either *kinetic energy* (energy of motion) or *potential energy* (energy of position) and the sum of the two cannot change. In addition, atoms and molecules will tend toward the most probable arrangement. In general, we find that chemical reactions occur when the energy, potential and kinetic, of the atoms decreases and/or the atoms achieve their most probable arrangement.

The significance of geometric shapes of molecules is the fourth important concept. Large molecules such as DNA, RNA, enzymes, and antibodies have a three-dimensional structure that is important to their function. The three-dimensional shapes of much smaller molecules also affect their properties and reactivity. Indeed, the three-dimensional shape of these smaller structures dictates the shapes of the larger molecules. In this book we develop understanding three-dimensional shapes and the relationship between structure, properties, and reactivity.

These are the four important concepts that are developed throughout this book. Each of the following chapters adds increasing layers of details and depth. Recalling these concepts throughout your chemistry course will help keep you from being overwhelmed by the amount of material.

Using the chapter titles alone, assign one or two of chemistry's big ideas to each chapter and explain why you made your choice.¹

Practice Exercise 0.1

0.2 | Supernovas and the Elements

In the Beginning

We turn to physical cosmology for one of our most important ideas, the “**big-bang**” **theory**, to begin the story of chemistry. The big-bang theory postulates that the universe, as we know it, experienced a tremendous explosion of energy and subatomic particles approximately 14 billion years ago and that it has been expanding ever since.

Perhaps the first experimental data that suggested that the universe is expanding were observations by Edwin Hubble and others that the majority of stars and galaxies seem to shine with light that is shifted toward the red end of the visible spectrum. The well-known Doppler effect that explains why the whistle of a train has a higher pitch, or frequency, when the train is approaching and a lower pitch as it moves away, was used to give meaning to the red-shift observations. “Hubble’s law” proposes that the size of the red shift is proportional to the distance and speed of the star moving away from the earth. Cosmologists concluded that the only way to explain these data was to propose a universe that was expanding in all directions.

Working backwards, it was not difficult to imagine that the entire universe started from a single point that physicists call a singularity. Over time, the observations made by astronomers have all been explained by this theory. Interestingly, one of the supporting experiments was the serendipitous discovery in 1964 by two astronomers, Penzias and Wilson, who were trying to make very accurate measurements with a radio telescope. A persistent static was present no matter where they pointed the telescope. They expended great effort to clean the telescope in an attempt to remove the static. They even scrubbed off the “white dielectric material,” also known as pigeon droppings, from the telescope, to no avail. In the end, they questioned whether the static was more significant than just being some random noise. After careful calculations they concluded that the static was indeed microwave radiation characteristic of a temperature that matched the predicted temperature of the universe after cooling for 14 billion years. Today this is recognized as evidence that strongly supports the big-bang theory.

The First Elements

Using the big-bang theory, quantum mechanics, and some complex mathematics, physicists and cosmologists are able to provide us with some ideas on how the universe might have developed. The extreme temperature, density, and pressure of the singularity at the start of the universe allowed only the most basic particles such as quarks to exist. Within one second after the big bang, the universe expanded and cooled to about ten billion degrees, allowing the basic units of matter, quarks, in groups of three, to form protons and neutrons. Within three minutes, the temperature dropped to about a billion degrees, allowing **nucleosynthesis**, creation of atomic nuclei, to occur. In nucleosynthesis collisions between protons and neutrons resulted in the formation of deuterium, helium, and lithium nuclei.

When the universe became cool enough that nucleosynthesis could no longer occur, 91% of all atoms were hydrogen atoms, 8% were helium atoms, and all the rest comprised less than 1% of all the atoms as shown in Table 0.1. As the universe cooled further, electrons combined with these nuclei to form neutral atoms.

TABLE 0.1 Estimates of the Most Abundant Isotopes in the Solar System

Isotope	Solar System Atom Percent
Hydrogen-1	90.886
Helium-4	8.029
Oxygen-16	0.457
Carbon-12	0.316
Nitrogen-14	0.102
Neon-20	0.100

¹Answers to the Practice Exercises are found in Appendix B at the back of the book.

If the initial expansion of the universe had an even distribution of atoms, it would have remained as a dark, uniform, sea of atoms. Instead there were small disturbances in the dispersion of matter that grew with time. This led to the formation of the first stars as the matter coalesced.

Practice Exercise 0.2

Suggest conditions that are favorable for nucleosynthesis.

Practice Exercise 0.3

Suggest why only the lightest elements were formed during the big bang.

Elements Formed in Stars

As the stars grew in size, the temperature and pressure within each star increased to the point where nuclear fusion of hydrogen nuclei into helium started and stars began to shine. Heat generated from the fusion of hydrogen to helium maintained the volume and pressures within a star for millions of years. During that time the helium, being heavier than hydrogen, concentrated in the core, or center, of the star. In the core, the helium interfered with the collisions of the hydrogen nuclei and the rate of these nuclear reactions decreased. The star then cooled and contracted under gravitational forces. As the size decreased, the temperature and pressure of the core rose again and at about 100 million degrees the fusion of helium nuclei into carbon began. After a while the carbon was concentrated in the core and the helium core became a layer surrounding the carbon core. The hydrogen was still mostly found in the outer layer of the star.

Continuing, the carbon nuclei entered into nuclear reactions that produced argon. As the amount of argon increased, it migrated inward and became the core, now surrounded by a layer rich in carbon, then a helium layer, and finally the outer hydrogen layer.

We now have a pattern: Each successively heavier element becomes concentrated in the core of the star and when there are enough nuclei, nuclear reactions begin to produce an even heavier *nucleus*, which then concentrates in the core and repeats the process. In that way, oxygen and silicon cores are formed and then are forced out into layers by heavier elements. These layers and their nuclear reactions produce large quantities of heat to fuel and expand the star. A rapidly expanding star cannot generate enough heat to keep the hydrogen layer white hot, and as it cools the color becomes red. Stars like this are called **red giants**. Figure 0.1 illustrates the layered structure of a red giant star.

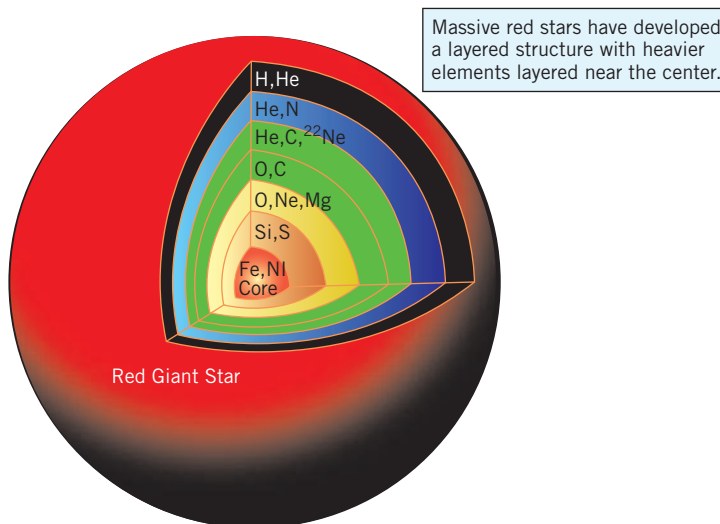


Figure 0.1 | Artist's rendering of the layered structure of a red giant star. Layering increases the density of specific nuclei that can fuse into larger elements, forming new layers.

Suggest why a core and enriched layers of nuclei are needed for nucleosynthesis in stars.

Suggest why, after some 14 billion years, hydrogen still makes up the overwhelming majority of the atoms in the universe.

Practice Exercise 0.4

Practice Exercise 0.5

Elements Formed in Supernovas

Finally, the silicon started fusing in nuclear reactions to form iron. The iron-forming reaction actually consumes heat and starts to cool the core. This cooling causes a cataclysmic collapse of the star, and as the nuclei rush toward the core the increase in pressure and density does two things. First, the speeding nuclei destroy many of the iron nuclei, creating a rich mixture of smaller particles such as helium nuclei and neutrons. In addition, the temperature of the collapsing star reaches levels that cannot be achieved even in the most massive stars. At its culmination, the collapsing star disintegrates, spewing all of its matter into interstellar space. This is called a **supernova**; in it exists a mix of nuclei that have very high energies and an atom density that has sufficient numbers of collisions to create even the heaviest elements. These conditions for nucleosynthesis last for less than a minute, perhaps for just seconds, when the expansion and cooling then make these reactions improbable.

The remnants of a supernova are eventually brought together to form a new star to repeat the process. In some instances, the formation of the new star leaves a ring of debris around it. This debris eventually accretes (clumps together) to form planets, moons, and asteroids.

Why don't elements heavier than iron form in stars?

What conditions do supernovas provide for synthesis of heavier elements?

Practice Exercises 0.6

Practice Exercises 0.7

0.3 | Elements and the Earth

As the stars formed, planets also formed from the debris surrounding the stars. The formation of the planets and the composition of the planets depended upon the matter that was available.

Planet Building

Nebula is the word that describes the debris left after the formation of a star forms a disk that can accrete into planets, moons, and asteroids. Depending on the debris, the planets can be rocky like the earth, Mars, and Venus or gaseous as Jupiter and Saturn. The final chemical makeup of a planet depends on the materials that accreted at the start and the elements that were retained by the gravitational forces of the planet itself. You can find a list of all the known elements inside the front cover of this book.

Table 0.2 lists the atom abundance in the whole earth, the crust, the oceans, and the atmosphere. We might expect that the distribution of the elements will be uniform on earth because the nebula that the earth condensed from had a relatively uniform distribution. Taking a quick look around us, we see that the earth does not have a uniform distribution of elements either on or below the surface, while the atmosphere and oceans tend to have more uniform compositions.

Distribution of the Elements

This uneven distribution can often be understood based on the properties of the elements such as their melting points, densities, and solubilities. When the earth formed some 4.5 billion years ago, the solid dust and gas particles in the nebula were slowly attracted to

TABLE 0.2

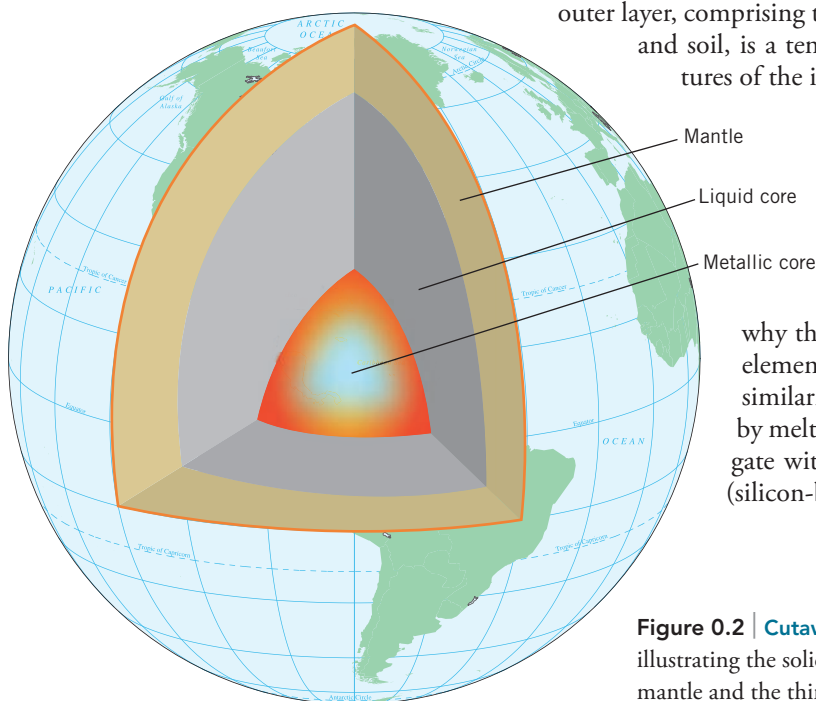
Estimates of the atom percentages in the earth as a whole, the crust, the atmosphere, and the oceans.*

Element	Earth	Crust	Atmosphere	Oceans
Oxygen	48.2	59.0	20.9	33.02
Iron	14.8	2.1		
Silicon	15.0	20.4		
Magnesium	16.4	2.0		0.03
Hydrogen	0.67	2.9		66.06
Chlorine				0.34
Sodium	0.20	2.1		0.17
Sulfur	0.52			0.02
Calcium	1.1	2.2		0.006
Potassium	0.01	1.1		0.006
Aluminum	1.5	0.57		
Bromine				0.0067
Carbon	0.16			0.0028
Nitrogen			78.1	
Argon			0.96	

* Blank entries indicate that an atom is present to a negligible extent.

each other by gravitational and electrostatic forces. Once the earth formed, it began heating due to the radioactive elements releasing heat as they decayed to stable isotopes. In addition, bombardment by meteorites also heated the earth's surface while continued gravitational contraction also added more heat.

Eventually a large proportion of the earth melted and iron and nickel migrated to the inner core. Based on measurements of seismic waves (vibrations due to earthquakes) the actual inner core of the earth is composed of solid iron and nickel that is surrounded by a liquid layer of these metals. The outer core is superheated lava. Surrounding the core is the mantle of superheated rock that comprises about 85% of the earth's mass. The outer layer, comprising the lighter substances that we observe as solid rock and soil, is a ten-mile-thick crust. Figure 0.2 illustrates these features of the inner workings of the earth.



The outer core, mantle, and crust of the earth are not very fluid, and so different materials did not have the opportunity to separate on a massive scale as the core did. However you may have seen the exotic patterns of crystals in a granite counter-top. Minerals do separate, but only in small areas. That is also why the surface of the earth is not uniform. Minerals or elements in the crust will separate to a small extent due to similarities in their composition and structure as well as by melting points. For instance, gold atoms tend to aggregate with other gold atoms, rather than silicate minerals (silicon-based rocks) because they have distinctly different

Figure 0.2 | Cutaway model of the interior of the earth illustrating the solid and liquid cores of iron/nickel. The mantle and the thin layer called the crust are shown.

crystal structures, densities, and melting points. When the crust cooled the gold separated from the silicate rocks as they solidified. This process is called differential crystallization. Due to the tremendous reservoir of heat in the earth's core, these processes continue to this day and are seen frequently in the form of earthquakes and volcanic eruptions.

0.4 | Dalton's Atomic Theory

Today we define an atom as the smallest representative sample of an element and a compound as a substance that contains two or more elements, always in a fixed ratio by mass. Originally, the concept of atoms began nearly 2500 years ago when certain Greek philosophers expressed the belief that matter is ultimately composed of tiny indivisible particles. The Greek word meaning “not cut,” is the source of our modern word “atom.” The philosophers had no experimental evidence for their concept of atoms and many argued against this idea. Scientific support for the existence of atoms awaited the discovery of the *law of definite proportions* and the *law of conservation of mass*. Amazingly, these two important general observations about the nature of compounds and chemical reactions became apparent through the work of many early chemists (or alchemists) whose lab equipment only measured mass and volume.

Laws of Chemical Combination

Prior to the 19th century, progress in science was slow because there was little understanding of the need for accurate measurements. As we will discuss in Chapter 1, accurate, precise, and reproducible measurements are necessary in all the sciences. Despite the lack of accuracy and precision of early scientific work, over the course of time data accumulated that revealed some principles that apply to all chemical compounds and chemical reactions.

The first principle is that, when a compound is formed, elements always combine in the same proportion by mass. For example, when hydrogen and oxygen combine to form water the mass of oxygen is always eight times the mass of hydrogen—never more and never less. Similar observations apply to every compound we study. Such observations led to a generalization, known as the law of definite proportions (or law of definite composition). That law states that *in any chemical compound the elements are always combined in a definite proportion by mass*.

The second observation is that when a reaction is carried out in a sealed vessel, so that nothing can escape or enter, the total mass after the reaction is over is exactly the same as at the start. For instance, if we place hydrogen and oxygen into a sealed container and initiate the reaction to form water, the mass of water and whatever hydrogen or oxygen is left over is the same as the mass of the hydrogen and oxygen we started with. Such observations, repeated over and over for large numbers of chemical reactions, led to the generalization known as the law of conservation of mass. This law states that *mass is neither lost nor created during a chemical reaction*.

Law of Definite Proportions

In a given chemical compound, the elements are always combined in the *same proportions by mass*.

Law of Conservation of Mass

No detectable gain or loss of mass occurs in chemical reactions. Mass is *conserved*.

In Chapter 3 you will see how these laws can be used to perform calculations related to chemical composition.

The Atomic Theory

The laws of definite proportions and conservation of mass served as the *experimental foundation* for the atomic theory. They prompted the question: “What must be true about the nature of matter, given the truth of these laws?”



At the beginning of the 19th century, John Dalton (1766–1844), an English scientist, used the Greek concept of atoms to make sense out of the laws of definite proportions and conservation of mass. Dalton reasoned that if atoms really exist, they must have certain properties to account for these laws. He postulated what those properties must be, and the list of postulates constitutes what we now call **Dalton's atomic theory**.

Dalton's Atomic Theory

1. Matter consists of tiny particles called *atoms*.
2. In any sample of a *pure element*, all the atoms are identical in mass and other properties.
3. The atoms of *different elements* differ in mass and other properties.
4. When atoms of *different elements* combine to form compounds, new and more complex particles form. However, in a given compound the constituent atoms are always present in the *same fixed numerical ratio*.
5. *Atoms are indestructible*. In chemical reactions, the atoms rearrange but they do not themselves break apart.

Modern Experimental Evidence for Atoms

In the early years of the 19th century scientists and alchemists had little more than rudimentary balances and graduated cylinders to make measurements. Modern chemical instrumentation now provides additional proof that atoms actually exist. Although atoms and most molecules are so incredibly tiny that even the most powerful optical microscopes are unable to detect them, experiments have been performed that provide pretty convincing evidence that atoms are real.

Scientists have developed very sensitive instruments that are able to map the surfaces of solids with remarkable resolution. One such instrument is called a **scanning tunneling microscope**. It was invented in the early 1980s by Gerd Binnig and Heinrich Rohrer and earned them the 1986 Nobel Prize in physics. With this instrument, the tip of a sharp metal probe is brought very close to an electrically conducting surface and an electric current bridging the gap is begun. The flow of current is extremely sensitive to the distance between the tip of the probe and the sample. As the tip is moved across the surface, the height of the tip is continually adjusted to keep the current

flow constant. By accurately recording the height fluctuations of the tip, a map of the hills and valleys on the surface is obtained. The data are processed using a computer to reveal an image of atoms on the surface as illustrated in Figure 0.3. Other, more complex instruments are also used to “observe” individual atoms and molecules, thus increasing our confidence that atoms exist and the atomic theory is correct. A newer instrument called the **atomic force microscope** is described in On the Cutting Edge 0.1.

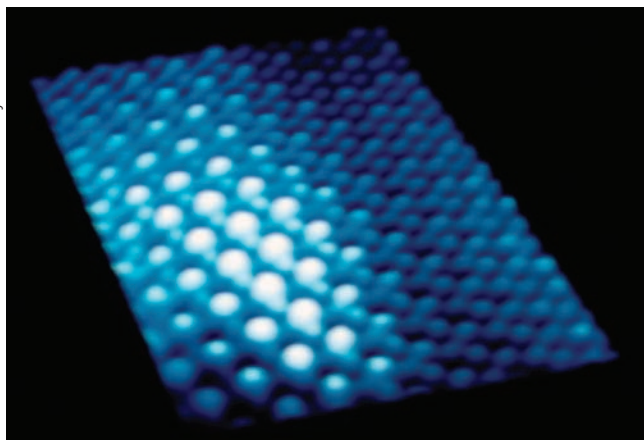


Figure 0.3 | Individual atoms can be imaged using a scanning tunneling microscope. This STM micrograph reveals the pattern of individual atoms of palladium deposited on a graphite surface. Palladium is a silvery white metal used in alloys such as white gold and dental crowns.

0.5 | Internal Structure of the Atom

The earliest models of atoms imagined them to be indestructible and totally unable to be broken into smaller pieces. However, as you probably know, atoms are not quite as indestructible as Dalton and other early philosophers had thought. During the late 1800s and early 1900s, experiments were performed that demonstrated that atoms are composed of **subatomic particles**. From this work the current theoretical model of atomic structure evolved. We will examine it in general terms in this chapter. A more detailed discussion of the electronic structure of the atom will follow in Chapter 7.

ON THE CUTTING EDGE 0.1

Seeing and Manipulating Atoms and Molecules

Atoms and small molecules are incredibly tiny. Experiments have shown that they have diameters of the order of several billionths of an inch. For example, the diameter of a carbon atom is about 6 billionths of an inch (6×10^{-9} in.). As you will learn in Chapter 1, the prefix nano implies 10^{-9} , so when we examine matter at the nano-scale level, we are looking at very small structures, usually with dimensions of perhaps tens to hundreds of atoms. Nanotechnology deals with using such small-scale objects and the special properties that

accompany them to develop useful applications. Ultimately, the goal of nanotechnology (also sometimes called molecular nanotechnology) is to be able to build materials from the atom up. Such technology doesn't quite exist yet, but scientists are beginning to make progress in that direction. This discussion, therefore, is kind of a progress report that will give you some feeling of where science is now and where it's heading—sort of a glimpse at the future.

There are several reasons why there is so much interest in nanotechnology. For one, the properties of materials are related to their structures. By controlling structures at the atomic and molecular level, we can (in principle) tailor materials to have specific properties. Driving much of the research in this area are the continuing efforts by computer and electronics designers to produce ever-smaller circuits. The reductions in size achieved through traditional methods are near their limit, so new ways to achieve smaller circuits and smaller electrical devices are being sought.

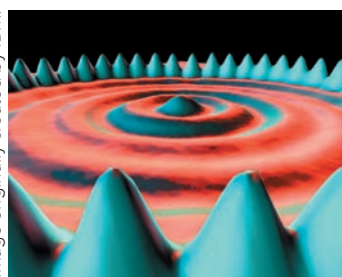


Figure 1 Scientists have control of not only the atomic landscape, but the electronic landscape also. Here they have positioned 48 iron atoms into a circular ring in order to "corral" some surface state electrons and force them into this circular structure. The ripples in the ring of atoms are predicted by quantum theory that is introduced in Chapter 8.

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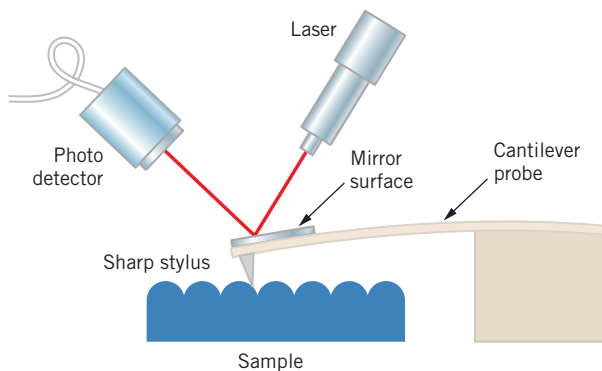


Figure 2 An atomic force microscope (AFM). A sharp stylus attached to the end of a cantilever probe rides up and down over the surface features of the sample. A laser beam, reflected off a mirrored surface at the end of the probe, changes angle as the probe moves up and down. A photo detector reads these changes and sends the information to a computer, which translates the data into an image.

Molecular Self-Assembly

An area of research that is of great interest today is the field of molecular self-assembly, in which certain molecules, when brought together, spontaneously arrange themselves into desirable structures. Biological systems employ this strategy in constructing structures such as cellular membranes. The goal of scientists is to mimic biology by designing molecules that will self-assemble into specific arrangements.

Visualizing and Manipulating Very Tiny Structures

What has enabled scientists to begin the exploration of the nano-world is the development of tools that allow them to see and sometimes manipulate individual atoms and molecules. We've already discussed one of these important devices, the scanning tunneling microscope (STM), when we discussed experimental evidence for atoms (see Section 0.4). This instrument, which can only be used with electrically conducting samples, makes it possible to image individual atoms. What is very interesting is that it can also be used to move atoms around on a surface. To illustrate this, scientists have arranged atoms to corral electrons (Figure 1). Although this experiment may not have much practical use, it demonstrates that one of the required capabilities for working with substances at the molecular level is achievable.

To study nonconducting samples, a device called an atomic force microscope (AFM) can be used. Figure 2 illustrates its basic principles. A very sharp stylus (sort of like the needle used in a DJ's vinyl record player) is moved across the surface of the sample under study. Forces between the tip of the probe and the surface molecules cause the probe to flex as it follows the ups and downs of the bumps that are the individual molecules and atoms. A mirrored surface attached to the probe reflects a laser beam at angles proportional to the amount of deflection of the probe. A sensor picks up the signal from the laser and translates it into data that can be analyzed by a computer to give three-dimensional images of the sample's surface. A typical image produced by an AFM is shown in Figure 3.

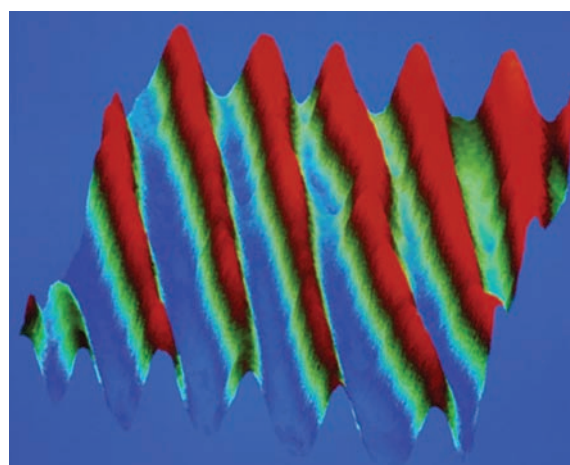


Figure 3 Silver nanowires imaged using an atomic force microscope. This colored micrograph shows thin silver nanowires spaced about 0.8 millionth of an inch apart on a calcium fluoride crystal surface. Such wires could be used for miniature electronics.