Fundamental Constants

Avogadro's number (N_A)	6.0221418×10^{23}
Electron charge (e)	1.6022×10^{-19} C
Electron mass	9.109387×10^{-28} g
Faraday constant (F)	96,485.3 C/mol e^-
Gas constant (R)	0.08206 L · atm/K · mol
	8.314 J/K · mol
	62.36 L · torr/K · mol
	1.987 cal/K · mol
Planck's constant (h)	6.6256×10^{-34} J · s
Proton mass	1.672623×10^{-24} g
Neutron mass	1.674928×10^{-24} g
Speed of light in a vacuum (c)	2.99792458×10^{8} m/s

Some Prefixes Used with SI Units

tera (T)	10^{12}	centi (c)	10^{-2}
giga (G)	10^{9}	milli (m)	10^{-3}
mega (M)	10^{6}	micro (μ)	10^{-6}
kilo (k)	10^{3}	nano (n)	10^{-9}
deci (d)	10^{-1}	pico (p)	10^{-12}

Useful Conversion Factors and Relationships

1 lb = 453.6 g

1 in = 2.54 cm (exactly)

1 mi = 1.609 km

1 km = 0.6215 mi

$1 \text{ pm} = 1 \times 10^{-12} \text{ m} = 1 \times 10^{-10} \text{ cm}$

$1 \text{ atm} = 760 \text{ mmHg} = 760 \text{ torr} = 101{,}325 \text{ N/m}^2 = 101{,}325 \text{ Pa}$

1 cal = 4.184 J (exactly)

1 L · atm = 101.325 J

1 J = 1 C × 1 V

$$?°\text{C} = (°\text{F} - 32°\text{F}) \times \frac{5°\text{C}}{9°\text{F}}$$

$$?°\text{F} = \frac{9°\text{F}}{5°\text{C}} \times (°\text{C}) + 32°\text{F}$$

$$?\text{K} = (°\text{C} + 273.15°\text{C})\left(\frac{1\text{K}}{1°\text{C}}\right)$$

Periodic Table of the Elements

Key (An element): Atomic number 6; Symbol C; Name Carbon; Average atomic mass 12.01

Main group: groups 1A–2A and 3A–8A. Transition metals: groups 3B–2B.

Period number	1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 H Hydrogen 1.008																	2 He Helium 4.003
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.41	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
6	55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (271)	107 Bh Bohrium (272)	108 Hs Hassium (270)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (293)	118 Og Oganesson (294)

Lanthanides 6	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0	6
Actinides 7	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)	7

Metals

Nonmetals

Metalloids

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List of the Elements with Their Symbols and Atomic Masses*

Element	Symbol	Atomic Number	Atomic Mass†	Element	Symbol	Atomic Number	Atomic Mass†
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.9815386	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.94
Antimony	Sb	51	121.760	Moscovium	Mc	115	(289)
Argon	Ar	18	39.948	Neodymium	Nd	60	144.242
Arsenic	As	33	74.92160	Neon	Ne	10	20.1797
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.327	Nickel	Ni	28	58.6934
Berkelium	Bk	97	(247)	Niobium	Nb	41	92.90638
Beryllium	Be	4	9.012182	Nihonium	Nh	113	(286)
Bismuth	Bi	83	208.98040	Nitrogen	N	7	14.0067
Bohrium	Bh	107	(272)	Nobelium	No	102	(259)
Boron	B	5	10.811	Oganesson	Og	118	(294)
Bromine	Br	35	79.904	Osmium	Os	76	190.23
Cadmium	Cd	48	112.411	Oxygen	O	8	15.9994
Calcium	Ca	20	40.078	Palladium	Pd	46	106.42
Californium	Cf	98	(251)	Phosphorus	P	15	30.973762
Carbon	C	6	12.0107	Platinum	Pt	78	195.084
Cerium	Ce	58	140.116	Plutonium	Pu	94	(244)
Cesium	Cs	55	132.9054519	Polonium	Po	84	(209)
Chlorine	Cl	17	35.453	Potassium	K	19	39.0983
Chromium	Cr	24	51.9961	Praseodymium	Pr	59	140.90765
Cobalt	Co	27	58.933195	Promethium	Pm	61	(145)
Copernicium	Cn	112	(285)	Protactinium	Pa	91	231.03588
Copper	Cu	29	63.546	Radium	Ra	88	(226)
Curium	Cm	96	(247)	Radon	Rn	86	(222)
Darmstadtium	Ds	110	(281)	Rhenium	Re	75	186.207
Dubnium	Db	105	(268)	Rhodium	Rh	45	102.90550
Dysprosium	Dy	66	162.500	Roentgenium	Rg	111	(280)
Einsteinium	Es	99	(252)	Rubidium	Rb	37	85.4678
Erbium	Er	68	167.259	Ruthenium	Ru	44	101.07
Europium	Eu	63	151.964	Rutherfordium	Rf	104	(267)
Fermium	Fm	100	(257)	Samarium	Sm	62	150.36
Flerovium	Fl	114	(289)	Scandium	Sc	21	44.955912
Fluorine	F	9	18.9984032	Seaborgium	Sg	106	(271)
Francium	Fr	87	(223)	Selenium	Se	34	78.96
Gadolinium	Gd	64	157.25	Silicon	Si	14	28.0855
Gallium	Ga	31	69.723	Silver	Ag	47	107.8682
Germanium	Ge	32	72.64	Sodium	Na	11	22.98976928
Gold	Au	79	196.966569	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.49	Sulfur	S	16	32.065
Hassium	Hs	108	(270)	Tantalum	Ta	73	180.94788
Helium	He	2	4.002602	Technetium	Tc	43	(98)
Holmium	Ho	67	164.93032	Tellurium	Te	52	127.60
Hydrogen	H	1	1.00794	Tennessine	Ts	117	(293)
Indium	In	49	114.818	Terbium	Tb	65	158.92535
Iodine	I	53	126.90447	Thallium	Tl	81	204.3833
Iridium	Ir	77	192.217	Thorium	Th	90	232.03806
Iron	Fe	26	55.845	Thulium	Tm	69	168.93421
Krypton	Kr	36	83.798	Tin	Sn	50	118.710
Lanthanum	La	57	138.90547	Titanium	Ti	22	47.867
Lawrencium	Lr	103	(262)	Tungsten	W	74	183.84
Lead	Pb	82	207.2	Uranium	U	92	238.02891
Lithium	Li	3	6.941	Vanadium	V	23	50.9415
Livermorium	Lv	116	(293)	Xenon	Xe	54	131.293
Lutetium	Lu	71	174.967	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.3050	Yttrium	Y	39	88.90585
Manganese	Mn	25	54.938045	Zinc	Zn	30	65.409
Meitnerium	Mt	109	(276)	Zirconium	Zr	40	91.224

*These atomic masses show as many significant figures as are known for each element. The atomic masses in the periodic table are shown to four significant figures, which is sufficient for solving the problems in this book.

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

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Chemistry

ATOMS FIRST

FOURTH EDITION

Julia Burdge
COLLEGE OF WESTERN IDAHO

Jason Overby
COLLEGE OF CHARLESTON

McGraw Hill

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To the people who will always matter the most: Katie, Beau, and Sam.
Julia Burdge

To my wonderful wife, Robin, and daughters, Emma and Sarah.
Jason Overby

CHEMISTRY: ATOMS FIRST, FOURTH EDITION

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About the Authors

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Julia Burdge received her Ph.D. (1994) from the University of Idaho in Moscow, Idaho. Her research and dissertation focused on instrument development for analysis of trace sulfur compounds in air and the statistical evaluation of data near the detection limit.

In 1994 she accepted a position at The University of Akron in Akron, Ohio, as an assistant professor and director of the Introductory Chemistry program. In the year 2000, she was tenured and promoted to associate professor at The University of Akron on the merits of her teaching, service, and research in chemistry education. In addition to directing the general chemistry program and supervising the teaching activities of graduate students, she helped establish a future-faculty development program and served as a mentor for graduate students and post-doctoral associates. In 2008, Julia relocated back to the northwest to be near family. She lives in Boise, Idaho; and she holds an affiliate faculty position as associate professor in the Chemistry Department at the University of Idaho and teaches general chemistry at the College of Western Idaho.

In her free time, Julia enjoys horseback riding, precious time with her three children, and quiet time at home with Erik Nelson, her husband and best friend.

Jason Overby received his B.S. degree in chemistry and political science from the University of Tennessee at Martin. He then received his Ph.D. in inorganic chemistry from Vanderbilt University (1997) studying main group and transition metal metallocenes and related compounds. Afterwards, Jason conducted postdoctoral research in transition metal organometallic chemistry at Dartmouth College.

Jason began his academic career at the College of Charleston in 1999 as an assistant professor. Currently, he is an associate professor with teaching interests in general and inorganic chemistry. He is also interested in the integration of technology into the classroom, with a particular focus on adaptive learning. Additionally, he conducts research with undergraduates in inorganic and organic synthetic chemistry as well as computational organometallic chemistry.

In his free time, Jason enjoys boating, bowling, and cooking. On many weekends throughout the year, he can often be found on the deck of a pool working as a nationally certified USA Swimming official. He lives in South Carolina with his wife Robin and two daughters, Emma and Sarah.

Brief Contents

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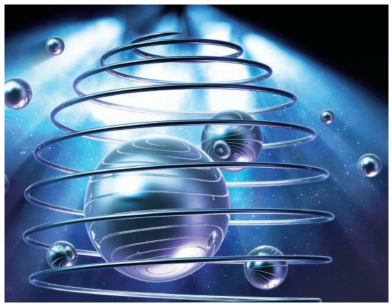

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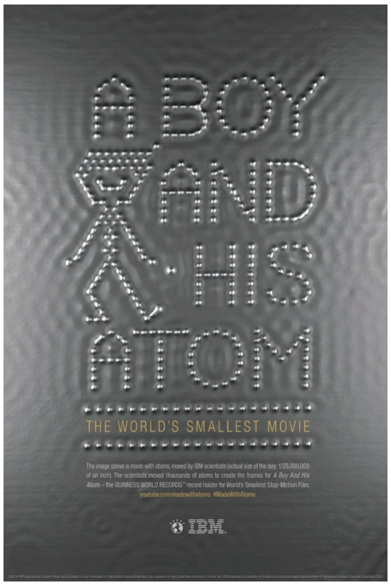

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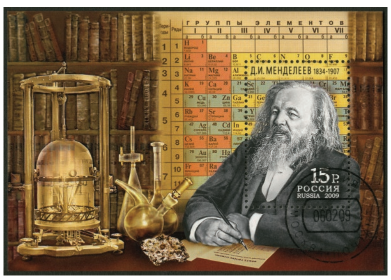

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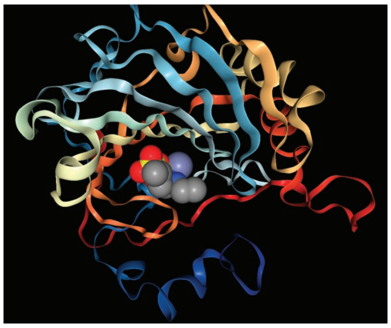

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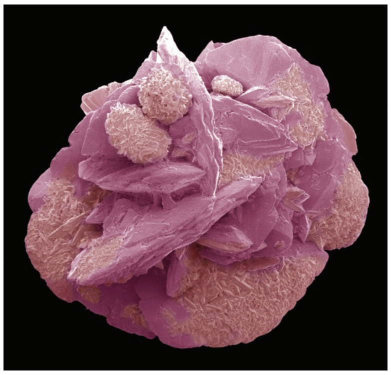

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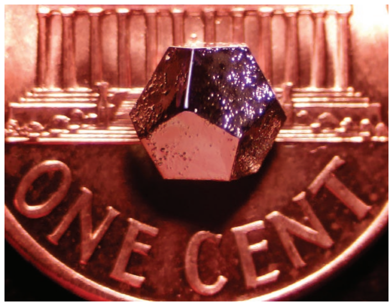

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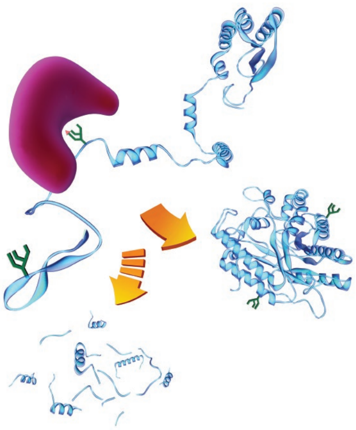

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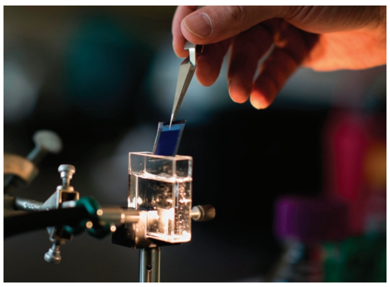
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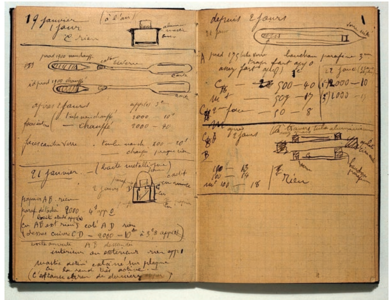

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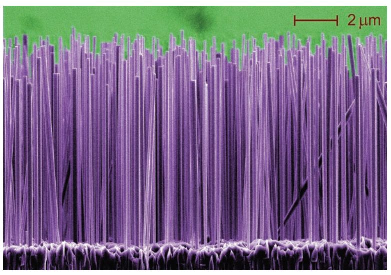

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List of Applications

Thinking Outside the Box

Environmental Aspects

Key Skills

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Preface

The fourth edition of *Chemistry: Atoms First* by Burdge and Overby builds further on the success of the first three editions. Changes to this edition focus on new additions to the pedagogy, refinement of the current approach, and other innovations driven by feedback from instructors and students alike.

NEW! Environmental Aspects

Given the current climate of environmental awareness in both the classroom and the public in general, we have added a new series of vignettes in the form of boxed features titled Environmental Aspects. Each of the first twenty chapters of the text contains one of these boxes, which provides instructors an opportunity to include timely, environmentally focused material within the context of each chapter. To encourage student engagement with the Environmental Aspects material, many of the boxes have accompanying end-of-chapter problems associated with them. These problems are designated with the Environmental Aspects icon.

Environmental Aspects

Global Climate Change

Those who describe themselves as "skeptical" about climate change sometimes posit that global temperature change is normal, and that any observed increase in temperature is simply the result of natural processes—outside the control of humans. However, there is an enormous body of climate research that clearly demonstrates otherwise. One line of inquiry that has helped to established the connection between human activity and so-called "global warming" involves what is known as *vertical structure of temperature*.

Earth's atmosphere is divided into a series of altitudinal layers: the troposphere (ground-level to 8–14.5 km), the stratosphere (top of the troposphere–50 km), the mesosphere (50–80 km), the thermosphere (80–700 km), and the exosphere (700–10,000 km). The troposphere is where we live, where weather events occur, and where nearly all human activity takes place. When we burn fossil fuels, we increase the amount of CO_2 in the *troposphere*.

In 1988, atmospheric scientist V. Ramanathan, now of the Scripps Institution of Oceanography at the University of California, San Diego, proposed that global temperature change caused by the anthropogenic increase in atmospheric CO_2 could be readily distinguished from that caused by *natural* events, such as increased solar activity. Global temperature increase caused by the sun, he reasoned, would occur in both the troposphere *and* the stratosphere. Conversely, changes caused by the enhanced greenhouse effect (the result of increased atmospheric CO_2 concentration) would cause warming of the troposphere; but *cooling* of the stratosphere—because more of the heat radiating from Earth's surface would be trapped by greenhouse gases in the troposphere, thus never reaching the stratosphere. Indeed, temperature monitoring over several decades has demonstrated an *increase* in tropospheric temperature, and a *decrease* in stratospheric temperature. This is one of the observations that climate scientists refer to as a *human fingerprint* on global climate change.

Updated Pedagogy

To refresh student self-assessments, we have updated all Section Review questions to reimagined or completely new questions. Students report benefiting from

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these self-evaluation questions as they assess their level of mastery of the material in one section before proceeding to the next. They also report using them to review for quizzes and exams. In addition, there is a significant number of new or revised end-of-chapter problems.

In accordance with the IUPAC recommendation for numbering groups on the periodic table, we have switched to the 1–18 numbering system, as have most modern chemists. We show and make mention of the A and B group designations when the periodic table is introduced (Figure 2.10), but throughout the rest of the book, we consistently use only the 1–18 numbering system.

New and Updated Chapter Content

Chapter 1—A new Thinking Outside The Box feature has been included to focus on the states of matter. It appears that many students in high school are taught that there are only four (or only *three*) states of matter. This feature box describes several of the dozens of different states of matter that have been designated or proposed.

Chapter 3—The most significant change to this chapter is a splitting of the content for a more manageable and systematic approach to quantum mechanics. While continuing the successful flow of material from previous editions, we now conclude this chapter with coverage of the quantum mechanical approach to the hydrogen atom—moving coverage of many-electron atoms to the beginning of Chapter 4.

We have also refined much of the discussion with respect to the Planck equation and other equations involving Planck's constant. We believe it is useful for students to understand the significance of the incredibly tiny magnitude of the Planck constant as a defining characteristic of any calculations involving quantum-scale systems.

Chapter 4—This chapter has undergone more change than any other in this edition. We begin with a new introduction to the periodic table, providing an improved segue to understanding the quantum mechanical approach to many-electron atoms. Content on many-electron atoms, previously found in Chapter 3, is now integrated into Chapter 4. We feel that moving this to Chapter 4 makes for a better logical progression in the understanding periodic properties. Further, we think this reorganization of Chapters 3 and 4 offers a more streamlined coverage of quantum mechanics and periodic properties.

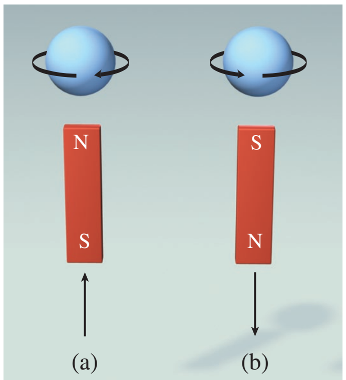

Figure 3.16 (a) Clockwise and (b) counterclockwise spins of an electron. The magnetic fields generated by these two spinning motions are analogous to those from the two magnets. The upward and downward arrows are used to denote the direction of spin.

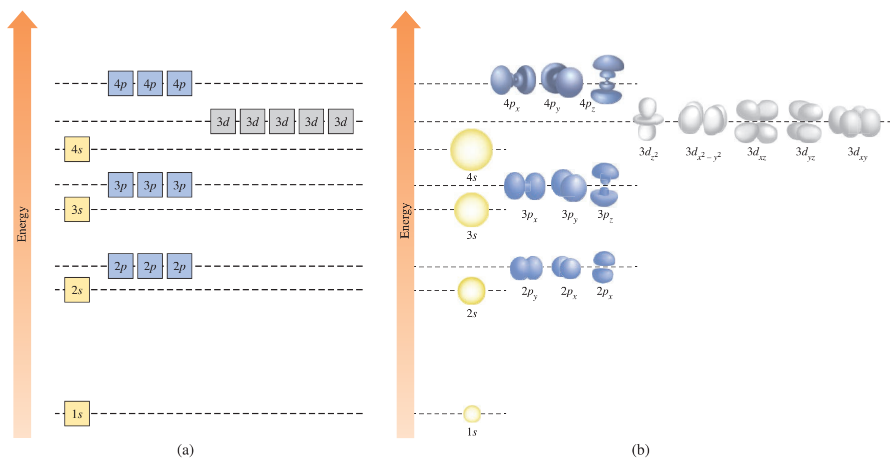

Figure 4.2 Orbital energy levels in many-electron atoms. For a given value of *n,* orbital energy increases with the value of ℓ.

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Chapter 14—In response to feedback from instructors, we have moved the coverage of kinetics earlier in the book, to Chapter 14. While physical chemistry informs us that the subject of chemical kinetics occupies a unique position in chemistry, we believe that this order will provide flexibility to instructors, and will enable students to understand better the definition of chemical equilibrium.

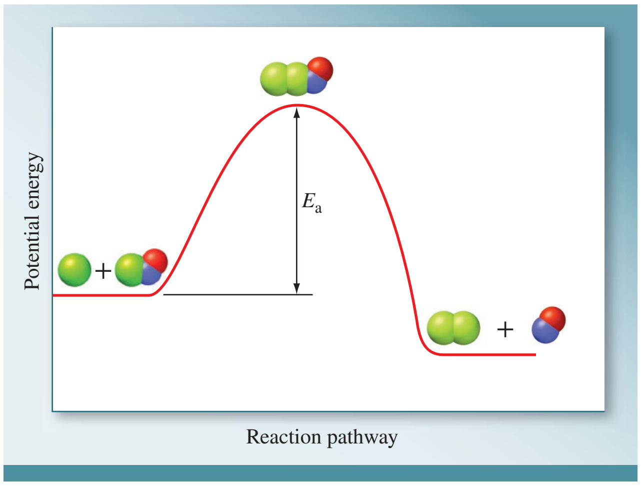
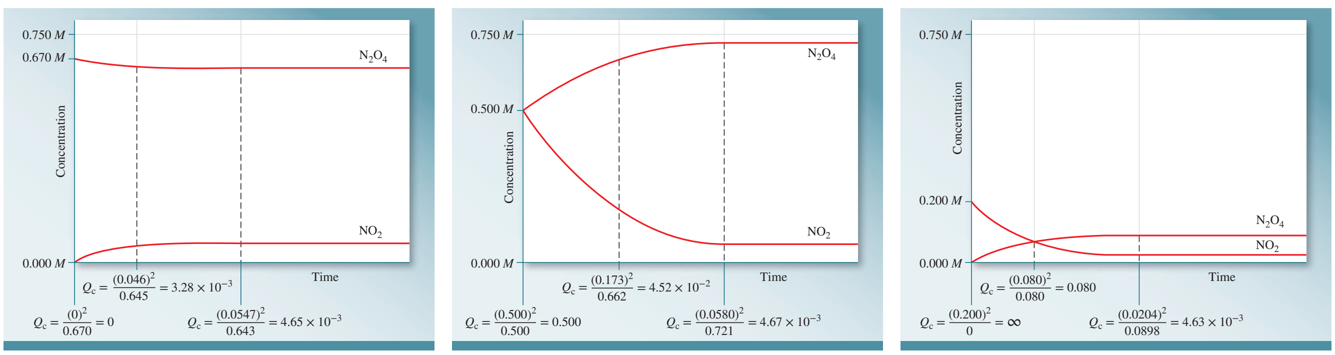


Figure 14.2 Energy profile for the reaction of Cl with NOCl. In addition to being oriented properly, reactant molecules must possess sufficient energy to overcome the activation energy.

Chapter 16—The introductory equilibrium chapter has an improved and expanded figure developed to clarify understanding of the process by which equilibrium is established. The chapter also contains a new Thinking Outside the Box feature that focuses on the inductive effect in acid strength—material particularly useful for students who go on to organic chemistry.



(a) (b) (c)

Figure 16.3 Graphical representation of the data from experiments 1, 3, and 5 in Table 16.1. The value of the reaction quotient, Q_c, changes as the reaction progresses. When the system reaches equilibrium, Q_c is equal to the equilibrium constant.