

GLOBAL
EDITION



Chemistry

EIGHTH EDITION

Robinson • McMurry • Fay



List of the Elements with Their Atomic Symbols and Atomic Weights

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	(227)*	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.981538	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.96
Antimony	Sb	51	121.760	Moscovium	Mc	115	(288)
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)	Nihonium	Nh	113	(284)
Beryllium	Be	4	9.012182	Niobium	Nb	41	92.90638
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	195.094
Cerium	Ce	58	140.116	Plutonium	Pu	94	(244)
Cesium	Cs	55	132.90545	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	(265)
Fermium	Fm	100	(257)	Samarium	Sm	62	150.36
Flerovium	Fl	114	(289)	Scandium	Sc	21	44.955912
Fluorine	F	9	18.998403	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	22.989769
Gold	Au	79	196.96657	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.49	Sulfur	S	16	32.065
Hassium	Hs	108	(270)	Tantalum	Ta	73	180.9479
Helium	He	2	4.002602	Technetium	Tc	43	(98)
Holmium	Ho	67	164.93032	Tellurium	Te	52	127.60
Hydrogen	H	1	1.00794	Tennessee	Ts	117	(292)
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	232.0381
Iron	Fe	26	55.845	Thulium	Tm	69	168.93421
Krypton	Kr	36	83.798	Tin	Sn	50	118.710
Lanthanum	La	57	138.9055	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	174.9668	Ytterbium	Yb	70	173.054
Magnesium	Mg	12	24.3050	Yttrium	Y	39	88.90585
Manganese	Mn	25	54.938045	Zinc	Zn	30	65.38
Meitnerium	Mt	109	(276)	Zirconium	Zr	40	91.224

*Values in parentheses are the mass numbers of the most common or longest lived isotopes of radioactive elements.

Periodic Table of the Elements

Main groups		Transition metals										Main groups																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
1 1A		2 2A		3 3B		4 4B		5 5B		6 6B		7 7B		8 8B		9 9B		10 10B		11 11B		12 12B		13 3A		14 4A		15 5A		16 6A		17 7A		18 8A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
1 1.00794	2 He	3 Li	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne	11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000

* Lanthanide series

† Actinide series

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Brief Contents

Preface	15
For Instructors	18
1 Chemical Tools: Experimentation and Measurement	35
2 Atoms, Molecules, and Ions	67
3 Mass Relationships in Chemical Reactions	117
4 Reactions in Aqueous Solution	150
5 Periodicity and the Electronic Structure of Atoms	195
6 Ionic Compounds: Periodic Trends and Bonding Theory	242
7 Covalent Bonding and Electron-Dot Structures	272
8 Covalent Compounds: Bonding Theories and Molecular Structure	312
9 Thermochemistry: Chemical Energy	361
10 Gases: Their Properties and Behavior	408
11 Liquids and Phase Changes	456
12 Solids and Solid-State Materials	484
13 Solutions and Their Properties	528
14 Chemical Kinetics	572
15 Chemical Equilibrium	635
16 Aqueous Equilibria: Acids and Bases	688
17 Applications of Aqueous Equilibria	742
18 Thermodynamics: Entropy, Free Energy, and Spontaneity	802
19 Electrochemistry	847
20 Nuclear Chemistry	904
21 Transition Elements and Coordination Chemistry	938
22 The Main-Group Elements	988
23 Organic and Biological Chemistry	1037

Contents

Preface 15

For Instructors 18

1 Chemical Tools: Experimentation and Measurement 35

- 1.1 The Scientific Method: Nanoparticle Catalysts for Fuel Cells 36
- 1.2 Measurements: SI Units and Scientific Notation 39
- 1.3 Mass and Its Measurement 41
- 1.4 Length and Its Measurement 42
- 1.5 Temperature and Its Measurement 43
- 1.6 Derived Units: Volume and Its Measurement 45
- 1.7 Derived Units: Density and Its Measurement 47
- 1.8 Derived Units: Energy and Its Measurement 48
- 1.9 Accuracy, Precision, and Significant Figures in Measurement 50
- 1.10 Significant Figures in Calculations 52
- 1.11 Converting from One Unit to Another 54

INQUIRY ? What are the unique properties of nanoscale materials? 57

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

2 Atoms, Molecules, and Ions 67

- 2.1 Chemistry and the Elements 68
- 2.2 Elements and the Periodic Table 70
- 2.3 Some Common Groups of Elements and Their Properties 72
- 2.4 Observations Supporting Atomic Theory: The Conservation of Mass and the Law of Definite Proportions 75
- 2.5 The Law of Multiple Proportions and Dalton's Atomic Theory 77
- 2.6 Atomic Structure: Electrons 79
- 2.7 Atomic Structure: Protons and Neutrons 81
- 2.8 Atomic Numbers 83
- 2.9 Atomic Weights and the Mole 85
- 2.10 Measuring Atomic Weight: Mass Spectrometry 89
- 2.11 Mixtures and Chemical Compounds; Molecules and Covalent Bonds 91

2.12 Ions and Ionic Bonds 95

2.13 Naming Chemical Compounds 97

INQUIRY ? How can measurements of oxygen and hydrogen isotopes in ice cores determine past climates? 103

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

3 Mass Relationships in Chemical Reactions 117

- 3.1 Representing Chemistry on Different Levels 118
- 3.2 Balancing Chemical Equations 119
- 3.3 Molecular Weight and Molar Mass 122
- 3.4 Stoichiometry: Relating Amounts of Reactants and Products 124
- 3.5 Yields of Chemical Reactions 126
- 3.6 Reactions with Limiting Amounts of Reactants 128
- 3.7 Percent Composition and Empirical Formulas 131
- 3.8 Determining Empirical Formulas: Elemental Analysis 134
- 3.9 Determining Molecular Weights: Mass Spectrometry 137

INQUIRY ? How is the principle of atom economy used to minimize waste in a chemical synthesis? 139

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

4 Reactions in Aqueous Solution 150

- 4.1 Solution Concentration: Molarity 151
- 4.2 Diluting Concentrated Solutions 153
- 4.3 Electrolytes in Aqueous Solution 155
- 4.4 Types of Chemical Reactions in Aqueous Solution 157
- 4.5 Aqueous Reactions and Net Ionic Equations 158
- 4.6 Precipitation Reactions and Solubility Guidelines 159
- 4.7 Acids, Bases, and Neutralization Reactions 162
- 4.8 Solution Stoichiometry 166
- 4.9 Measuring the Concentration of a Solution: Titration 167


- 4.10 Oxidation–Reduction (Redox) Reactions 169
- 4.11 Identifying Redox Reactions 172
- 4.12 The Activity Series of the Elements 175
- 4.13 Redox Titrations 178
- 4.14 Some Applications of Redox Reactions 180

INQUIRY  How do sports drinks replenish the substances lost in sweat? 182

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

5 Periodicity and the Electronic Structure of Atoms 195

- 5.1 Wave Properties of Radiant Energy and the Electromagnetic Spectrum 196
- 5.2 Particlelike Properties of Radiant Energy: The Photoelectric Effect and Planck's Postulate 200
- 5.3 Atomic Line Spectra and Quantized Energy 203
- 5.4 Wavelike Properties of Matter: de Broglie's Hypothesis 207
- 5.5 The Quantum Mechanical Model of the Atom: Heisenberg's Uncertainty Principle 209
- 5.6 The Quantum Mechanical Model of the Atom: Orbitals and Quantum Numbers 210
- 5.7 The Shapes of Orbitals 213
- 5.8 Electron Spin and the Pauli Exclusion Principle 218
- 5.9 Orbital Energy Levels in Multielectron Atoms 219
- 5.10 Electron Configurations of Multielectron Atoms 221
- 5.11 Anomalous Electron Configurations 223
- 5.12 Electron Configurations and the Periodic Table 223
- 5.13 Electron Configurations and Periodic Properties: Atomic Radii 226


INQUIRY  How does knowledge of atomic emission spectra help us build more efficient light bulbs? 229

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

6 Ionic Compounds: Periodic Trends and Bonding Theory 242

- 6.1 Electron Configurations of Ions 243
- 6.2 Ionic Radii 246
- 6.3 Ionization Energy 248
- 6.4 Higher Ionization Energies 250


- 6.5 Electron Affinity 252
- 6.6 The Octet Rule 254
- 6.7 Ionic Bonds and the Formation of Ionic Solids 256
- 6.8 Lattice Energies in Ionic Solids 260

INQUIRY  How do ionic liquids lead to more environmentally friendly processes? 262

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

7 Covalent Bonding and Electron-Dot Structures 272


- 7.1 Covalent Bonding in Molecules 273
- 7.2 Strengths of Covalent Bonds 274
- 7.3 Polar Covalent Bonds: Electronegativity 276
- 7.4 A Comparison of Ionic and Covalent Compounds 280
- 7.5 Electron-Dot Structures: The Octet Rule 281
- 7.6 Procedure for Drawing Electron-Dot Structures 284
- 7.7 Drawing Electron-Dot Structures for Radicals 288
- 7.8 Electron-Dot Structures of Compounds Containing Only Hydrogen and Second-Row Elements 289
- 7.9 Electron-Dot Structures and Resonance 291
- 7.10 Formal Charges 295

INQUIRY  How does bond polarity affect the toxicity of organophosphate insecticides? 299

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

8 Covalent Compounds: Bonding Theories and Molecular Structure 312

- 8.1 Molecular Shapes: The VSEPR Model 313
- 8.2 Valence Bond Theory 320
- 8.3 Hybridization and sp^3 Hybrid Orbitals 321
- 8.4 Other Kinds of Hybrid Orbitals 324
- 8.5 Polar Covalent Bonds and Dipole Moments 329
- 8.6 Intermolecular Forces 332
- 8.7 Molecular Orbital Theory: The Hydrogen Molecule 340
- 8.8 Molecular Orbital Theory: Other Diatomic Molecules 342
- 8.9 Combining Valence Bond Theory and Molecular Orbital Theory 346

INQUIRY  Which is better for human health, natural or synthetic vitamins? 348

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

9 Thermochemistry: Chemical Energy 361

- 9.1 Energy and Its Conservation 362
- 9.2 Internal Energy and State Functions 364
- 9.3 Expansion Work 366
- 9.4 Energy and Enthalpy 368
- 9.5 Thermochemical Equations and the Thermodynamic Standard State 370
- 9.6 Enthalpies of Chemical and Physical Changes 372
- 9.7 Calorimetry and Heat Capacity 375
- 9.8 Hess's Law 379
- 9.9 Standard Heats of Formation 382
- 9.10 Bond Dissociation Energies 384
- 9.11 An Introduction to Entropy 386
- 9.12 An Introduction to Free Energy 389

INQUIRY ? How do we determine the energy content of biofuels? 393

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

10 Gases: Their Properties and Behavior 408

- 10.1 Gases and Gas Pressure 409
- 10.2 The Gas Laws 414
- 10.3 The Ideal Gas Law 419
- 10.4 Stoichiometric Relationships with Gases 421
- 10.5 Mixtures of Gases: Partial Pressure and Dalton's Law 424
- 10.6 The Kinetic–Molecular Theory of Gases 427
- 10.7 Gas Diffusion and Effusion: Graham's Law 429
- 10.8 The Behavior of Real Gases 431
- 10.9 The Earth's Atmosphere and the Greenhouse Effect 432
- 10.10 Greenhouse Gases 435
- 10.11 Climate Change 437

INQUIRY ? How do inhaled anesthetics work? 441

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

11 Liquids and Phase Changes 456

- 11.1 Properties of Liquids 457
- 11.2 Vapor Pressure and Boiling Point 458
- 11.3 Phase Changes between Solids, Liquids, and Gases 462

- 11.4 Energy Changes during Phase Transitions 465
- 11.5 Phase Diagrams 467
- 11.6 Liquid Crystals 470

INQUIRY ? How is caffeine removed from coffee? 473

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

12 Solids and Solid-State Materials 484

- 12.1 Types of Solids 485
- 12.2 Probing the Structure of Solids: X-Ray Crystallography 487
- 12.3 The Packing of Spheres in Crystalline Solids: Unit Cells 489
- 12.4 Structures of Some Ionic Solids 493
- 12.5 Structures of Some Covalent Network Solids 496
- 12.6 Bonding in Metals 498
- 12.7 Semiconductors 502
- 12.8 Semiconductor Applications 505
- 12.9 Superconductors 509
- 12.10 Ceramics and Composites 511

INQUIRY ? What are quantum dots, and what controls their color? 516

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

13 Solutions and Their Properties 528

- 13.1 Solutions 529
- 13.2 Enthalpy Changes and the Solution Process 530
- 13.3 Predicting Solubility 532
- 13.4 Concentration Units for Solutions 535
- 13.5 Some Factors That Affect Solubility 540
- 13.6 Physical Behavior of Solutions: Colligative Properties 544
- 13.7 Vapor-Pressure Lowering of Solutions: Raoult's Law 545
- 13.8 Boiling-Point Elevation and Freezing-Point Depression of Solutions 551
- 13.9 Osmosis and Osmotic Pressure 555

INQUIRY ? How does hemodialysis cleanse the blood of patients with kidney failure? 559

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

14 Chemical Kinetics 572

- 14.1 Reaction Rates 573
- 14.2 Rate Laws and Reaction Order 578
- 14.3 Method of Initial Rates: Experimental Determination of a Rate Law 580
- 14.4 Integrated Rate Law: Zeroth-Order Reactions 584
- 14.5 Integrated Rate Law: First-Order Reactions 586
- 14.6 Integrated Rate Law: Second-Order Reactions 591
- 14.7 Reaction Rates and Temperature: The Arrhenius Equation 594
- 14.8 Using the Arrhenius Equation 598
- 14.9 Reaction Mechanisms 601
- 14.10 Rate Laws for Elementary Reactions 604
- 14.11 Rate Laws for Overall Reactions 607
- 14.12 Catalysis 611
- 14.13 Homogeneous and Heterogeneous Catalysts 614

INQUIRY ? How do enzymes work? 617

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

15 Chemical Equilibrium 635

- 15.1 The Equilibrium State 637
- 15.2 The Equilibrium Constant K_c 639
- 15.3 The Equilibrium Constant K_p 644
- 15.4 Heterogeneous Equilibria 646
- 15.5 Using the Equilibrium Constant 648
- 15.6 Factors That Alter the Composition of an Equilibrium Mixture: Le Châtelier's Principle 658
- 15.7 Altering an Equilibrium Mixture: Changes in Concentration 659
- 15.8 Altering an Equilibrium Mixture: Changes in Pressure and Volume 663
- 15.9 Altering an Equilibrium Mixture: Changes in Temperature 665
- 15.10 The Link between Chemical Equilibrium and Chemical Kinetics 668

INQUIRY ? How does high altitude affect oxygen transport in the body? 671

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

16 Aqueous Equilibria: Acids and Bases 688

- 16.1 Acid–Base Concepts: The Brønsted–Lowry Theory 689
- 16.2 Acid Strength and Base Strength 692
- 16.3 Factors That Affect Acid Strength 695

- 16.4 Dissociation of Water 698
- 16.5 The pH Scale 700
- 16.6 Measuring pH 702
- 16.7 The pH in Solutions of Strong Acids and Strong Bases 703
- 16.8 Equilibria in Solutions of Weak Acids 705
- 16.9 Calculating Equilibrium Concentrations in Solutions of Weak Acids 707
- 16.10 Percent Dissociation in Solutions of Weak Acids 711
- 16.11 Polyprotic Acids 712
- 16.12 Equilibria in Solutions of Weak Bases 716
- 16.13 Relation Between K_a and K_b 718
- 16.14 Acid–Base Properties of Salts 720
- 16.15 Lewis Acids and Bases 725

INQUIRY ? Has the problem of acid rain been solved? 728

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

17 Applications of Aqueous Equilibria 742

- 17.1 Neutralization Reactions 743
- 17.2 The Common-Ion Effect 746
- 17.3 Buffer Solutions 750
- 17.4 The Henderson–Hasselbalch Equation 754
- 17.5 pH Titration Curves 757
- 17.6 Strong Acid–Strong Base Titrations 758
- 17.7 Weak Acid–Strong Base Titrations 761
- 17.8 Weak Base–Strong Acid Titrations 766
- 17.9 Polyprotic Acid–Strong Base Titrations 767
- 17.10 Solubility Equilibria for Ionic Compounds 772
- 17.11 Measuring K_{sp} and Calculating Solubility from K_{sp} 773
- 17.12 Factors That Affect Solubility 776
- 17.13 Precipitation of Ionic Compounds 784
- 17.14 Separation of Ions by Selective Precipitation 785
- 17.15 Qualitative Analysis 786

INQUIRY ? What is causing ocean acidification? 788

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

18 Thermodynamics: Entropy, Free Energy, and Spontaneity 802

- 18.1 Spontaneous Processes 803
- 18.2 Enthalpy, Entropy, and Spontaneous Processes 804
- 18.3 Entropy and Probability 807

- 18.4** Entropy and Temperature 811
18.5 Standard Molar Entropies and Standard Entropies of Reaction 813
18.6 Entropy and the Second Law of Thermodynamics 815
18.7 Free Energy and the Spontaneity of Chemical Reactions 818
18.8 Standard Free-Energy Changes for Reactions 821
18.9 Standard Free Energies of Formation 823
18.10 Free-Energy Changes for Reactions under Nonstandard-State Conditions 826
18.11 Free Energy and Chemical Equilibrium 828

INQUIRY ? Does the formation of highly ordered molecules violate the second law of thermodynamics? 832

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

19 Electrochemistry 847

- 19.1** Balancing Redox Reactions by the Half-Reaction Method 848
19.2 Galvanic Cells 853
19.3 Shorthand Notation for Galvanic Cells 858
19.4 Cell Potentials and Free-Energy Changes for Cell Reactions 859
19.5 Standard Reduction Potentials 861
19.6 Using Standard Reduction Potentials 864
19.7 Cell Potentials under Nonstandard-State Conditions: The Nernst Equation 867
19.8 Electrochemical Determination of pH 870
19.9 Standard Cell Potentials and Equilibrium Constants 872
19.10 Batteries 874
19.11 Corrosion 877
19.12 Electrolysis and Electrolytic Cells 880
19.13 Commercial Applications of Electrolysis 883
19.14 Quantitative Aspects of Electrolysis 886

INQUIRY ? How do hydrogen fuel cells work? 888

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

20 Nuclear Chemistry 904

- 20.1** Nuclear Reactions and Their Characteristics 905
20.2 Radioactivity 906
20.3 Nuclear Stability 909
20.4 Radioactive Decay Rates 911
20.5 Dating with Radioisotopes 915

- 20.6** Energy Changes during Nuclear Reactions 916
20.7 Nuclear Fission and Fusion 920
20.8 Nuclear Transmutation 924
20.9 Detecting and Measuring Radioactivity 925

INQUIRY ? How are radioisotopes used in medicine? 928

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

21 Transition Elements and Coordination Chemistry 938

- 21.1** Electron Configurations 940
21.2 Properties of Transition Elements 942
21.3 Oxidation States of Transition Elements 946
21.4 Coordination Compounds 947
21.5 Ligands 949
21.6 Naming Coordination Compounds 952
21.7 Isomers 955
21.8 Enantiomers and Molecular Handedness 960
21.9 Color of Transition Metal Complexes 963
21.10 Crystal Field Theory 964
21.11 Bonding in Complexes: Valence Bond Theory 970

INQUIRY ? How does cisplatin kill cancer cells? 974

Study Guide • Key Terms • Key Equation • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

22 The Main-Group Elements 988


- 22.1** A Review of General Properties and Periodic Trends 989
22.2 Distinctive Properties of the Second-Row Elements 991
22.3 Group 1A: Hydrogen 993
22.4 Group 1A: Alkali Metals and Group 2A: Alkaline Earth Metals 996
22.5 Group 3A Elements 999
22.6 Group 4A Elements 1001
22.7 Group 5A Elements 1008
22.8 Group 6A Elements 1014
22.9 Group 7A: The Halogens 1021
22.10 Group 8A: Noble Gases 1023

INQUIRY ? What are the barriers to a hydrogen economy? 1024

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

23 Organic and Biological Chemistry 1037

- 23.1 Organic Molecules and Their Structures: Constitutional Isomers 1038
- 23.2 Stereoisomers: Chiral Molecules 1042
- 23.3 Families of Organic Compounds: Functional Groups 1045
- 23.4 Carbohydrates: A Biological Example of Isomers 1048
- 23.5 Valence Bond Theory and Orbital Overlap Pictures 1051
- 23.6 Lipids: A Biological Example of Cis–Trans Isomerism 1055
- 23.7 Formal Charge and Resonance in Organic Compounds 1059
- 23.8 Conjugated Systems 1064
- 23.9 Proteins: A Biological Example of Conjugation 1068
- 23.10 Aromatic Compounds and Molecular Orbital Theory 1072
- 23.11 Nucleic Acids: A Biological Example of Aromaticity 1075

INQUIRY  Why do enantiomers have different biological responses? 1079

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

Appendix A: Mathematical Operations A-1

- A.1 Scientific Notation A-1
- A.2 Logarithms A-4
- A.3 Straight-Line Graphs and Linear Equations A-6
- A.4 Quadratic Equations A-7
- A.5 Calculus Derivations of Integrated Rate Laws A-7

Appendix B: Thermodynamic Properties at 25 °C A-9

Appendix C: Equilibrium Constants at 25 °C A-14

Appendix D: Standard Reduction Potentials at 25 °C A-18

Appendix E: Properties of Water A-20

Answers to Selected Problems A-21

Glossary G-1

Index I-1

Photo/Text Credits C-1

List of Interactive Videos

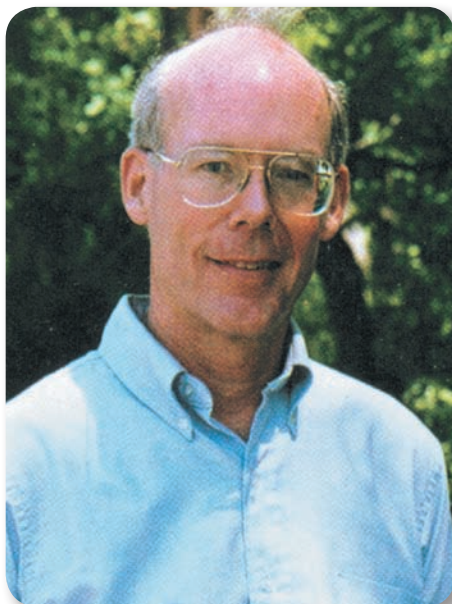
- 1 WORKED EXAMPLE 1.8** Unit conversions using significant figures 55
WORKED EXAMPLE 1.9 Unit conversions with squared and cubed units 56
- 2 WORKED EXAMPLE 2.5** Calculating an atomic weight 86
WORKED EXAMPLE 2.6 Converting between mass and numbers of moles and atoms 88
- 3 WORKED EXAMPLE 3.5** Relating the masses of reactants and products 125
WORKED EXAMPLE 3.6 Calculating percent yield 127
WORKED EXAMPLE 3.8 Calculating the amount of product or excess reactant when one reactant is limiting 130
- 4 WORKED EXAMPLE 4.2** Calculating the number of moles of solute in a solution 153
WORKED EXAMPLE 4.11 Determining the concentration of a solution using a titration procedure 168
- 5 WORKED EXAMPLE 5.4** Relating the Bohr model and the Balmer–Rydberg equation 207
WORKED EXAMPLE 5.6 Assigning quantum numbers to an orbital 213
CONCEPTUAL WORKED EXAMPLE 5.8 Assigning a ground-state electron configuration to an atom 226
- 6 WORKED EXAMPLE 6.4** Higher ionization energies 252
WORKED EXAMPLE 6.7 Calculating the energy change in the formation of an ionic compound 259
WORKED EXAMPLE 6.8 Lattice energies 261
- 7 WORKED EXAMPLE 7.5** Drawing electron-dot structures for molecules with one central atom and multiple bonds 287
CONCEPTUAL WORKED EXAMPLE 7.10 Drawing resonance structures in organic compounds 294
WORKED EXAMPLE 7.11 Calculating formal charges 297
- 8 WORKED EXAMPLE 8.4** Identifying hybridization and orbital overlap in single and double bonds 326
CONCEPTUAL WORKED EXAMPLE 8.6 Predicting the presence of a dipole moment 331
- 9 WORKED EXAMPLE 9.6** Calculating ΔH in a constant-pressure calorimetry experiment 377
WORKED EXAMPLE 9.7 Calculating ΔE in constant-volume calorimetry 378
CONCEPTUAL WORKED EXAMPLE 9.12 Predicting the signs of ΔH , ΔS , and ΔG for a reaction 391
- 10 CONCEPTUAL WORKED EXAMPLE 10.3** Visual representations of gas laws 417
WORKED EXAMPLE 10.5 Using the ideal gas law when variables change 421

- WORKED EXAMPLE 10.8** Calculating partial pressure 426
- 11 WORKED EXAMPLE 11.3** Calculating the amount of heat of a temperature change 467
- 12 WORKED EXAMPLE 12.2** Using unit-cell dimensions to calculate the density of a metal 493
- WORKED EXAMPLE 12.4** Using band theory to account for melting points 501
- 13 WORKED EXAMPLE 13.5** Using density to convert molarity to other measures of concentration 539
- WORKED EXAMPLE 13.7** Calculating the vapor pressure of an electrolyte solution 548
- 14 WORKED EXAMPLE 14.3** Determining a rate law from initial rates 582
- WORKED EXAMPLE 14.6** Using the integrated rate law for a first-order reaction 587
- 15 WORKED EXAMPLE 15.9** Calculating equilibrium concentrations (solving the equilibrium equation by taking the square root of both sides of the equation) 653
- WORKED EXAMPLE 15.12** Calculating equilibrium partial pressures from initial partial pressures 657
- 16 WORKED EXAMPLE 16.10** Calculating the pH and the equilibrium concentrations in a solution of a weak acid 709
- WORKED EXAMPLE 16.12** Calculating the pH and the equilibrium concentrations in a solution of a weak base 717
- 17 WORKED EXAMPLE 17.4** Calculating the pH of a buffer after addition of OH^- or H_3O^+ 752
- WORKED EXAMPLE 17.8** Calculating the pH at the equivalence point in the titration of a weak acid with a strong base 765
- 18 WORKED EXAMPLE 18.1** Predicting the sign of ΔS 807
- WORKED EXAMPLE 18.8** Calculating ΔG for a reaction under nonstandard-state conditions 826
- 19 WORKED EXAMPLE 19.1** Balancing a redox equation for a reaction in acidic solution 850
- WORKED EXAMPLE 19.8** Calculating the voltage of a galvanic cell under standard-state conditions 866
- WORKED EXAMPLE 19.13** Calculating the amount of product produced by electrolysis 887
- 20 WORKED EXAMPLE 20.3** Using half-life to calculate an amount remaining 913
- WORKED EXAMPLE 20.6** Calculating a mass defect and a binding energy 919
- WORKED EXAMPLE 20.9** Balancing a Nuclear Transmutation Equation 925
- 21 WORKED EXAMPLE 21.7** Drawing diastereoisomers and enantiomers 962
- WORKED EXAMPLE 21.8** Drawing crystal field energy-level diagrams for octahedral complexes 968
- 22 CONCEPTUAL WORKED EXAMPLE 22.4** Interpreting representations of silicate anions 1007
- 23 WORKED EXAMPLE 23.3** Identifying chiral molecules 1044
- WORKED EXAMPLE 23.13** Predicting if an organic compound is aromatic 1074

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Preface

FOR THE STUDENT

Francie came away from her first chemistry lecture in a glow. In one hour she found out that everything was made up of atoms which were in continual motion. She grasped the idea that nothing was ever lost or destroyed. Even if something was burned up or rotted away, it did not disappear from the face of the earth; it changed into something else—gases, liquids, and powders. Everything, decided Francie after that first lecture, was vibrant with life and there was no death in chemistry. She was puzzled as to why learned people didn't adopt chemistry as a religion.

—Betty Smith, *A Tree Grows in Brooklyn*

We know that not everyone has such a breathless response to their chemistry lectures, and few would mistake chemistry as a religion, yet chemistry *is* a subject with great logical beauty. We love chemistry because it explains the “why” behind many observations of the world around us and we use it every day to help us make informed choices about our health, lifestyle, and politics. Moreover, chemistry is the fundamental, enabling science that underlies many of the great advances of the last century that have so lengthened and enriched our lives. Chemistry provides a strong understanding of the physical world and will give you the foundation you need to go on and make important contributions to science and humanity.

HOW TO USE THIS BOOK

You no doubt have experience using textbooks and know they are not meant to read like a novel. We have written this book to provide you with a clear, cohesive introduction to chemistry in a way that will help you, as a new student of chemistry, understand and relate to the subject. While you *could* curl up with this book, you will greatly benefit from continually formulating questions and checking your understanding as you *work* through each section. The way this book is designed and written will help you keep your mind active, thus allowing you to digest important concepts as you learn some of the many principles of chemistry.

The 8th edition was revised to create an **interactive** study cycle based on research of effective learning methods. Many common study habits such as highlighting, rereading, and long study sessions create the illusion of fast progress, but these gains fade quickly. More deep and durable learning occurs from self-testing, difficulty in practice, and spaced practice of different skills. Let's see how specific steps in the study cycle use proven strategies to maximize your learning.

Step 1. Learning New Material

The 8th edition contains many new features that should be used to quiz yourself and receive feedback as you work through the material in each chapter.

- **Narrative:** As you read through the text, always challenge yourself to understand the “why” behind the concept. For example, you will learn that carbon forms four bonds, and the narrative will give the reason why. By gaining a conceptual understanding, you will *not need to memorize* a large collection of facts, making learning and retaining important principles much easier! **Big Idea Questions** were written to help you digest and apply the most important concepts.

- **Figures:** Figures are not optional! Most summarize and convey important points. *Figure It Out Questions* draw your attention to a key principle and provide guidance in interpreting graphs. Answer the question by examining the figure and perhaps rereading the related narrative. We've provided answers to Figure It Out Questions near the figure.
- **Worked Examples:** Numerous worked examples throughout the text show the approach for solving a certain type of problem. Each worked example uses a step-by-step procedure.
 - **Identify**—The first step in problem solving is to identify key information and classify it as a known or unknown quantity. This step also involves translating between words and chemical symbols. Listing knowns on one side and unknowns on the other organizes the information and makes the process of identifying the correct strategy more visual. The *Identify* step is used in numerical problems.
 - **Strategy**—The strategy describes how to solve the problem without actually solving it. Failing to articulate the needed strategy is a common pitfall; too often students start manipulating numbers and variables without first identifying key equations or making a plan. Articulating a strategy will develop conceptual understanding and is highly preferable to simply memorizing the steps involved in solving a certain type of problem.
 - **Solution**—Once the plan is outlined, the key information is used to answer the question.
 - **Check**—A problem is not completed until you have thought about whether the answer makes sense. Use both your practical knowledge of the world and knowledge of chemistry to evaluate your answer. For example, if heat is added to a sample of liquid water and you are asked to calculate the final temperature, you should critically consider your answer: Is the final temperature lower than the original? Shouldn't adding heat raise the temperature? Is the new temperature above 100 °C, the boiling point of water? The *Check* step is used in problems when the magnitude and sign of a number can be estimated or the physical meaning of the answer verified based on familiar observations.

To test your mastery of the concept explored in Worked Examples, two problems will follow. **PRACTICE** problems are similar in style and complexity to the Worked Example and will test your basic understanding.

Once you have correctly completed this problem, tackle the **APPLY** problem, in which the concept is used in a new situation to assess a deeper understanding of the topic. Answers to Apply Problems can be found at the end of the book.

- **Interactive Worked Examples:** Each chapter has two video tutorials for challenging problems that model the process of expert thinking. The videos are interactive and ask you to make predictions before moving forward to the complete solution.
- **Conceptual Problems:** Conceptual understanding is a primary focus of this book. Conceptual problems are intended to help you with the critical skill of visualizing the structure and interactions of atoms and molecules while probing your understanding of key principles rather than your ability to correctly use numbers in an equation. The time you spend mastering these problems will provide high long-term returns by solidifying main ideas.

Step 2. Problem-Solving Practice

We achieve more complex and long-lasting learning by practicing problems that require more effort and slow down the pace of learning.

- **End-of-Chapter Problem Sets:** Working problems is essential for success in chemistry! The number and variety of problems at the end of chapter will give you the

practice needed to gain mastery of specific concepts. Answers to every other problem are given in the “Answers” section at the back of the book so that you can assess your understanding. Your instructor may assign problems in an online format using the Mastering™ Chemistry platform, which comes with the added benefit of tutorials, feedback, and links to relevant content in the eText.

Step 3. Mastery

Once you have read the chapter and completed the end-of-chapter problems, you will need to review for the exam and assess which topics you have mastered and which still need to be solidified. Inquiry sections and practice tests are chapter capstones that strengthen mental representations by replaying learning and giving it meaning.

- **Inquiries:** Inquiry sections connect chemistry to the world around you by highlighting useful links in the future careers of many science students. Typical themes are materials, medicine, and the environment. The goal of these sections is to deepen your understanding and aid in retention by tying concepts to memorable applications. These sections can be considered as a capstone for each chapter because *Inquiry* problems review several main concepts and calculations. These sections will also help you prepare for professional exams because they were written in the same style as new versions of these exams: a passage of text describing an application followed by a set of questions probing your ability to apply basic scientific concepts to the situation.
- **End-of-Chapter Practice Test and Study Guide:** The end-of-chapter practice test and study guide are useful tools for exam preparation. Each practice test question is linked to a learning objective in the study guide. If you answer a question incorrectly or want more practice on that skill, refer to the study guide, which matches the learning objective to a concept summary, key skills for solving the problem, Worked Examples for assistance, and end-of-chapter problems so that you can practice your mastery of that skill.

NEW TO THIS EDITION

A primary change in the 8th edition is the development of an interactive learning environment. We designed interactive features for the text and classroom based on educational research and strategies proven to help students succeed. Questions have been developed to help instructors engage students during class using Learning Catalytics, a personal response system used with smart devices. A large body of educational literature has clearly demonstrated increased learning gains, higher attendance, and lower failure rates in classrooms that employ active learning. New features include:

1. **Big Idea Questions:** Efficient and skilled reading requires students to parse out main ideas and important details and relate new information to prior knowledge. Big Idea Questions probe understanding of important concepts from a text passage. These questions teach students how to actively read a science text by modeling the kinds of questions they should ask themselves and stimulate them to make connections between concepts and mathematical problems.
2. **Figure It Out Questions:** These questions test knowledge of key principles shown in a figure and the ability to read and interpret graphs. Answers to Figure It Out Questions are provided near the figure in the printed book.
3. **Interactive Worked Examples:** Each chapter has two video tutorials featuring lead author Jill Robinson as she models the process of expert problem solving. The videos require students to pause and digest information and then predict how to proceed at key points before moving forward to the complete solution.
4. **PRACTICE Problems:** These problems follow a Worked Example and test basic understanding. Answers to Practice Problems are provided at the end of the printed book.
5. **APPLY Problems:** These problems follow the Practice Problems and discourage a plug-and-chug approach to problem solving by providing an example of how the same principle can be used in different types of problems with different levels of complexity. Answers to Apply problems are provided at the end of the printed book.
6. **Practice Test Linked to Study Guide:** A useful way for students to review each chapter is by taking the Practice Test, which assesses mastery of chapter learning objectives. The Study Guide provides a targeted follow-up to the Practice Test through the linking of learning objectives to the main lessons in each chapter, associated worked examples, and end-of-chapter problems for more practice. When a student answers incorrectly in Mastering Chemistry, the Practice Test automatically links to worked examples and additional practice problems.
7. **Interactive Learning Catalytics Questions:** The Learning Catalytics questions developed for each chapter promote strong conceptual understanding and advanced problem-solving skills. Learning Catalytics includes prebuilt questions for every key topic in chemistry written by lead author Jill Robinson.

Inquiry Sections have been updated and integrated conceptually into each chapter.

Inquiry sections highlight the importance of chemistry, promote student interest, and deepen students' understanding of the content. The Inquiry sections include problems that revisit several chapter concepts and can be covered in class or recitation sections or assigned as homework in Mastering Chemistry. In the 8th edition, the delivery of

Inquiry problems in Mastering Chemistry has been improved and new topics have been developed. New Inquiries for the 8th edition are:

- Chapter 2: How can measurements of oxygen and hydrogen isotopes determine past climates?
- Chapter 3: How is the principle of atom economy used to minimize waste in a chemical synthesis?
- Chapter 8: Which is better for human health, natural or synthetic vitamins?
- Chapter 10: How do inhaled anesthetics work?
- Chapter 12: What are quantum dots, and what controls their color?
- Chapter 14: How do enzymes work?
- Chapter 15: How does high altitude affect oxygen transport in the blood?
- Chapter 20: How are radioisotopes used in medicine?

NEW! End-of-chapter problems continually build on concepts and skills from earlier in the chapter.

Educational research shows that interleaved and varied practice with different concepts and skills produces higher learning gains than drilling on a single topic. Section Problems at the end of the chapter now include questions that build on concepts taught earlier in the chapter. In previous editions, Section Problems focused only on learning objectives from that specific section in the text. New questions and questions from the Chapter Problems sections in previous editions that integrate multiple chapter concepts have been incorporated into Section Problems to revisit key ideas on a regular basis and apply them in different situations.

Here is a list of some of the key chemistry content changes made in each chapter:

Chapter 1 Chemical Tools: Experimentation and Measurement

- The scientific method is described in the context of a new case study in the field of nanoscience to help students see the utility of chemistry in solving important world problems.
- Nanotechnology Inquiry problems were updated to promote better understanding of the unique properties of matter on the nanoscale and the size of nanoparticles.
- Figure 1.8 was updated to show the most commonly used laboratory glassware.

Chapter 2 Atoms, Molecules, and Ions

- Several updates to terminology and the periodic table were made. The names of recently discovered elements 113, 115, 117, and 118 were officially assigned in 2016 and listed in Section 2.1 Chemistry and the Elements. A clarification about the definition and common use of the term *atomic mass unit* was added. The atomic mass unit (*amu*) is an obsolete unit, but it is commonly used interchangeably with the correct unit, unified atomic mass unit (*u*). Since 2011, the Union of Pure and Applied Chemistry gives the atomic weights for some elements as a range of values instead of a single value due to isotopic abundances that vary with the source of the sample.
- Section 2.10 Measuring Atomic Weight: Mass Spectrometry was added to describe how atomic weights are experimentally measured. The process of using a mass spectrum to

calculate an atomic weight is described in a Worked Example, and follow-up problems and new end-of-chapter problems were written. The description of a mass spectrometer from Chapter 3 was moved into Chapter 2 because it is the instrument used to measure atomic weight.

- In Section 2.12 Ions and Ionic Bonds, additional details on writing formulas for ionic compounds were added for clarification.
- A new Inquiry on isotopes and the climate record provides a strong connection with the Chapter 2 topics of isotopes, atomic weight, and the mole concept.

Chapter 3 Mass Relationships in Chemical Reactions

- Chemical Arithmetic: Stoichiometry was a very long section and contained many concepts. It has been divided into two sections: Section 3.3 Molecular Weight and Molar Mass and Section 3.4 Stoichiometry: Relating Amounts of Reactants and Products.
- A new Inquiry on atom economy concisely summarizes the important concept of relating amounts of reactants and products and introduces green chemistry.
- The section on measuring molecular weight was revised because the mass spectrometer was previously described in Chapter 2 in the section on atomic weight.

Chapter 4 Reactions in Aqueous Solution

- Added a Remember note in the margin at the beginning of Section 4.3 Electrolytes in Aqueous Solution to remind students about the differences between molecules and ions.

- Section 4.7 Acids, Bases, and Neutralization Reactions: Added a Looking Ahead note regarding acids/bases coverage in Chapter 16. Also, added the dissociation reaction for sodium hydroxide and barium hydroxide when discussing strong and weak bases.
- More explanation added to Worked Example 4.12 to help students assign oxidation numbers.
- Section 4.11 Identifying Redox Reactions: New figure shows that silver-colored powdered iron is oxidized by oxygen to produce iron(III)oxide, which is red in color.

Chapter 5 Periodicity and Electronic Structure of Atoms

Chapter 5 contains abstract ideas such as particles behaving as waves and the notion of wave functions of electrons. Eight new figures and descriptive text were added to help students grasp these difficult concepts.

- In Section 5.1 Wave Properties of Radiant Energy and the Electromagnetic Spectrum, the double-slit experiment was described to show that both light and matter have wave properties. New Figure 5.4: Diffraction and interference are phenomena exhibited by waves. New Figure 5.5: Radiant energy exhibits wave properties in a double-slit experiment.
- Section 5.3 Atomic Line Spectra and Quantized Energy: The connection between quantized energy and atomic line spectra was strengthened by condensing content and placing both concepts into the same section. Also, radial distribution plots were added to help visualize the meaning of an orbital and explain electron shielding and the ordering of orbital energies.
- Section 5.4 Wavelike Properties of Matter: de Broglie's Hypothesis: New Figure 5.11: Wave properties of electrons illustrate the different behaviors of particles and waves in a double-slit experiment. Figure also shows that electrons have wave properties, which is a key idea for understanding orbitals.
- Added an electron microscope image that shows individual DNA molecules to illustrate the utility of the wave properties of an electron in Worked Example 5.5 and Apply problem 5.10.
- Section 5.7 The Shapes of Orbitals: New Figure 5.14: Representations of a 1s orbital. New Figure 5.15: Concert hall analogy for radial probability. A figure was added to help explain the concept of radial probability in a familiar way.
- New Figure 5.18: Radial probability plots for the 1s, 2s, and 3s orbitals in a hydrogen atom. Radial probability plots are a useful way to explain the differences in size, energy, and number of nodes for the different s orbitals.
- Section 5.9 Orbital Energy Levels in Multielectron Atoms: New Figure 5.23: Radial distribution plots for 3s, 3p, and 3d orbitals. The penetration of the different orbitals determines the ordering of orbital energies ($3s < 3p < 3d$).
- Section 5.10 Electron Configurations of Multielectron Atoms: New Figure 5.24: Energy levels of orbitals in multielectron atoms was placed in the margin for easy reference when writing electron configurations.

Chapter 6 Ionic Compounds: Periodic Trends and Bonding Theory

- Section 6.1 Electron Configurations of Ions: Added text and a figure to make it more clear why ns electrons are lost before $(n - 1)d$ electrons when forming transition metal ions. A relatively recent article in the *Journal of Chemical Education* describes how many textbooks contain incomplete or inaccurate discussions of this topic. The d orbital collapse for transition metals was described as concisely as possible. (Reference: The Full Story of the Electron Configurations of the Transition Elements, J. Chem Ed., Vol 87, No. 4, April 2010)
- Modified Figure 6.6 so negative electron affinities appear below zero on the graph.
- In the reactions in the Born-Haber cycle, the energy of the reaction is written in units of kJ, not kJ/mol. Figures 6.7 and 6.8 were updated to reflect the change.
- Updated Inquiry questions on ionic liquids.

Chapter 7 Covalent Bonding and Electron-Dot Structures

- Electronegativity was defined earlier in the section to more clearly explain the existence of polar covalent bonds. Electrostatic potential maps of Cl_2 , HCl, and NaCl were combined into one figure for comparison and to relate the extent of electron transfer to differences in electronegativity between the elements in the bond.
- Added the topics of dipole moment and percent ionic character to illustrate the extent of electron transfer as a continuum instead of as a sharp cutoff between a polar covalent bond and an ionic bond. A new Worked Example and new Practice and Apply problems were added. End-of-chapter problems were added as well. The content on percent ionic character was moved from Chapter 8 to Chapter 7 because it is much more relevant in this section.
- New Looking Ahead note about intermolecular forces in Section 7.4 A Comparison of Ionic and Covalent Compounds.
- Revised Inquiry Questions.

Chapter 8 Covalent Compounds: Bonding Theories and Molecular Structure

- Developed a new style for representing orbitals in all figures to more clearly show orbital overlap to form chemical bonds in valence bond theory.
- Clarified answer key for orbital overlap diagrams. Terminal atoms that have multiple bonds use the hybrid orbital model.
- References added to help students/instructors learn more about the vague statement "main-group compounds with five and six charge clouds use a more complex bonding pattern that is not easily explained by valence bond theory." The reference appears as a footnote. Some books report that main-group atoms that expand their octets use sp^3d or sp^3d^2 hybrid orbitals, which is not considered an accurate representation based on density functional theory calculations.
- The quantitative aspects of dipole moments were moved to Chapter 7 to help students better understand the differences

between a nonpolar covalent bond, polar covalent bond, and ionic bond. A qualitative discussion of dipole moments of molecules is sufficient for Chapter 8 and is aligned with how instructors cover this topic.

- Changed the order of presentation of the different types of intermolecular forces. We now start with London dispersion forces because all molecules have these types of forces. We then get more restrictive and describe polar molecules with dipole-dipole forces, followed by hydrogen bonding, which is more restrictive and a special case of dipole-dipole forces. Finally, ion-dipole is described. The ordering of presentation of forces is from weakest to strongest.
- New Inquiry topic on the difference between natural and synthetic compounds such as vitamins.

Chapter 9 Thermochemistry: Chemical Energy

- A new chapter introduction was written to better connect chapter topics to examples familiar to students.
- Improved the strategy for solving constant-pressure calorimetry problems in Worked Example 9.6.
- Changed the way constant-volume calorimetry was presented to more accurately reflect the way this type of experiment was carried out in the laboratory. A new Worked Example (9.7) and follow-up problems were written. End-of-chapter problems were revised to fit with this pedagogy.
- Section 9.11 on fossil fuels was removed. This section did not teach any new chemistry content, and the Inquiry on biofuels serves to connect thermochemistry concepts to fuels.

Chapter 10 Gases: Their Properties and Behavior

- Changed formulas for Graham's Law in Section 10.7 Gas Diffusion and Effusion: Graham's Law to replace mass (m) with molar mass (M).
- Removed the section on pollution to shorten the chapter. Most instructors do want to cover some relevant topic about the atmosphere, and the climate change section was improved. Figures on greenhouse gases and climate change were updated to include data from years since the last revision.
- New Inquiry on inhaled anesthetics.

Chapter 11 Liquids and Phase Changes

- The focus of Chapter 11 is on liquids, their properties, and phase changes. The topics of solids and unit cells have been moved to Chapter 12 on solids and solid-state materials.
- A new section on liquid crystals and end-of-chapter problems have been added.

Chapter 12 Solids and Solid-State Materials

- The topics of unit cells of solids and solid-state materials are closely related and are now contained in one chapter. (Chapters 11 and 21 content from the 7th edition is combined to make one coherent unit on solids.)
- Revised Inquiry on quantum dots.

Chapter 13 Solutions and Their Properties

- Added a new figure to show the difference between a solution and colloid using light-scattering properties.
- Divided Section 12.2 from the 7th edition into two new sections to improve the description of the solution-making process.
- Section 13.2 Enthalpy Changes and the Solution Process focuses on describing the intermolecular forces involved in solution formation and the overall effect on the heat of solution.
- New Figure 13.1: A molecular view of the solution making process.
- Section 13.3 Predicting Solubility relates the thermodynamic value of ΔG to the simple rule for solubility "like dissolves like."
- Added a paragraph to Section 13.5 Some Factors That Affect Solubility to explain why increasing temperature increases the solubility of solids but decreases the solubility of gases. A new Big Idea Question highlights this concept.
- Added a figure and description in Section 13.7 Vapor-Pressure Lowering of Solutions: Raoult's Law to illustrate ion pairing and explain why the dissociation of ionic compounds is not complete.
- Section 12.9 from the 7th edition on the fractional distillation of mixtures was deleted. There is already a lot of difficult material in this chapter, and this topic is not covered in most general chemistry courses.

Chapter 14 Chemical Kinetics

- Revised Figure 14.2 and text description to more clearly show how the instantaneous rate is determined from experimental data.
- Worked Example 14.8 (to replace 13.8) was revised to focus on the main idea of calculating half-life and not have students get lost in the details by referring to previous graphs.
- New analogy for rate-limiting step in Section 14.11 Rate Laws for Overall Reactions.
- New Inquiry on enzyme kinetics.
- Data in numerous end-of-chapter problems involving graphing were revised.

Chapter 15 Chemical Equilibrium

- Figure 15.1 was revised to show a macroscale and molecular scale representation of the $\text{N}_2\text{O}_4/\text{NO}_2$ equilibrium. This figure provides a picture of the data in the concentration versus time graphs in Figures 15.2 and 15.3.
- The feedback for practice problems in the eText provides an opportunity to give remediation in the mathematical operations including the quadratic equation. All steps in solving the algebraic expressions are shown to help students who may need a review.
- Inquiry focus was changed from the general concept of the equilibrium reaction of oxygen and hemoglobin to the more specific focus of the effect of altitude on oxygen supply in muscles.

Chapter 16 Aqueous Equilibria: Acids and Bases

- The procedure for solving acid-base equilibrium problems was reduced from eight steps to five steps, which are simpler to understand. All subsequent worked examples in Chapters 16 and 17 were modified using the new procedure. Figure 16.7 and the description of solving acid–base problems were revised to eliminate wording that was unusual and confusing. Examples are “big” concentrations and “small” concentrations.
- A photo sequence showing the pH change when CO_2 dissolves to produce carbonic acid was added to Worked Example 16.11.
- The Inquiry section was updated to discuss current problems related to acid rain.

Chapter 17 Applications of Aqueous Equilibria

- Section 17.2 The Common-Ion Effect was revised in three ways. The concept of the common-ion effect was presented before mathematical calculations to give students an understanding of the main idea first. Calculating the pH of a weak acid and conjugate base mixture was modified to follow the new simplified approach to solving equilibrium problems given in Figure 16.7. Two example calculations that were repetitive were combined into one example in Worked Example 17.2.
- Section 17.3 Buffer Solutions was rearranged to present the concept of a buffer before showing the calculation of pH change of a buffer upon addition of a strong acid or base. Figure 17.3 describes a buffer by showing pH change after adding a strong base to two different solutions: a strong acid and a buffer. The color change of an acid–base indicator shows that the buffer resists changes in pH. A conceptual Big Idea Question was created on the definition of a buffer.
- The Inquiry section on ocean acidification was updated with recent CO_2 and pH measurements. The problems were revised to promote understanding of the problem and for clarity.

Chapter 18 Thermodynamics: Entropy, Free Energy, and Spontaneity

- The introductory paragraph was revised to include familiar examples to students and review the concepts of reaction direction and extent of reaction.
- Two new figures were created to clarify the question in Worked Example 18.2 on calculating entropy.
- A more realistic example of a process that represents the standard free-energy change was described in Section 18.8 Standard Free-Energy Changes for Reactions.

Chapter 19 Electrochemistry

- In Section 19.1 Balancing Redox Reactions by the Half-Reaction Method, a brief review of oxidation numbers was added that includes a Remember note, a new figure showing oxidation numbers in redox reaction, and a Big Idea Question for students to assess themselves on this important concept from Chapter 4.

- Figure 19.1 showing the steps needed for balancing redox reactions by the half-reaction method was revised to make the individual steps clearer.
- New Worked Example 19.1 (Balancing a Redox Reaction in Acidic Solution): From the previous edition more detail was included so students can more easily follow the steps and canceling process when adding half-reactions.
- Revised Worked Example 19.2 (Balancing a Redox Reaction in Basic Solution): Added more detail so students can more easily follow the steps and canceling process when adding half-reactions.
- It is a convention in electrochemistry to put the anode half-cell on the left and cathode half-cell on the right. Several figures were changed to reflect this common convention.
- Worked Example 19.6 was revised to more clearly show the thought process for determining strengths of reducing agents.
- New Worked Example 19.8 was added on the very important concept of calculating voltage of a galvanic cell (a battery).
- The Inquiry was updated with recent status of commercialization of fuel-cell vehicles.

Chapter 20 Nuclear Chemistry

- In Section 20.3 Nuclear Stability, superheavy elements 113, 115, 117, and 118 were added to the periodic table. The discovery of these elements was connected to nuclear theory and the island of stability.
- In Section 20.3 Nuclear Stability, real examples of nuclear equations were provided instead of general equations to more clearly show how radioactive decay processes affect the neutron to proton ratio.
- Section 20.5 Dating with Radioisotopes was given its own section. The age of artifacts such as the Dead Sea Scrolls were updated based on improved methods of radiocarbon dating. The method of reporting artifact age using the term “Before Present (BP)” with the reference year 1950 was removed because it adds an extra step and is potentially confusing. The age of the object is now reported in the more conventional method of the time frame when the artifact was living. End-of-chapter problems were revised to match this change.
- In Section 20.7 Nuclear Fission and Fusion, Figure 20.9, which provides information on the number of nuclear reactors and nuclear power output worldwide, was updated.
- In Section 20.8 Nuclear Transmutation, information about the nuclear transformation reactions used in the synthesis of new elements $Z = 113\text{--}118$ was added, and new problems were written on this topic.
- New Inquiry topic: How are radioisotopes used in medicine? The previous text section was updated and expanded with some recent advances in nuclear medicine such as boron neutron capture therapy.

Chapter 21 Transition Elements and Coordination Chemistry

- Section 20.4 Chemistry of Selected Transition Elements was removed because it did not cover any new chemistry concepts

and involved memorization of specific reactions that would not be retained easily. This content in this section is not needed to understand the main concepts of transition metal chemistry such as the color and magnetic properties of complexes.

- Modified Figure 21.9 to label the chelate ring discussed in the text description and added a Figure It Out Question in order to identify a chelate ring.
- Figure 21.24 showing colors of nickel complexes was moved next to text describing the accompanying crystal field diagrams. A description of the connection between the crystal field energy diagrams and the observed color of the complexes was added.
- The section Valence Bond Theory of Coordination Complexes is now placed at the end of the chapter to strengthen the connection between the color of coordination compounds and crystal field theory. The key terms *high-spin* and *low-spin complex* are now defined based on crystal field theory instead of valence bond theory.
- Also, crystal field theory was developed before valence bond theory. The text was modified to reiterate how crystal field theory is different from bonding theories based on quantum mechanics. (Also, many books do not cover valence bond theory of coordination complexes, so placing it last gives instructors the option to omit it.)

Chapter 22 The Main-Group Elements

- The chemistry of each main group was merged into its own section and the content trimmed to avoid excessive memorization.
- Continued emphasis on relating main-group chemistry to previous topics in the book such as periodic trends, bonding, structure, equilibrium, and acid-base chemistry. New end-of-chapter problems were written with emphasis on reviewing important chemical principles.

Chapter 23 Organic and Biological Chemistry

- Section 23.3 Naming Organic Compounds, was removed because the focus of the chapter is on bonding and structure, and naming is not needed to address these topics.
- In Section 23.1 Organic Molecules and Their Structures: Constitutional Isomers on organic molecules and their structures, the concept of constitutional isomers (instead of simply isomers) was stressed. This allows other important types of isomers such as enantiomers and cis-trans isomers to be distinguished and addressed in later sections.
- Unnumbered figure of 2-methylbutane was revised to more clearly show the zigzag structure of the carbon chain, which serves as the basis for organic line drawings.
- New Section 23.2 Stereoisomers: Chiral Molecules. Chirality is an extremely important concept with organic molecules, and the topic warrants its own section. Worked Examples and a set of end-of-chapter problems were developed.
- New Worked Example 23.4: Interpreting Line Drawings for Molecules with Functional Groups.
- New Inquiry on chiral molecules and their biological response to connect with new Section 23.2 Stereoisomers: Chiral Molecules on chiral molecules.

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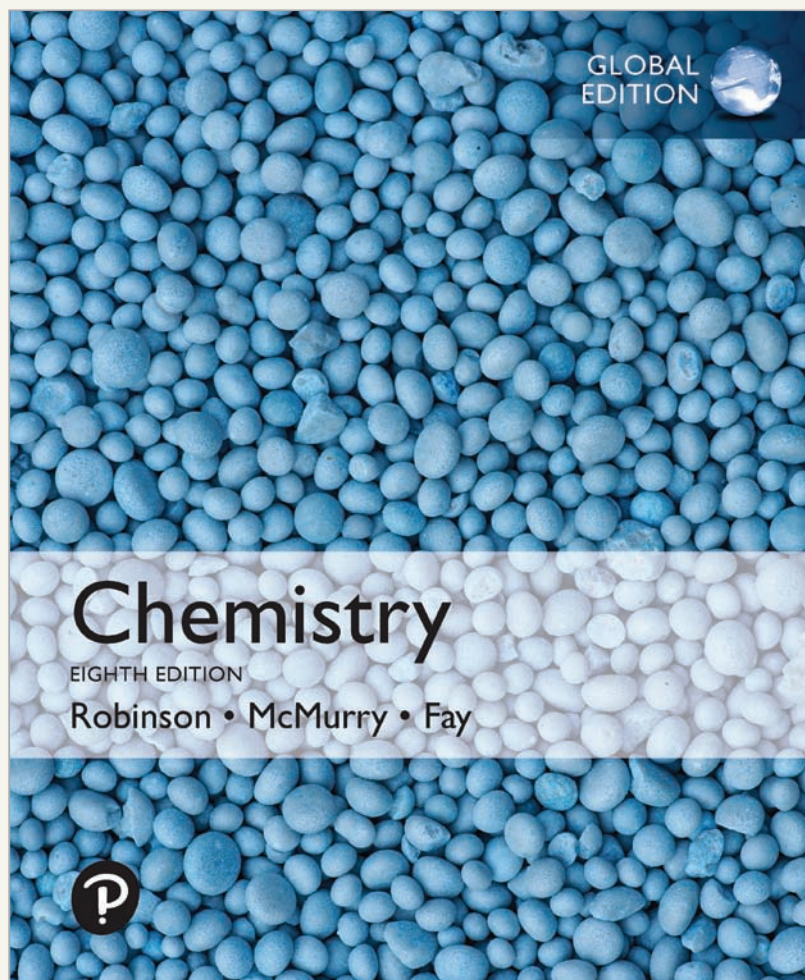
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Click on the different series of emission lines of atomic hydrogen to observe the nature of the representative transitions from excited to ground states.

Shell

$n = \infty$

$n = 5$

$n = 4$

$n = 3$

$n = 2$

$n = 1$

Excited States

Ground State

$E_3 = -B/3^2$

$E_2 = -B/2^2$

$E_1 = -B/1^2$

$= -2.179 \times 10^{-18} \text{ J}$

Balmer series

Transition from $n = _ _$ to $n = _ _$

Lyman Series Balmer Series Paschen Series Reset

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5. Periodicity and the Electronic Structure of Atoms

Interactive Activity—Energy Levels of a Hydrogen Atom

Constants | Periodic Table

When an electronic transition from a higher energy shell to a lower energy shell takes place, a photon of light is released. The energy of the photon released during the transition is equal to the energy difference between the two shells.

Select the image to explore the simulation that demonstrates three emission series.

Click on the Lyman series in the simulation to observe the pathway of the electronic transitions from excited (or higher energy) states to the ground (or lowest energy) state. Similarly, click on the other series (Balmer and Paschen) to observe their associated electronic transitions.

Part A

Sort the following transitions from an excited state to a ground state according to the series into which they fall. Drag the appropriate transitions to their respective bins.

View Available Item(s)

Reset Help

Paschen series Balmer series Lyman series

$n=3 \rightarrow n=1$ $n=3 \rightarrow n=2$ $n=7 \rightarrow n=2$

$n=7 \rightarrow n=1$ $n=4 \rightarrow n=2$ $n=4 \rightarrow n=1$

Submit Previous Answers

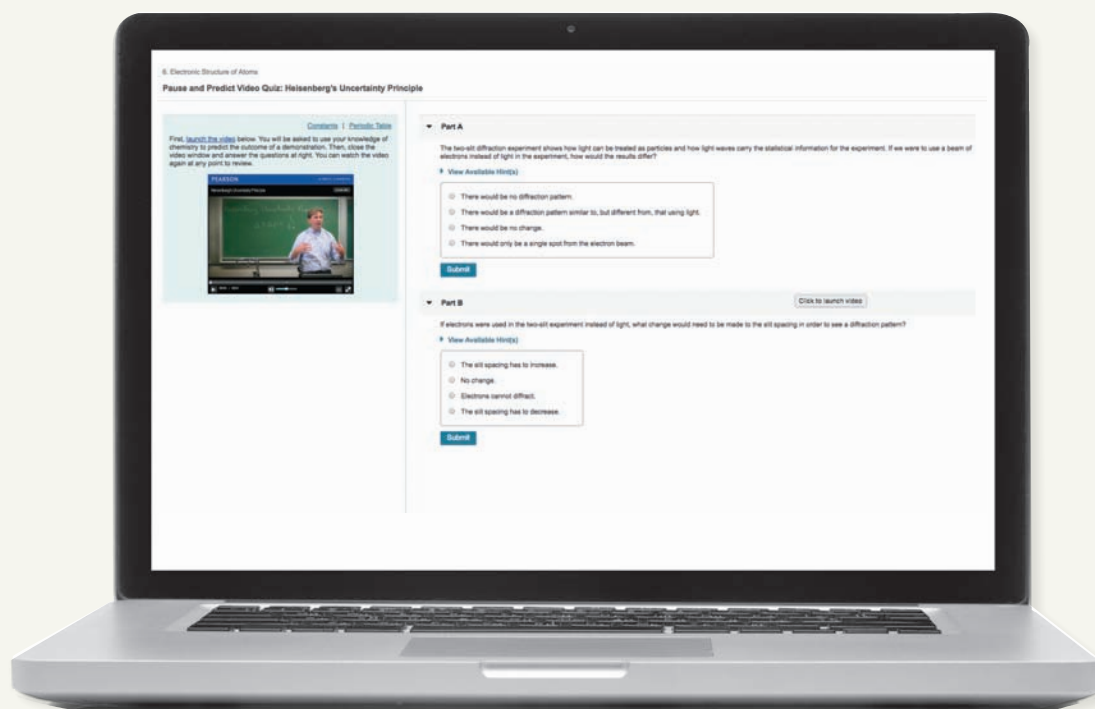
Incorrect; Try Again

You worked 4 out of 6 items incorrectly. Observe that the lowest energy shell (or ground state) for the Paschen series is always the third shell.

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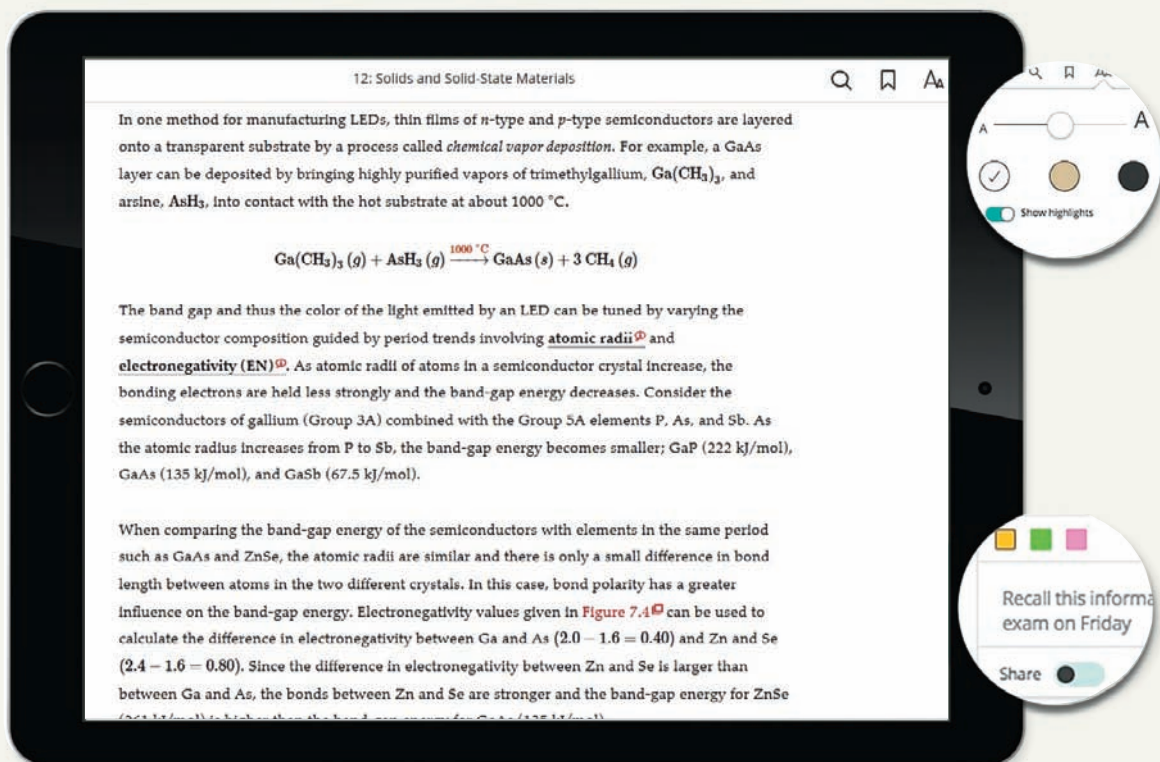
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12: Solids and Solid-State Materials

In one method for manufacturing LEDs, thin films of *n*-type and *p*-type semiconductors are layered onto a transparent substrate by a process called *chemical vapor deposition*. For example, a GaAs layer can be deposited by bringing highly purified vapors of trimethylgallium, Ga(CH₃)₃, and arsine, AsH₃, into contact with the hot substrate at about 1000 °C.

$$\text{Ga}(\text{CH}_3)_3(g) + \text{AsH}_3(g) \xrightarrow{1000\text{ }^\circ\text{C}} \text{GaAs}(s) + 3\text{CH}_4(g)$$

The band gap and thus the color of the light emitted by an LED can be tuned by varying the semiconductor composition guided by period trends involving **atomic radii** and **electronegativity (EN)**. As atomic radii of atoms in a semiconductor crystal increase, the bonding electrons are held less strongly and the band-gap energy decreases. Consider the semiconductors of gallium (Group 3A) combined with the Group 5A elements P, As, and Sb. As the atomic radius increases from P to Sb, the band-gap energy becomes smaller; GaP (222 kJ/mol), GaAs (135 kJ/mol), and GaSb (67.5 kJ/mol).

When comparing the band-gap energy of the semiconductors with elements in the same period such as GaAs and ZnSe, the atomic radii are similar and there is only a small difference in bond length between atoms in the two different crystals. In this case, bond polarity has a greater influence on the band-gap energy. Electronegativity values given in Figure 7.4 can be used to calculate the difference in electronegativity between Ga and As (2.0 – 1.6 = 0.40) and Zn and Se (2.4 – 1.6 = 0.80). Since the difference in electronegativity between Zn and Se is larger than between Ga and As, the bonds between Zn and Se are stronger and the band-gap energy for ZnSe (221 kJ/mol) is higher than the band-gap energy for GaAs (135 kJ/mol).

Search, bookmark, and font size icons are visible at the top of the page.

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Callout 2: A note-taking tool with a "Recall this information on Friday" button and a "Share" toggle switch.