

**THE PHYSICS AND
CHEMISTRY OF
MATERIALS**

THE PHYSICS AND CHEMISTRY OF MATERIALS

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The City College of the City University of New York



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For Harriet and Françoise

CONTENTS

PREFACE	xxi
LIST OF TABLES	xxvii
Introduction	1
SECTION I STRUCTURE OF MATERIALS	
1 Structure of Crystals	5
1.1 Introduction	5
Introduction to Lattices	6
1.2 Translation Vectors	6
1.3 Unit Cells	8
1.4 Bravais Lattices	8
1.5 Lattice Axes, Planes, and Directions	11
Local Atomic Bonding Units and Crystal Structures	14
1.6 Local Atomic Bonding Units	15
1.7 Crystal Structures	20
1.8 Packing Fractions and Densities	32
References	34
Problems	35
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W1.1 Crystal Structures Based on Icosahedral Bonding Units</i>	
<i>W1.2 Packing Fractions of BCC and CsCl Crystal Structures</i>	
<i>W1.3 Density of CsCl</i>	
<i>Problem</i>	
2 Bonding in Solids	37
2.1 Introduction	37
Bonding in Elemental Solids	39
2.2 Covalent Bonding	40
2.3 Metallic Bonding	44
2.4 van der Waals Bonding	45
Bonding in Multielement Crystals	47
2.5 Ionic Bonding	48
2.6 Mixed Ionic–Covalent Bonding and Ionicity	53
2.7 Hydrogen Bonding	53
	vii

Cohesive Energies	54
Summary of Some Atomic Properties and Parameters	57
2.8 Ionization Energy and Electron Affinity	58
2.9 Electronegativity	58
2.10 Atomic Radii: Ionic, Covalent, Metallic, and van der Waals	60
References	65
Problems	65
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W2.1 Atomic, Hybrid, and Molecular Orbitals Involved in Bonding in Solid-State Materials	
W2.2 Absence of Covalent Bonding in White Sn (β -Sn) and Pb	
W2.3 Madelung Energy of Ionic Crystals	
W2.4 Hydrogen Bonding in Ice (Solid H_2O)	
W2.5 Standard Enthalpies of Formation	
W2.6 Bond Energies	
W2.7 Ionization Energies and Electron Affinities	
W2.8 Valence	
W2.9 Electronegativity	
W2.10 Atomic Radii	
References	
Problems	
3 Diffraction and the Reciprocal Lattice	67
Diffraction	67
3.1 Fourier Analysis in One and Three Dimensions	68
3.2 Examples of Reciprocal Lattices	71
Elastic Scattering from Ordered and Disordered Materials	73
3.3 Crystalline Solids	75
3.4 Bragg and von Laue Descriptions of Diffraction	77
3.5 Polycrystalline Solids or Powders	78
3.6 Elastic Scattering from an Amorphous Solid	81
References	82
Problems	83
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W3.1 Voronoi Polyhedra	
W3.2 Molecular Geometry and Basis Structure from Diffraction Data	
Reference	
Problem	
4 Order and Disorder in Solids	85
4.1 Introduction	85
Order and Disorder	86
4.2 Examples of Ordered and Disordered Solids	91
4.3 Amorphous Solids	96

Defects in Solids	100
4.4 Localized Defects	103
4.5 Extended Defects	106
4.6 Thermodynamics of Defect Formation: Entropy	111
4.7 Examples of Defect Studies	115
References	117
Problems	117
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
<i>W4.1 Further Discussion of the Random Close-Packing Model</i>	
<i>W4.2 Further Discussion of the Continuous Random Network Model</i>	
<i>W4.3 Illustrations of the Law of Mass Action</i>	
<i>W4.4 Nonstoichiometry</i>	
<i>Reference</i>	

SECTION II PHYSICAL PROPERTIES OF MATERIALS

5 Phonons	121
Excitations of the Lattice: Phonons	121
5.1 One-Dimensional Monatomic Lattice	122
5.2 One-Dimensional Diatomic Lattice	126
5.3 Phonons: General Case	128
5.4 Phonon Density of States	130
Lattice Specific Heat of Solids	133
5.5 Specific Heat of Solids	134
5.6 Debye Theory of Specific Heat	135
5.7 Einstein Theory of Specific Heat	138
5.8 Debye–Waller Factor	139
Anharmonic Effects	139
5.9 Thermal Expansion	140
5.10 Thermal Conductivity	144
References	150
Problems	151
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
<i>W5.1 Monatomic Lattice with Random Interactions</i>	
<i>W5.2 Debye–Waller Factor</i>	
<i>Appendix W5A: Quantization of Elastic Waves</i>	
<i>Appendix W5B: Dispersion Relations in the General Case</i>	
<i>Appendix W5C: Van Hove Singularities</i>	
6 Thermally Activated Processes, Phase Diagrams, and Phase Transitions	153
6.1 Introduction	153
Thermally Activated Processes	153

6.2 Diffusion	153
6.3 Vaporization	160
Equilibrium Phase Diagrams	161
6.4 Pure Substances	162
6.5 Binary Systems	163
Structural Phase Transitions	173
6.6 Melting	173
6.7 Solid-State Phase Transitions	178
References	184
Problems	185

Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)

W6.1 Concentration Profiles Resulting from Diffusion

W6.2 Examples of Diffusion Studies

W6.3 Examples of Vaporization Studies

W6.4 Gibbs Phase Rule

Problems

7 Electrons in Solids: Electrical and Thermal Properties 187

7.1 Introduction	187
Classical Theory of Electrical Conduction	188
7.2 Drude Theory	188
7.3 Hall Effect in Metals	190
Free-Electron Gases	191
7.4 Sommerfeld Theory	191
Transport Theory	196
7.5 Onsager Relations	196
The Quantum Theory of Solids	197
7.6 Bloch's Theorem	197
7.7 Nearly Free Electron Approximation	200
7.8 Tight-Binding Approximation in One Dimension	204
7.9 Tight-Binding Approximation in Two Dimensions	207
7.10 Metals, Insulators, Semiconductors, and Semimetals	209
Quantum Effects in Electrical Conduction	211
7.11 Temperature Dependence of Resistivity in Metals	211
7.12 Semiconductors	212
7.13 Magnetoresistance	214
Conduction in Insulators	216
7.14 Variable-Range Hopping	216
7.15 Poole–Frenkel Effect	218
Metal–Insulator Transition	219
7.16 Percolation	219
7.17 Mott Metal–Insulator Transition	222
Conductivity of Reduced-Dimensional Systems	223
7.18 Carbon Nanotubes	223

7.19 Landauer Theory of Conduction	228
References	229
Problems	229
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W7.1 Boltzmann Equation	
W7.2 Random Tight-Binding Approximation	
W7.3 Kronig–Penney Model	
W7.4 Hall Effect in Band Theory	
W7.5 Localization	
W7.6 Properties of Carbon Nanotubes	
Appendix W7A: Evaluation of Fermi Integrals	
8 Optical Properties of Materials	231
8.1 Introduction	231
8.2 The Electromagnetic Spectrum	232
8.3 AC Conductivity of Metals	233
8.4 Reflectivity	234
8.5 Optical Properties of Semiconductors	241
8.6 Optical Dielectric Function	243
8.7 Kramers–Kronig Relations	245
8.8 Optical Properties of Composite Media	246
8.9 Nonlinear Polarization	247
8.10 Excitons	250
8.11 Color Centers	253
8.12 Polaritons	254
8.13 Emissivity	254
References	258
Problems	258
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W8.1 Index Ellipsoid and Phase Matching	
W8.2 Polaritons	
Appendix W8A: Maxwell's Equations	
Appendix W8B: Nonlocal Dielectric Function	
Appendix W8C: Quantum-Mechanical Derivation of the Dielectric Function	
9 Magnetic Properties of Materials	261
9.1 Introduction	261
Origins of Magnetism in Solids	261
9.2 Free Atoms and Ions	261
9.3 Atoms and Ions in Solids	266
Types of Magnetism and Magnetic Behavior in Materials	276
9.4 Paramagnetism	278
9.5 Interactions Between Magnetic Moments	283
9.6 Ferromagnetism	287

9.7 Antiferromagnetism	297
9.8 Ferrimagnetism	301
9.9 Magnetic Behavior of Electrons in Closed Shells and of Conduction Electrons	304
References	309
Problems	309

Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)

<i>W9.1 Jahn–Teller Effect</i>	
<i>W9.2 Examples of Weak and Strong Crystal Field Effects</i>	
<i>W9.3 Crystal Fields and Cr^{3+} in Al_2O_3</i>	
<i>W9.4 Experimental Results for χ in the Free-Spin Limit</i>	
<i>W9.5 Spin Glasses and the RKKY Interaction</i>	
<i>W9.6 Kondo Effect and s–d Interaction</i>	
<i>W9.7 $\chi(T)$ for Ni</i>	
<i>W9.8 Hubbard Model</i>	
<i>W9.9 Microscopic Origins of Magnetocrystalline Anisotropy</i>	
<i>W9.10 χ_{\parallel} and χ_{\perp} for Antiferromagnetic Materials</i>	
<i>W9.11 Magnetism in Disordered Materials</i>	
<i>References</i>	
<i>Problems</i>	

10 Mechanical Properties of Materials 311

10.1 Introduction	311
Stress, Strain, and Elastic Constants	311
10.2 Stress	312
10.3 Strain	314
10.4 Relationships Between Stress and Strain: Elastic Constants	317
Elastic Properties of Materials	320
10.5 Hooke’s Law, Young’s Modulus, and Shear Modulus	320
10.6 Compressibility and Bulk Modulus	323
10.7 Poisson’s Ratio	324
10.8 Isotropic Solids: Relationships Between the Elastic Moduli	325
10.9 Elastic Potential Energy	326
10.10 Elastic Waves	327
Anelastic Properties of Materials	330
10.11 Macroscopic Aspects of Anelasticity	330
10.12 Microscopic Aspects of Anelasticity	332
Inelastic Properties of Materials	334
10.13 Macroscopic Aspects of Plasticity and Fracture	335
10.14 Microscopic Aspects of Plasticity and Fracture	341
References	351
Problems	351

Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)

<i>W10.1 Relationship of Hooke’s Law to the Interatomic $U(r)$</i>	
<i>W10.2 Zener Model for Anelasticity</i>	

<i>W10.3 Typical Relaxation Times for Microscopic Processes</i>	
<i>W10.4 Further Discussion of Work Hardening</i>	
<i>W10.5 Strengthening Mechanisms</i>	
<i>W10.6 Creep Testing</i>	
<i>W10.7 Further Discussion of Fatigue</i>	
<i>W10.8 Hardness Testing</i>	
<i>W10.9 Further Discussion of Hall–Petch Relation</i>	
<i>W10.10 Analysis of Crack Propagation</i>	
<i>Reference</i>	
<i>Problems</i>	

SECTION III CLASSES OF MATERIALS

11 Semiconductors	357
11.1 Introduction	357
Characteristic Properties of Semiconductors	357
Microscopic Properties	359
11.2 Energy-Band Structure and Energy Gaps	359
11.3 Dynamics of Electron Motion	366
11.4 Excited States of Electrons	367
11.5 Doping and Defects	374
11.6 Dimensionality and Quantum Confinement	382
Macroscopic Properties	387
11.7 Electrical Conductivity and Mobility	388
11.8 Effects of Magnetic Fields	394
11.9 Optical Properties	396
Examples of Semiconductors	404
11.10 Elemental Semiconductors and Their Compounds and Alloys	405
11.11 Compound Semiconductors and Their Alloys	409
Applications of Semiconductors	419
11.12 Critical Issues	419
11.13 Specific Applications	434
References	439
Problems	440
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W11.1 Details of the Calculation of $n(T)$ for an n-Type Semiconductor</i>	
<i>W11.2 Effects of Doping on Resistivity of Silicon</i>	
<i>W11.3 Optical Absorption Edge of Silicon</i>	
<i>W11.4 Thermoelectric Effects</i>	
<i>W11.5 Dielectric Model for Bonding</i>	
<i>W11.6 Nonstandard Semiconductors</i>	
<i>W11.7 Further Discussion of Nonequilibrium Effects and Recombination</i>	
<i>W11.8 Transistors</i>	

W11.9 Quantum Hall Effect
W11.10 Photovoltaic Solar Cells
W11.11 Thermoelectric Devices
Appendix W11A: Landau Levels
References
Problems

12 Metals and Alloys 443

12.1 Introduction 443
 Three Classes of Metals 444
 12.2 *sp*-Bonded Metals 444
 12.3 Transition Metals 449
 12.4 Rare Earth Metals 451
 Alloys 452
 12.5 Hume–Rothery Rules 453
 12.6 Electrical Resistance of Metallic Alloys 455
 Examples and Applications of Metallic Alloys 457
 12.7 Steel 457
 12.8 Intermetallic Compounds and Superalloys 458
 12.9 Electromigration 462
 References 463
 Problems 464

Topics at the Web Site (*ftp://ftp.wiley.com/public/sci_tech_med/materials*)

W12.1 Density-Functional Theory
W12.2 Embedded-Atom Method
W12.3 Peierls Instability
W12.4 Corrosion and Oxidation
W12.5 Coatings
W12.6 Shape-Memory Alloys
W12.7 Metallic Glasses
W12.8 Metal Hydrides
W12.9 Solder Joints and Their Failure
W12.10 Porous Metals
References

13 Ceramics 465

13.1 Introduction 465
 13.2 Pauling Bonding Rules 467
 13.3 Ionic Interactions 469
 Applications 471
 13.4 Refractories 471
 13.5 Silicon Nitride 475
 13.6 Zeolites 477
 13.7 Glasses 481
 References 488

Problems	489
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
<i>W13.1 Ternary Phase Diagrams</i>	
<i>W13.2 Silicates</i>	
<i>W13.3 Clay</i>	
<i>W13.4 Cement</i>	
<i>Appendix W13A: Radius Ratios and Polyhedral Coordination</i>	
<i>References</i>	
<i>Problems</i>	
14 Polymers	491
14.1 Introduction	491
Structure of Polymers	492
14.2 Geometry of Polymers	495
14.3 Polymer Crystals	497
14.4 Defects in Polymers	498
Mechanical Properties	501
14.5 Polymers Under Tension	502
14.6 Viscoelasticity	506
Thermal Properties	510
14.7 Thermal Properties of Polymers	510
Applications	514
14.8 Structural Plastics	514
14.9 Polymeric Ionic Conductors	515
14.10 Photoresists	516
14.11 Piezoelectric Polymers	517
14.12 Liquid Crystals	519
References	522
Problems	523
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
<i>W14.1 Structure of Ideal Linear Polymers</i>	
<i>W14.2 Self-Avoiding Walks</i>	
<i>W14.3 Persistence Length</i>	
<i>W14.4 Free-Volume Theory</i>	
<i>W14.5 Polymeric Foams</i>	
<i>W14.6 Porous Films</i>	
<i>W14.7 Electrical Conductivity of Polymers</i>	
<i>W14.8 Polymers as Nonlinear Optical Materials</i>	
<i>Problems</i>	
15 Dielectric and Ferroelectric Materials	525
15.1 Introduction	525
15.2 Lorentz Oscillator Model for the Dielectric Function	525
15.3 Dielectric Properties of Ionic Crystals	529

15.4 Dielectric Breakdown	530
Applications	533
15.5 Ferroelectric Phase Transitions	533
15.6 Ferroelectricity and Piezoelectricity	536
15.7 Thermistors	541
15.8 Varistors	543
15.9 β -Aluminas and Ionic Transport in Solids	545
References	547
Problems	547
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W15.1 Capacitors	
W15.2 Substrates	
W15.3 First-Order Ferroelectric Phase Transitions	
W15.4 Nonvolatile Ferroelectric Random-Access Memory	
W15.5 Quartz Crystal Oscillator	
W15.6 Lithium-Ion Battery	
W15.7 Fuel Cells	
References	
Problem	
16 Superconductors	549
16.1 Introduction	549
Characteristic Properties of Superconductors	550
16.2 Macroscopic Properties and Models	551
16.3 Microscopic Properties and Models	571
Examples of Superconductors	581
16.4 Metallic Elements	581
16.5 Oxide-Based Ceramics	582
Applications of Superconductors	589
16.6 Critical Issues	589
16.7 Specific Applications	595
References	599
Problems	599
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W16.1 Further Discussion of Thermal Conductivity in Superconductors	
W16.2 Two-Fluid Model	
W16.3 Superconducting Alloys of Metallic Elements	
W16.4 Superconducting Intermetallic Compounds	
W16.5 Further Discussion of Structure, Bonding, Composition, and Normal-State Properties of the Oxide-Based Ceramic Superconductors	
W16.6 Further Discussion of Superconducting-State Properties of the Oxide-Based Ceramic Superconductors	
W16.7 Unusual Superconductors	
W16.8 Further Discussion of Critical Currents	

<i>W16.9 Further Discussion of Large-Scale Applications</i>	
<i>W16.10 Josephson Effects</i>	
<i>W16.11 SQUIDS and Other Small-Scale Applications</i>	
Reference	
Problems	
17 Magnetic Materials	603
17.1 Introduction	603
Characteristic Properties of Magnetic Materials	603
17.2 Magnetic Microstructure and Domains	604
17.3 Magnetization Processes and Magnetization Curves	611
17.4 Magnetically Hard and Soft Materials	616
17.5 Effects of Magnetic Anisotropy	617
17.6 Effects of Shape and Size	620
Important Effects in Magnetic Materials	622
17.7 Magnetostriction	623
17.8 Magnetoresistance	626
17.9 Magneto-Optical Effects	627
17.10 Dynamic Magnetic Effects	628
Examples and Applications of Magnetic Materials	629
17.11 Hard Magnetic Materials	631
17.12 Soft Magnetic Materials	635
References	641
Problems	641
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W17.1 Details on Domain Structures</i>	
<i>W17.2 Details on Size and Shape Effects</i>	
<i>W17.3 Details on Magnetostriction</i>	
<i>W17.4 Giant and Colossal Magnetoresistance</i>	
<i>W17.5 Faraday and Kerr Effects</i>	
<i>W17.6 Details on Dynamic Magnetic Effects</i>	
<i>W17.7 Technologically Important Magnetic Materials</i>	
<i>W17.8 Details on Permanent-Magnet Materials</i>	
<i>W17.9 Details on Magnetic Recording Materials</i>	
<i>W17.10 Details on Magneto-Optical Recording Materials</i>	
<i>W17.11 Details on Fe Alloys and Electrical Steels</i>	
<i>W17.12 Details on Materials for Read/Write Heads</i>	
<i>W17.13 Details on Magnetostrictive Materials</i>	
<i>W17.14 Dilute Magnetic Semiconductors</i>	
References	
Problems	
18 Optical Materials	645
18.1 Introduction	645
Propagation of Light	646

18.2 Optical Fibers	646
Generation of Light	650
18.3 Lasers	650
18.4 Light-Emitting Diodes and Semiconductor Lasers	653
18.5 Ceramics for Lasers	657
18.6 Bandgap Engineering of Optical Materials	659
Recording of Light	662
18.7 Photography	662
18.8 Photoconductors and Xerography	666
18.9 Electro-optic Effect and Photorefractive Materials	668
References	674
Problems	675
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W18.1 Optical Polarizers</i>	
<i>W18.2 Faraday Rotation</i>	
<i>W18.3 Theory of Optical Band Structure</i>	
<i>W18.4 Damage</i>	
<i>References</i>	
<i>Problem</i>	

SECTION IV SURFACES, THIN FILMS, INTERFACES, AND MULTILAYERS

19 Surfaces	679
19.1 Introduction	679
19.2 Ideal Surfaces	680
Real Surfaces	682
19.3 Relaxation	682
19.4 Reconstruction	685
19.5 Surface Defects	687
Electronic Properties of Surfaces	690
19.6 Work Function	690
19.7 Thermionic Emission	693
19.8 Field Emission	695
19.9 Photoemission	697
19.10 Surface States	698
Surface Modification	699
19.11 Anodization	699
19.12 Passivation	700
19.13 Surface Phonons	702
19.14 Surface Processes	705
Adhesion and Friction	707
19.15 Surface Plasmons	707
19.16 Dispersion Forces	708

19.17 Friction	710
References	713
Problems	713
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W19.1 Surface States</i>	
<i>W19.2 Surfactants</i>	
<i>W19.3 Adsorption</i>	
<i>W19.4 Desorption</i>	
<i>W19.5 Surface Diffusion</i>	
<i>W19.6 Catalysis</i>	
<i>W19.7 Friction</i>	
<i>Appendix W19A: Construction of the Surface Net</i>	
<i>Appendix W19B: Fowler–Nordheim Formula</i>	
<i>Appendix W19C: Photoemission Yields</i>	
20 Thin Films, Interfaces, and Multilayers	715
20.1 Introduction	715
Thin Films	716
20.2 Surface Tension	716
20.3 Thin-Film Fabrication	718
20.4 Morphology Maps	721
20.5 Langmuir–Blodgett Films	723
Interfaces	725
20.6 Grain Boundaries	726
20.7 Band Bending in Semiconductors	729
20.8 Schottky Barrier	732
20.9 Semiconductor–Heterostructure Superlattices	734
20.10 Quantum Dot	737
20.11 Si/a-SiO ₂ Interface	740
Multilayers	742
20.12 X-ray Mirrors	742
20.13 Hardness of Multilayers	743
20.14 Stoichiometric Optimization of Physical Parameters	744
References	746
Problems	747
Topics at the Web Site (<i>ftp://ftp.wiley.com/public/sci_tech_med/materials</i>)	
<i>W20.1 Strength and Toughness</i>	
<i>W20.2 Critical Thickness</i>	
<i>W20.3 Ionic Solutions</i>	
<i>W20.4 Solid–Electrolyte Interface</i>	
<i>W20.5 Multilayer Materials</i>	
<i>W20.6 Second-Harmonic Generation in Phase-Matched Multilayers</i>	
<i>W20.7 Organic Light-Emitting Diodes</i>	
<i>W20.8 Quasiperiodic Nonlinear Optical Crystals</i>	
<i>W20.9 Graphite Intercalated Compounds</i>	

References
Problem

SECTION V SYNTHESIS AND PROCESSING OF MATERIALS

21 Synthesis and Processing of Materials	751
21.1 Introduction	751
Issues in Synthesis and Processing	752
21.2 Thermodynamic and Chemical Effects	753
21.3 Kinetic Effects	757
21.4 Crystal Growth	762
21.5 Annealing	764
Synthesis and Processing of Semiconductors	767
21.6 Czochralski Growth of Single-Crystal Silicon	768
21.7 Thermal Oxidation of Silicon	771
21.8 Fabrication of Silicon Devices	775
Synthesis and Processing of Metals	778
21.9 Synthesis and Processing of Steels	779
21.10 Synthesis and Processing of Stainless Steels	785
Synthesis and Processing of Ceramics and Glasses	787
21.11 Powder Synthesis	788
21.12 Sol–Gel Synthesis	790
Synthesis and Processing of Polymers and Carbon Molecules	792
21.13 Polymerization	792
21.14 Catalysts in Polymer Synthesis	794
21.15 Synthesis of Carbon Nanotubes	796
References	798
Problems	799
Topics at the Web Site (ftp://ftp.wiley.com/public/sci_tech_med/materials)	
W21.1 <i>Synthesis and Processing Procedures</i>	
W21.2 <i>Heteroepitaxial Growth</i>	
W21.3 <i>Processing Using Ion Beams</i>	
W21.4 <i>Float-Zone Purification of Single-Crystal Si</i>	
W21.5 <i>Epitaxial Growth of Single-Crystal Si Layers via CVD</i>	
W21.6 <i>Molecular-Beam Epitaxial Growth of GaAs</i>	
W21.7 <i>Plasma-Enhanced CVD of Amorphous Semiconductors</i>	
W21.8 <i>Fabrication of Si Devices</i>	
W21.9 <i>Processing of Microelectromechanical Systems</i>	
W21.10 <i>Synthesis and Processing of Steels</i>	
W21.11 <i>Precipitation Hardening of Aluminum Alloys</i>	
W21.12 <i>Synthesis of Metals via Rapid Solidification</i>	
W21.13 <i>Surface Treatments for Metals</i>	
W21.14 <i>Chemical Vapor Deposition of Diamond</i>	
W21.15 <i>Synthesis of $YBa_2Cu_3O_{7-x}$</i>	

W21.16 Synthesis of Si₃N₄
W21.17 Synthesis of SiC
W21.18 Synthesis of the Zeolite ZSM-5
W21.19 Synthesis of the Perovskite PLZT
W21.20 Synthesis of Glasses: Pilkington Process
W21.21 Synthesis of Polycarbonate
W21.22 Synthesis of Polystyrene
W21.23 Synthesis of Electro-active Polymers
W21.24 Spin Coating
W21.25 Microwave and Plasma Processing of Polymers
References
Problems

22 Characterization of Materials

(ftp://ftp.wiley.com/public/sci_tech_med/materials)

W22.1 Introduction
Diffraction Techniques
W22.2 X-ray Diffraction
W22.3 Low-Energy Electron Diffraction
W22.4 Reflection High-Energy Electron Diffraction
W22.5 Neutron Scattering
Optical Spectroscopy
W22.6 Optical Spectroscopy in the Infrared, Visible, and Ultraviolet
W22.7 Ellipsometry
W22.8 Fourier Transform Infrared Spectroscopy
W22.9 Raman Spectroscopy
W22.10 Luminescence
W22.11 Nonlinear Optical Spectroscopy
Electron Microscopy
W22.12 Scanning-Electron Microscopy
W22.13 Transmission-Electron Microscopy
W22.14 High-Resolution Transmission-Electron Microscopy
W22.15 Low-Energy Electron Microscopy
Electron Spectroscopy and Ion Scattering
W22.16 Photoemission
W22.17 Low-Energy Electron Loss Spectroscopy
W22.18 Extended X-ray Absorption Fine Structure
W22.19 Auger Emission Spectroscopy
W22.20 Secondary-Ion Mass Spectrometry
W22.21 Rutherford Backscattering
Surface Microscopy
W22.22 Atomic-Force Microscopy
W22.23 Scanning-Tunneling Microscope
W22.24 Lateral-Force Microscope and Surface Force Apparatus
Transport Measurements
W22.25 Electrical Resistivity and Hall Effect

W22.26 Thermopower, Peltier Coefficient, and Thermal Conductivity

Magnetic Measurements

W22.27 Foner Magnetometer

W22.28 Faraday Balance

W22.29 AC Bridge

Resonance Techniques

W22.30 Nuclear Magnetic Resonance

W22.31 Nuclear Quadrupole Resonance

W22.32 Electron-Spin Resonance

W22.33 Mössbauer Spectroscopy

Elementary Particles

W22.34 Positron-Annihilation Spectroscopy

W22.35 Muon-Precession Spectroscopy

Appendix W22A: Quantum-Mechanical Description of NMR

References

Problems

Appendix WA: Thermodynamics

Appendix WB: Statistical Mechanics

Appendix WC: Quantum Mechanics

MATERIALS INDEX

803

INDEX

811

PREFACE

As science has become more interdisciplinary and impinges ever more heavily on technology, we have been led to the conclusion that there is a great need now for a textbook that emphasizes the physical and chemical origins of the properties of solids while at the same time focusing on the technologically important materials that are being developed and used by scientists and engineers. A panel of physicists, chemists, and materials scientists who participated in the NSF Undergraduate Curriculum Workshop in Materials in 1989, which addressed educational needs and opportunities in the area of materials research and technology, issued a report that indicated clearly the need for advanced textbooks in materials beyond the introductory level. Our textbook is meant to address this need.

This textbook is designed to serve courses that provide engineering and science majors with their first in-depth introduction to the properties and applications of a wide range of materials. This ordinarily occurs at the advanced undergraduate level but can also occur at the graduate level. The philosophy of our approach has been to define consistently the structure and properties of solids on the basis of the local chemical bonding and atomic order (or disorder!) present in the material. Our goal has been to bring the science of materials closer to technology than is done in most traditional textbooks on solid-state physics. We have stressed properties and their interpretation and have avoided the development of formalism for its own sake. We feel that the specialized mathematical techniques that can be applied to predict the properties of solids are better left for more advanced, graduate-level courses.

This textbook will be appropriate for use in the advanced materials courses given in engineering departments. Such courses are widely taught at the junior/senior level with such titles as “Principles of Materials Science & Engineering,” “Physical Electronics,” “Electronics of Materials,” and “Engineering Materials.” This textbook is also designed to be appropriate for use by physics and chemistry majors. We note that a course in materials chemistry is a relatively new one in most chemistry undergraduate curricula but that an introductory course in solid-state physics has long been standard in physics undergraduate curricula.

To gain the most benefit from courses based on this textbook, students should have had at least one year each of introductory physics, chemistry, and calculus, along with a course in modern physics or physical chemistry. For optimal use of the textbook it would be helpful if the students have had courses in thermodynamics, electricity and magnetism, and an introduction to quantum mechanics.

As the title indicates, the range of topics covered in this textbook is quite broad. The 21 chapters are divided into five sections. The range of topics covered is comprehensive, but not exhaustive. For example, topics not covered in detail due to lack of space include biomaterials, a field with a bright future, and composites, examples of which are discussed only within specific classes of materials. Much more material is presented

than can be covered in a one-semester course. Actual usage of the text in courses will be discussed after the proposed subject matter has been outlined.

Following an introduction, which emphasizes the importance of materials in modern science and technology, Section I, on the “Structure of Materials,” consists of four chapters on the structure of crystals, bonding in solids, diffraction and the reciprocal lattice, and order and disorder in solids.

Section II, on the “Physical Properties of Materials,” consists of six chapters on phonons; thermally activated processes, phase diagrams, and phase transitions; electrons in solids; electrical and thermal properties; optical properties; magnetic properties; and mechanical properties.

Section III, titled “Classes of Materials,” consists of eight chapters on semiconductors; metals and alloys; ceramics; polymers; dielectric and ferroelectric materials; superconductors; magnetic materials; and optical materials. In each chapter the distinctive properties of each class of materials are discussed using technologically-important examples from each class. In addition, the structure and key properties of selected materials are highlighted. In this way an indication of the wide spectrum of materials in each class is presented.

Section IV, titled “Surfaces, Thin Films, Interfaces, and Multilayers,” consists of two chapters covering these important topics. Here the effects of spatial discontinuities in the physical and chemical structure on the properties of materials are presented, both from the point of view of creating materials with new properties and also of minimizing the potential materials problems associated with surfaces and interfaces.

Section V, titled “Synthesis and Processing of Materials,” consists of a single chapter. Representative examples of how the structure and properties of materials are determined by the techniques used to synthesize them are presented. “Atomic engineering” is stressed. The tuning of structure and properties using postsynthesis processing is also illustrated.

Problem sets are presented at the end of each chapter and are used to emphasize the most important concepts introduced, as well as to present further examples of important materials. Illustrations are employed for the purpose of presenting crystal structures and key properties of materials. Tables are used to summarize and contrast the properties of related groups of materials. The units used throughout this textbook are SI units, except in cases where the use of electron volt, cm^{-1} , poise, etc., were felt to be too standard to ignore.

We have created a home page at www.wiley.com that provides a valuable supplement to the textbook by describing additional properties of materials, along with additional examples of current materials and their applications. Chapter W22 on our home page emphasizes the structural and chemical characterization of materials, as well as the characterization of their optical, electrical, and magnetic properties. As new materials and applications are developed, the home page will be regularly updated.

Since this text will likely be used most often in a one-semester course, we recommend that Chapters 1–4 on structure be covered in as much detail as needed, given the backgrounds of the students. A selection of chapters on the properties of materials (5–10) and on the classes of materials (11–18) of particular interest can then be covered. According to the tastes of the instructor and the needs of the students, some of the remaining chapters (surfaces; thin films, interfaces, and multilayers; synthesis and processing of materials) can be covered. For example, a course on engineering materials

could consist of the following: Chapters 1–4 on structure; Chapter 6 on thermally activated processes, etc.; Chapter 10 on mechanical properties; Chapter 12 on metals and alloys; Chapter 13 on ceramics; Chapter 14 on polymers; and Chapter 21 on synthesis and processing.

Physics majors usually take an introductory course in solid-state physics in their senior year. Therefore in such a course it will be necessary to start at “the beginning,” i.e., Chapter 1 on the structure of crystals. Students in MS&E or engineering departments who have already taken an introductory course on materials can quickly review (or skip) much of the basic material and focus on more advanced topics, beginning with Chapter 5 on phonons, if desired, or Chapter 7 on electrons in solids.

We owe a debt of gratitude to our colleagues at The City College and City University who, over the years, have shared with us their enthusiasm for and interest in the broad and fascinating subject of materials. They include R. R. Alfano, J. L. Birman, T. Boyer, F. Cadieu, H. Z. Cummins, H. Falk, A. Genack, M. E. Green, L. L. Isaacs, M. Lax, D. M. Lindsay (deceased), V. Petricevic, F. H. Pollak, S. R. Radel, M. P. Sarachik, D. Schmeltzer, S. Schwarz, J. Steiner, M. Tamargo, M. Tomkiewicz, and N. Tzoar (deceased). Colleagues outside CUNY who have shared their knowledge with us include Z. L. Akkerman, R. Dessau, H. Efstathiadis, B. Gersten, Y. Goldstein, P. Jacoby, L. Ley, K. G. Lynn, D. Rahoi, and Z. Yin. Our thanks also go to our students and postdocs who have challenged us, both in our research and teaching, to refine our thinking about materials and their behavior.

Special thanks are due to Gregory Franklin who served as our editor at John Wiley & Sons for the bulk of the preparation of this textbook. His unflagging support of this effort and his patience are deeply appreciated. Thanks are also due to our current editor, George Telecki, who has helped us with sound advice to bring this project to a successful conclusion. We acknowledge with gratitude the skill of Angiolina Loreda who supervised the production of both the textbook and supplementary Web-based material. We have appreciated the useful comments of all the anonymous reviewers of our textbook and also wish to thank all the authors who granted permission for us to use their artwork.

Finally, we gratefully acknowledge the constant support, encouragement, and patience of our wives, Harriet and Françoise, and our families during the years in which this textbook was prepared. Little did we (or they) know how long it would take to accomplish our goals.

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LIST OF TABLES

1.1	Bravais lattices in three dimensions	10
1.2	Local atomic bonding units	16
1.3	Elements with HCP crystal structure	22
1.4	Periodic table with crystal structures and lattice constants	23
1.5	Elements with FCC crystal structure	24
1.6	Elements with BCC crystal structure	26
1.7	Crystals with CsCl crystal structure	27
1.8	Crystals with NaCl crystal structure	28
1.9	Elements with diamond crystal structure	29
1.10	Crystals with zinblende crystal structure	30
1.11	Periodic table with densities and atomic concentrations	33
2.1	Structures of covalently bonded elements	43
2.2	Classification of solids according to bonding	47
2.3	Radius ratios and crystal structures	50
2.4	Ionic radii	52
2.5	Radius ratios and crystal structures of alkali chlorides	52
2.6	Ionicities of some crystals	54
2.7	Periodic table of cohesive energies	56
2.8	Cohesive energies of some crystals	57
2.9	Periodic table of first and second ionization energies	59
2.10	Periodic table of electron affinities	61
2.11	Periodic table of electronegativities	62
2.12	Periodic table of atomic radii	63
2.13	Van der Waals radii	64
4.1	Crystallite sizes and types of structural order	87
4.2	Properties of vacancies in FCC metals	117
5.1	Molar specific heat	133
5.2	Debye temperatures	138
5.3	Thermal expansion coefficients and Gruneisen constants	143
5.4	Thermal conductivities	144
6.1	Periodic table of melting points and enthalpies of fusion	174
6.2	Test of Lindemann criterion	176
6.3	Melting points and cohesion data for crystals	179
6.4	Characteristics of solid-state structural phase transitions	180
7.1	Atomic numbers, valences, mass densities, electron densities, conductivities, and collision times of metals	189
7.2	Hall coefficients	191
7.3	Free-electron parameters	193
7.4	Percolation thresholds	221

8.1	The electromagnetic spectrum	232
8.2	Plasma energies	235
8.3	Ionic frequencies	241
8.4	Nonlinear optical coefficients at $\lambda = 1.06 \mu\text{m}$	249
8.5	Some third-order susceptibilities	250
8.6	Exciton parameters for several semiconductors	252
9.1	Ground states of $3d$ transition elements	268
9.2	Crystal field stabilization energies and spins for $3d$ ions	272
9.3	Ground states of $4f$ rare earth elements	275
9.4	Magnetic properties of ferro-, antiferro-, and ferrimagnets	288
9.5	1st and 2nd-order magnetocrystalline anisotropy coefficients	296
9.6	Crystals containing magnetic Fe ions	303
9.7	Magnetic susceptibilities for selected materials	308
10.1	Independent elastic constants for different Bravais lattices	319
10.2	Elastic properties of polycrystalline cubic metals	322
10.3	Elastic constants for various single crystals	323
10.4	Relationships between elastic moduli of isotropic solids	325
10.5	Elastic wave velocities in cubic crystals	329
10.6	Mechanical properties of selected materials	338
10.7	Slip planes and directions	346
10.8	Fracture toughness of various materials	350
11.1	Energy gaps and electron concentrations of selected semiconductors	358
11.2	Properties of electrons and holes	371
11.3	Comparison of Bohr theory and dopant impurity model	376
11.4	Dopant activation energies	377
11.5	Properties of electrons in solids of reduced dimensionality	384
11.6	Electron and hole mobilities and conductivities	390
11.7	Properties of group IV semiconductors	406
11.8	Effective masses and mobilities of charge carriers	407
11.9	Properties of group III–V, II–VI, and IV–VI semiconductors	411
11.10	Interfaces between semiconductors and other materials	435
12.1	Properties of sp -bonded metals	448
12.2	Selected properties of the rare earth metals	453
12.3	Chemical composition of superalloys	461
13.1	Properties of ceramic materials: crystal structure, melting temperature, Young's modulus, thermal expansion coefficient, thermal conductivity and Knoop hardness	466
13.2	Madelung constant for binary ionic solids	471
13.3	Melting temperatures of refractory materials	472
13.4	Melting temperatures of glass-forming materials	482
13.5	Composition of some common commercial glasses	487
14.1	Crystal structure parameters for polymers	499
14.2	Mechanical properties of polymers	502
14.3	Thermal properties of polymers	511
14.4	Glass-transition and melting temperatures for polymers	513
15.1	Optical phonon energies and dielectric constants	530
15.2	Dielectric strengths	532
15.3	Polarization properties of ferroelectrics	536

15.4	Barrier heights and conductivities for beta aluminas	546
16.1	Periodic table of superconducting T_c and H_{c0}	557
16.2	Superconducting energy gap ratio $2\varepsilon(0)/k_B T_c$	563
16.3	Predictions of BCS theory in weak-coupling limit	578
16.4	Properties [$\lambda(0\text{ K})$, $\xi(0\text{ K})$, $\kappa(T_c)$] of various superconductors	583
16.5	Families of cuprate superconductors	585
16.6	Upper critical fields for various high-field superconductors	592
17.1	Magnetostrictions of ferromagnets and ferrimagnets	626
17.2	Properties of permanent-magnet materials	632
17.3	Magnetic properties of Fe, Fe alloys, and electrical steels	637
17.4	Magnetic materials with giant magnetostrictions	638
17.5	Magnetic properties of ferrimagnetic garnets	640
18.1	Lattice constants, band gap energies, conduction band masses, light- and heavy-hole band masses, static relative permittivities, high-frequency relative permittivities, thermal conductivities, coefficients of linear thermal expansion, phonon frequencies, and band-offset parameters for III–V semiconductors	656
18.2	Triboelectric series	668
18.3	Electro-optic tensor components	671
19.1	Surface nets and primitive lattice vectors	682
19.2	Work functions and first ionization energies	692
19.3	Coefficients of static friction	712
20.1	Surface tensions	717
20.2	Typical quantum-dot systems	740
21.1	International Technology Road Map for Semiconductors	776
21.2	Important phases of Fe, Fe compounds and alloys, and their multicomponent mixtures	781
21.3	Compositions of typical austenitic stainless steels	786
21.4	Physical properties of fullerene	798