This International Student Edition is for use outside of the U.S.

Foundations of Materials Science and Engineering

WILLIAM SMITH | JAVAD HASHEMI



TABLE OF CONTENTS

	Preface xv		2.3.4 Quannon Monbees, Energy Levels, und Atomic Orbitals 47
CH.	APTER 1		2.3.5 The Energy State of Multielectron
	duction to Materials Science		Atoms 50
	Engineering 2		2.3.6 The Quantum-Mechanical Model on the Periodic Table 52
1.1	Materials and Engineering 3	2.4	Periodic Variations in Atomic
1.2	Materials Science and Engineering 7		Size, Ionization Energy, and Electron
1.3	Types of Materials 9		Affinity 55
	1.3.1 Metallic Muterials 9		2.4.1 Trends in Atomie Size 55
	1.3.2 Polymeric Materials 11		2.4.2 Trands in Ionization Energy 56
	1.3.3 Ceramic Materials 14		2.4.3 Trends in Electron Affinity 58
	1.3.4 Composite Materials 16		2.4.4 Meiats, Meiatloids, and Monmeiats 60
	1.3.5 Electronic Materials 18	2.5	Primary Bonds 60
1.4	Competition Among Materials 19		2.5.1 Joine Bonds 52
1.5	Recent Advances in Materials Science		2.5.2 Covalent Bonas 68
	and Technology and Future Trends 21		2.5.3 Metallie Bonds 75
	1.5.1 Smart Materials 21		25.4 Mixed Bonding 77
	1.5.2 Nanomaterials 23	2.6	Secondary Bonds 79
1.6	Design and Selection 24	2.7	Summary 82
1.7	Summary 26	2.8	Definitions 82
1.8	Definitions 25	2.9	Problems 84
1.9	Problems 27		
		$C \dashv A$	PTER 3
CH/	APTER 2	Cryst	al and Amorphous Structure
Aton	nic Structure and Bonding 30		terials 92
2.1	Atomic Structure and Subatomic	3.1	The Space Lattice and Unit Cells 93
	Particles 31	3.2	Crystal Systems and Braveis Lattices 94
2.2	Atomic Numbers, Mass Numbers,	3.3	Principal Metallic Crystal Structures 95
	and Atomic Masses 35		3.3.1 Body-Centered Cubic (BCC) Crystal
	2.2.1 Atomic Numbers and Mass Numbers 35		Structure 97
2.3	The Electronic Structure of Atoms 39		3.3.2 Face-Centered Cubic (FCC) Crystal
	2.3.1 Planck's Quantum Theory and		Structure 100
	Electromagnetic Radiation 39		3.3.3 Hexagonal Close-Packed (HCF) Crystal Structure 101
	2.3.2 Bohr's Theory of the Hydrogen Stom 40	3.4	
	2.3.3 The Uncertainty Principle and	3.5	조기 집에 가는 사람이 하다면서 살이 되었다면서 하다 모양이 하는데 하지만 하지만 하지만 하지만 하지만 하지만 하다.
133	Schrödinger's Wave Functions 44	.3.5	Directions in Cubic Unit Cells 105

			- 74
3.6	Miller Indices for Crystallographic Planes	4.4	Crystalline Imperfections 165
	in Cubic Unit Cells 109		4.4.1 Point Defects 16.5
3.7	Crystallographic Planes and Directions in		4.4.2 Line Defects (Dislocations) 166
	Hexagonal Crystal Structure 114		4.4.3 Planar Defects 170
	3.7.1 Indices for Crystal Planes in HCP Unit		4.4.4 Volume Defects 172
	Cetls 114	4.5	Experimental Techniques for Identification
* **	3.7.2 Direction Indices in HCP Unit Cells 115		of Microstructure and Defects 173
3.8	Comparison of FCC, HCP, and BCC Crystal Structures 116		4.5.1 Opnical Metallography, ASTM Grain Size, and Grain Diameter
	3.8.1 FCC and HCP Crystal Structures 116		Determination 173
	3.8.2 BCC Crystal Structure 119		4.5.2 Scanning Electron Microscopy
3.9	Volume, Planar, and Linear Density		(SEM) 178
	Unit-Cell Calculations 119 3.9.1 Volume Density 119		4.5.3 Transmission Electron Microscopy (TEM) 179
	3.9.2 Planar Atonic Density 120		4.5.4 High-Resolution Transmission Electron
	3.9.3 Linear Asomic Density and Repeat		Microscopy (HRTEM) 180
2.10	Distance 122		4.5.5 Scanning Probe Microscopes and Atomic Resolution 182
3,10	Folymorphism or Allocopy 123	4.6	Summary 186
3.11	Crystal Structure Analysis 124	4.7	Definitions 187
	3.11.1 X-Ray Sources 123	4.8	Problems 188
	3.11.2 X-Ray Diffraction /26		
	3.11.3 X Roy Differentian Analysis of Crystal Structures 128	CHZ	APTER 5
3.12	Amorphous Materials 134		mally Activated Processes and
3.13	Summary 135	Diffu	ision in Solids 198
3.14	Definitions 136	5.1	Rate Processes in Solids 197
3.15	Problems 137	5.2	Atomic Diffusion in Solids 201
			5.2.1 Diffusion in Solids in General 201
	PTER 4		5.2.2 Diffusion Mechanisms 201
	ification and Crystalline		5.2.3 Siegdy-State Diffusion 203
Impe	rfections 146		5.2.4 Non-Steady-State Diffusion 206
4.1	Solidification of Metals 147	5.3	Industrial Applications of Diffusion
	4.1.1 The Formation of Stable Nuclei in Liquid		Processes 208
	Metals 149 4.1.2 Geowth of Crystals in Liquid Metal and		5.3.1 Case Hardening of Steel by Gas Carburizing 208
	Formation of a Grain Structure 154 4.1.3 Grain Structure of Industrial		5.3.2 Impurity Diffusion into Silicon Wafers for Integrated Circuits 212
	Castings 155	5.4	Effect of Temperature on Diffusion
4.2	Solidification of Single Crystals 156	33777	in Solids 215
4.3	Metallic Solid Solutions 160	5.5	Summary 218
	4.3.1 Substitutional Solid Solutions 161	5.6	Definitions 219
	4,3.2 Interstitual Solid Solutions 163	5.7	Problems 219

Arrangements 267

CHAPTER 6		6.6.3 Effect of Cold Plastic Deformation of		
Mechanical Properties			Increasing the Strength of Metals 270	
of Me	tals 224	6.7	Solid-Solution Strengthening of Metals 271	
6.1	The Processing of Metals and Alloys 225 6.1.1 The Casting of Metals and Alloys 225 6.1.2 Hot and Cold Roiling of Metals and Alloys 227	6.8	Recovery and Recrystallization of Plastically Deformed Metals 272 6.8.1 Structure of a Heavily Cold-Worked Metal before Reheating 273	
	6.1.3 Extrusion of Metals and Alloys 231		6.8.2 Recovery 273	
	6.1.4 Forging 232		6.8.3 Recrystallization 275	
	6.1.5 Other Metal-Forming Processes 234	6.9	Superplasticity in Metals 279	
6.2	Stress and Strain in Metals 235	6.10	Nanocrystalline Metals 281	
	6.2.1 Elastic and Plastic Deformation 236	6.11	Summary 282	
	6.2.2 Engineering Stress and Engineering	6.12	Definitions 283 •	
	Strain 236	6.13	Problems 285	
	6.2.3 Poisson's Ratio 239	0.15	Problems 200	
	6.2.4 Shear Stress and Shear Strain 240	CHA	PTER 7	
6.3	The Tensile Test and The Engineering	Mechanical Properties		
	Stress-Strain Diagram 241		tals II 294	
	6.3.1 Mechanical Property Data Obtained from the Tensile Test and the Engineering Stress-Strain Diagram 243	7.1	Fracture of Metals 295 7.1.1 Ductile Fracture 296	
	6.3.2 Comparison of Engineering Stress-Strain Curves for Selected Alloys 249		7.1.2 Brinle Fracture 297	
	6.3.3 True Stress and True Strain 249		7.1.3 Toughness and Impact Testing 300	
6.4	Hardness and Hardness Testing 251		7.1.4 Ductile-to-Brittle Transition	
6.5	Plastic Deformation of Metal Single		Temperature 302	
	Crystals 253	~ ~	7.1.5 Fracture Toughness 303	
	6.5.1 Slipbands and Slip Lines on the Surjace of	7.2	Fatigue of Metals 305	
	Metal Crystals 253		7.2.1 Cyclic Stresses 309	
	6.5.2 Plastic Deformation in Metal Crystals by the Slip Mechanism 256		7.2.2 Basic Structural Changes that Occur in a Ductile Metal in the Fatigue Process 310	
	6.5.3 Slip Systems 256 6.5.4 Critical Resolved Shear Stress for Metal		7.2.3 Some Major Factors that Affect the	
	Single Crystals 261		Fatigue Strength of a Metal 311	
	6.5.5 Schmid's Law 261	7.3	Fatigue Crack Propagation Rate 312	
	6.5.6 Twinning 264		7.3.1 Correlation of Fatigue Crack	
6.6	Plastic Deformation of Polycrystalline Metals 265		Propagation with Stress and Crack Length 312	
	6.6.1 Effect of Grain Boundaries on the Strength of Metals 265		7.3.2 Fatigue Crack Growth Rate versus Stress-Intensity Factor Range Plots 314	
	6.6.2 Effect of Plastic Deformation on		7.3.3 Fatigue Life Calculations 316	
	Grain Shape and Dislocation	7.4	Creep and Stress Rupture of Metals 318	

7.4.1 Creep of Metals 318

	7.4.2 The Creep Test 320	CHA	APTER 9
	7.4.3 Creep-Rupture Test 321	Engi	neering Alloys 388
7.5	Graphical Representation of Creep- and		P. 1 17 1 20 1 200
	Stress-Rupture Time-Temperature Data	9.1	Production of Iron and Steel 389
7.6	Using the Lamen-Miller Parameter 322 A Case Study In Failure of Metallic		9.1.1 Production of Pig Iron in a Blast Furnace 390
7.7	Components 324 Recent Advances and Future Directions in		9.1.2 Steelmaking and Processing of Major Steel Product Forms 391
	Improving The Mechanical Performance of	9.2	The Iron-Carbon System 393
	Metals 327 7.7.1 Improving Ductility and Strength		9.2.1 The Iron-Iron-Carbide Phase Diagram 393
	Simultaneously 327 7.7.2 Fatigue Behavior in Nanocrystalline		9.2.2 Solid Phases in the Fe-Fe ₃ C Phase Diagram 393
70	Misals 329		9.2.3 Invariant Reactions in the Fe-Fe ₃ C Phase Diodram 394
7.8	Summary 329		9.2.4 Slow Cooling of Plain Carbon Steels 396
7.10	Definitions 330 Problems 331	9.3	Heat Treatment of Plain-Carbon Steels 403
	10-15w - 100		9.3.1 Martensite 403
CHA	PTER 8		9.3.2 Inothermal Decomposition of
Phase	e Diagrams 336		Austenite 408
8,1	Phase Diagrams of Pure Substances 337		9.3.3 Continuous-Cooling Transformation Diagram for a Eutecold Plain-Carbon
8.2	Gibbs Phase Rule 339		Steel 413
8.3	Cooling Curves 340 Binary Isomorphous Alloy Systems 342		9.3.4 Annealing and Normalizing of Plain- Carbon Steels. 415
8.5	The Lever Rule 344		9.3.5 Tempering of Plain-Curbon Sucels 417
8.6	Nonequilibrium Solidification of Alloys 348		9.3.6 Classification of Plain-Corbon Steels and Typical Mechanical Properties 421
8.7	Binary Eutectic Alloy Systems 351	9.4	Low-Alloy Steels 423
8.8	Binary Peritectic Alloy Systems 359		9.4.1 Classification of Alloy Steels 423
8.9	Binary Monotectic Systems 364		9.4.2 Distribution of Alloying Elements in Alloy Steels 423
8.10	Invariant Reactions 365		9.4.3 Effects of Alleying Elements on the
8.11	Phase Diagrams with Intermediate Phases		Entectoid Temperature of Steels 424
0.30	and Compounds 367		9.4.4 Hordenabilay 426
8.12	Ternary Phase Diagrams 371		9.4.5 Typical Mechanical Properties and
8.13	Summary 374	0.2	Applications for Lov-Alloy Steels 430
8.14	Definitions 375	9.5	Aluminum Alloys 432 9.5.1 Procipitation Strengthening
8.15	Problems 377		(Hardening) 432

	9.5.2 General Properties of Aluminum and I Production 438	t.s		10.2.2 Covalent Bonding Structure of an Activated Ethylene Molecule 492
	9.5.3 Wrought Aluminum Alloys 440			10.2.3 General Reaction for the Polymerization
	9.5.4 Aluminum Casting Alloys 444			of Polyethylene and the Degree of
9.6	Copper Alloys 446	7.51		Polymerization 493
	9.6.1 General Properties of Copper 446			10.2.4 Chain Polymerization Steps 493
	9.6.2 Production of Copper 446			10.2.5 Average Molecular Weight for Thermoplastics 495
	9.6.3 Classification of Copper Alloys 446			10.2.6 Functionality of a Monomer 496
9.7	9,6.4 Wrought Copper Alloys 447 Stainless Steels 452			10.2.7 Structure of Noncrystalline Linear
×***	9.7.1 Ferritic Stainless Steels 452			Polymers 496
	9.7.2 Martensitic Stainless Steels 453			10.2.8 Vinyl and Vinylidene Polymers 498
	9.7.3 Austenitic Stainless Steels 455			10.2.9 Homopolymers and Copolymers 499
9.8	Cast Irons 457			10.2.10 Other Methods of Polymerization 502
2.0	9.8.1 General Properties 457		10.3	Industrial Polymerization Methods 504
	9.8.2 Types of Cast Irons 457		10.4	Glass Transition Temperature and
	9.8.3 White Cast Iron 459			Crystallinity in Thermoplastics 506
	9.8.4 Gray Cast Iron 459			10.4.1 Glass Transition Temperature 506
	9.8.5 Ductile Cast Irons 460			10.4.2 Solidification of Noncrystalline
	9.8.6 Malleable Cast Irons 462			Thermoplastics 506
9.9	Magnesium, Titanium, and Nickel			10.4.3 Solidification of Partly Crystalline Thermoplastics 507
	Alloys 464 9.9.1 Magnesium Alloys 464			10.4.4 Structure of Partly Crystalline
	9.9.2 Titanium Alloys 466			Thermoplastic Materials 508
	9.9.3 Nickel Alioys 468			10.4.5 Stereoisomerism in Thermoplastics 510
9.10	Special-Purpose Alloys and Applications	468	10.5	10.4.6 Ziegler and Natta Catalysts 510
2.10	9.10.1 Intermetallics 468	100	10.5	Processing of Plastic Materials 512
	9.10.2 Shape-Memory Alloys 470			10.5.1 Processes Used for Thermoplastic Materials 512
	9.10.3 Amorphous Metals 474			10.5.2 Processes Used for Thermosetting Materials 516
9.11	Summary 475		10.4	
9.12	Definitions 476		10.6	General-Purpose Thermoplastics 518
9.13	Problems 478			10.6.1 Polyethylene 520
				10.6.2 Polyvinyl Chloride and Copolymers 523
	PTER 10			10.6.3 Polypropylene 525
Poly	meric Materials 488			10.6.4 Polystyrene 525
10.1	Introduction 489			10.6.5 Polyacrylonitrile 526
	10.1.1 Thermoplastics 490			10.6.6 Styrene-Acrylonitrile (SAN) 527
	10.1.2 Thermosetting Plastics (Thermosets)	490		10.6.7 ABS 527
10,2	Polymerization Reactions 491			10.6.8 Polymethyl Methacrylate (PMMA) 529
	10.2.1 Covalent Bonding Structure of an			10.60 Elizarantarias 530

10.7	Engineering Thermoplastics 531		CHAPTER 11		
	10.7.1 Palvanides (Nylons) 532	Cera	mics 584		
	10.7.2 Polycarbonaie 535		(Fall) (Sc. 50 - 18828)		
	10.7.3 Phenylene Oxide Based Resins 536	11.1	Introduction 585		
	10.7.4 Acetals 537	11.2	Simple Ceramic Crystal Structures 587		
	10.7.5 Thermoplessic Polyesters 338 10.7.6 Polyphenytene Sulfide 539		11.2.1 Ionic and Covalent Bonding in Simple Ceramic Compounds 587		
	10.7.7 Polyetherimide 540		11.2.2 Simple Ionic Arrangements Found to Ionically Bonded Solids - 588		
	10.7.8 Polymer Alloys 546		11.2.3 Cesture Chloride (CtCl) Crystal		
10.8	Thermosetting Plastics (Thermosets) 541		Structure 591		
	10.8.1 Phenolics 543		11.2.4 Sodium Caloride (NaCl) Crystal		
	10.8.2 Epoxy Resins 544		Structure 592		
	19.8.3 Unsaturated Polyesters 546		11.2.5 Interstitiol Sites in FCC and HCP Crystal		
	10.8.4 Amino Resine (Ureas and		Lamces= 596		
	Melamines) 547		11.2.6 Zinc Blemie (ZuS) Crystal Structure 598		
10.9	Elastomers (Rubbers) 549		11.2.7 Calcium Fluoride (CaF ₂) Crystal		
	10.9.1 Natural Rubber 549		Structure 600		
	10.9.2 Synthetic Rubbers 553		11.2.8 Antifluorlie Crystal Structure 602		
	10.9.3 Properties of Polychloroprene		11.2.9 Corundian (Al ₂ O ₃) Crystal Structure 602		
	Elastomers 554		11.2.10 Spinel (MgAl ₂ O ₃) Crystal Structure 602		
	10.9.4 Videanization of Polychloroprene Elastomers 555		11.2.11 Perovskite (CaFO ₂) Crystal Structure 603		
10.10	Deformation and Strengthening of Plastic		11.2.12 Carbon and Its Allotropes 603		
	Materials 557	11.3	Silicate Structures 607		
	10.10.1 Deformation Mechanisms for Thermoplastics 557		11.3.1 Basic Structural Unit of the Silicate Structures 607		
	10.10.2 Strengthening of Thermoplastics 559		11.3.2 Island, Chain, and Ring Structures of		
	10.10.3 Strengthening of Thermosetting		Silicates 607		
	Plastics 562		11.3.3 Sheet Structures of Silicates 607		
	10.10.4 Fifect of Temperature on the Strength of		11.3.4 Silicate Networks: 608		
	Plattic Materials 563	11.4	Processing of Ceramics 610		
10.11	Creep and Fracture of Polymeric		11.4.1 Materials Preparation 611		
	Materials 564		11.4.2 Forming 611		
	10.11.1 Cresp of Polymeric Meterials 564		11.4.3 Thermal Treatments 615		
	10.11.2 Siress Relaxation of Polymeric Maserials 56%	11.5	Traditional and Structural Ceramics 618		
			11.5.1 Traditional Ceramics 618		
10:11	10.11.3 Fracture of Polymeric Materials 567		11.5.2 Steuerwood Ceromics 620		
10.12	Summary 570	11.6	Mechanical Properties of Ceramics 622		
10.13	Definitions 571	146.600	11.6.1 General 622		
10.14	Problems 574		11.6.2 Mechanisms for the Deformation of Ceramic Materials 622		

	11.6.3 Factors Affecting the Strength of Ceramic Materials 624		12.2.2 Carbon Fibers for Reinforced Plastics 662
	11.6.4 Toughness of Ceramic Materials 624 11.6.5 Transformation Toughening of Partially*		12.2.3 Aramid Fibers for Reinforcing Plastic Resins 664
	Stabilized Zirconia (PSZ) 626 11.6.6 Fatigue Failure of Ceramics 628 11.6.7 Ceramic Abrasive Materials 628		12.2.4 Comparison of Mechanical Properties of Carbon, Aramid, and Glass Fibers for Reinforced-Plastic Composite Materials 664
11.7	Thermal Properties of Ceramics 529	12.3	Matrix Materials for Composites 666
	11.7.1 Ceramic Refractory Materials 629 11.7.2 Acidic Refractories 630 11.7.3 Basic Refractories 631	12.4	Fiber-Reinforced Plastic Composite Materials 667
	11.7.3 Basic Regractories 6.51 11.7.4 Ceramic Tile Insulation for the Space		12.4.1 Fiberglass-Reinforced Plastics 667
11.8	Shuttle Orbiter 631 Glasses 633		12.4.2 Carbon Fiber-Reinforced Epoxy Resins 668
11.0	11.8.1 Definition of a Glass 633 11.8.2 Glass Transition Temperature 633	12.5	Equations for Elastic Modulus of Composite Laminates; Isostrain and Isostress Conditions 570
	11.8.3 Structure of Glasses 632 11.8.4 Compositions of Glasses 636		12.5.1 Isostrain Conditions 670
	11.8.5 Viscous Deformation of Glasses 636		12.5.2 Isostress Conditions 673
	11.8.6 Forming Methods for Glasses 640 11.8.7 Tempered Glass 641	12.6	Open-Mold Processes for Fiber-Reinforced Plastic Composite Materials 675
	11.8.8 Chemically Strengthened Glass 642		12.6.1 Hand Lay-Up Process 675
11.9	Ceramic Coatings and Surface		12.6.2 Spray Lay-Up Process 676
	Engineering 643		12.6.3 Vacuum Bag-Autoclave Process 677
	11.9.1 Silicate Glasses 643		12.6.4 Filament-Winding Process 678
11.10	11.9.2 Oxides and Carbides 643 Nanotechnology and Ceramics 644	12.7	Closed-Mold Processes for Fiber-Reinforced Plastic Composite Materials 678
11.11	Summary 646		12.7.1 Compression and Injection
11.12	Definitions 647		Molding 678
11.13	Problems 648		12.7.2 The Sheet-Molding Compound (SMC) Process 679
CHA	PTER 12		12.7.3 Continuous-Pultrusion Process 680
	osite Materials 656	12.8	Concrete 680 12.8.1 Portland Cement 681
12.1	Introduction 657		12.8.2 Mixing Water for Concrete 684
E.Mer.	12.1.1 Classification of Composite Materials 657		12.8.3 Aggregates for Concrete 685
	12.1.2 Advantages and Disadvantages of		12.8.4 Air Entrainment 685
	Composite Materials over Conventional Materials 658		12.8.5 Compressive Strength of Concrete 686
12.2	Fibers for Reinforced-Plastic Composite Materials 659		12.8.6 Proportioning of Concrete Mixtures 686 12.8.7 Reinforced and Prestressed Concrete 68.
	12.2.1 Glass Fibers for Reinforcing Plastic	12.9	12.8.8 Prestressed Concrete 688 Asphalt and Asphalt Mixes 690
	Resins 659	Lace	exspirate and exspirate Mixes 620

12.10	Wood 692	13.4	Corrosion Rates (Kinetics) 738
	12.10.1 Macrostructure of Wood 692		13.4.1 Rate of Uniform Corrosion or
	12.10.2 Microstructure of Softwoods 695 .		Electroplating of a Metal in an Aqueous
	12.10.3 Microstructure of Hardwoods 696		Solution 738
	12.10.4 Celt-Wail Ultrastructure 697		13.4.2 Corrosion Reactions and
	12.10.5 Properties of Wood 699		Polarization 741
12.11	Sandwich Structures 700		13.4.3 Passivation 745
	12.11.1 Honeycomb Sandwich Structure 702		13.4.4 The Galvenic Series 745
	12.11.2 Cladded Metal Structures 707	13.5	Types of Corrosion 746
12.12	Metal-Matrix and Ceramic-Matrix		13.5.1 Uniform or General Attack Corrosion 746
	Composites 703		13.5.2 Galvanic or Two-Metal Corrosion 748
	12.12.1 Metal-Mutrix Composites		13.5.3 Pitting Corrosion 749
	(MMCs) 703		13.5.4 Crevice Corrosion 751
	12.12.2 Ceramic-Matrix Composites (CMCs) 705		13.5.5 Intergranular Corrosion 753
	12.12.3 Ceramic Composites and		13.5.6 Stress Corrosion 755
	Nanotechnology 710		13.5.7 Evosion Corrosion 758
12.13	Summary 710		13.5.8 Cavitation Damage 759
12.14	Definitions 711		13.5.9 Fretting Corrosion 759
12.15	Problems 714		13.5.10 Selective Leaching 759
	7.11		13.5.11 Hydrogen Damage 760
CHAPTER 13		13.6	Oxidation of Metals 761
Corrosion 720			13.6.1 Protective Oxide Films 761
Corro	sion /20		13.6.2 Mechanisms of Oxidation 763
13.1	Corrosion and Its Economical Impact 721		13.6.3 Oxidation Rates (Kinetics) 764
13.2	Electrochemical Corrosion of Metals 722	13.7	Corrosion Control 766
	13.2.1 Oxidation-Reduction Reactions 723		13.7.1 Materials Selection 766
	13.2.2 Standard Electrode Half-Cell Potentials		13.7.2 Coatings 767
	for Metals 724		13.7.3 Design 768
13.3	Galvanic Cells 726		13.7.4 Alteration of Environment 769
	13.3.1 Macroscopic Galvanic Cells with		13.7.5 Cathodic and Anodic Protection 770
	Electrolytes That Are One Molar 726	13.8	Summary 771
	13.3.2 Galvanic Cells with Electrolytes That Are	13.9	Definitions 772
	Not One Molar 728		Problems 773
	13.3.3 Galvanic Cells with Acid or Alkuline Electrolytes with No Metal Ions		
	Present 730		PTER 14
	13.3.4 Microscopic Galvanic Cell Corrosion of Single Electrodes 731		rical Properties of Materials 780
	13.3.5 Concentration Galvanic Cells 733	14.1	Electrical Conduction In Metals 781
	13.3.6 Galvanic Cells Created by Differences in Composition, Structure, and Stress 736		14.1.1 The Classic Model for Electrical Conduction in Metals 781

	14.1.2 Ohm's Law 783	14.6	Microelectronics 818
	14.1.3 Drift Velocity of Electrons in a Conducting Metal 787	1.40	14.6.1 Microelectronic Planar Bipolar Transistors 818
14.2	14.1.4 Electrical Resistivity of Metals 788	•	14.6.2 Microelectronic Planar Field-Effect Transistors 819
14.2	Energy-Band Model for Electrical Conduction 792		14.6.3 Fabrication of Microelectronic
	14.2.1 Energy-Band Model for Metals 792	14.7	Integrated Circuits 822
795-262	14.2.2 Energy-Band Model for Insulators 794		Compound Semiconductors 829
14.3	Intrinsic Semiconductors 794	14.8	Electrical Properties of Ceramics 832
	14.3.1 The Mechanism of Electrical Conduction in Intrinsic Semiconductors 794		14.8.1 Basic Properties of Dielectrics 832 14.8.2 Ceramic Insulator Materials 834
	14.3.2 Electrical Charge Transport in the Crystal Lattice of Pure Silicon 795		14.8.3 Ceramic Materials for Capacitors 835 14.8.4 Ceramic Semiconductors 836
	14.3.3 Energy-Band Diagram for Intrinsic Elemental Semiconductors 796	110	14.8.5 Ferroelectric Ceramics 838
	14.3.4 Quantitative Relationships for Electrical	14.9	Nanoelectronics *841
	Conduction in Elemental Intrinsic	14.10	Summary 842
	Semiconductors 797	14.11	Definitions 843
	14.3.5 Effect of Temperature on Intrinsic Semiconductivity 799	14.12	Problems 845
14.4	Extrinsic Semiconductors 801	CHA	PTER 15
	14.4.1 n-Type (Negative-Type) Extrinsic Semiconductors 801	Optic	ral Properties and Superconductive
	14.4.2 p-Type (Positive-Type) Extrinsic	Wate	nais abo
	Semiconductors 803	15.1	Introduction 851
	14.4.3 Doping of Extrinsic Silicon	15.2	Light and the Electromagnetic Spectrum 85
	Semiconductor Material 805	15.3	Refraction of Light 853
	14.4.4 Effect of Doping on Carrier		15.3.1 index of Refraction 853
	Concentrations in Extrinsic		15.3.2 Snell's Law of Light Refraction 855
	Semiconductors 805 14.4.5 Effect of Total Ionized Impurity Concentration on the Mobility of	15.4	Absorption, Transmission, and Reflection o Light 856
	Charge Carriers in Silicon at Room		15.4.1 Metals 856
	Temperature 808		15.4.2 Silicote Glasses 857
	14.4.6 Effect of Temperature on the		15.4.3 Plastics 858
	Electrical Conductivity of Extrinsic		15.4.4 Semiconductors 860
	Semiconductors 809	15.5	Luminescence 861
14.5	Semiconductor Devices 811	1000	15.5.1 Photolyminescence 862
	14.5.1 The pn Junction 812		15.5.2 Cathodoluminescence 862
	14.5.2 Some Applications for pr. Junction	15.6	Stimulated Emission of Radiation and
	Diodes 815	15.0	Lasers 864
	14.5.3 The Bipolar Junction Transistor 816		15.6.1 Types of Lasers 866
			10.0.1 Types of Lasers 600

15.7	Optical Fibers 868	16.6	Types of Energies that Determine the	
	15.7.1 Light Loss in Optical Fibers 868		Structure of Ferromagnetic Domains 899	
	15.7.2 Single-Mode and Multimode Optical	•	16.6.1 Exchange Energy 900	
	Fibers 869		16.6.2 Magnetostatic Energy 990	
	15.7.3 Fabrication of Optical Fibers 870		16.6.3 Magnetocrystalline Anisotropy	
	15.7.4 Modern Optical-Fiber Communication		Energy 901	
100	Systems 872		16.6.4 Domain Wall Energy 962	
15.8	Superconducting Materials 873	-1,000	16.6.5 Magnetostrictive Energy 903	
	15.8.1 The Superconducting State 873 15.8.2 Magnetic Properties of	16.7	The Magnetization and Demagnetization of a Ferromagnetic Metal 905	
	Superconductors 874	16.8	Soft Magnetic Materials 906	
	15.8.3 Current Flow and Magnetic Fleids in Superconductors 876		16.8.1 Desirable Properties for Soft Magnetic Materials 906	
	15.8.4 High-Current, High-Field Superconductors 877		16.8.2 Energy Losses for Soft Magnetic Materials 906	
	15.8.5 High Critical Temperature (T_c)		16.8.3 Iron-Silicon Alloys 907	
orana .	Superconducting Oxides 879		16.8.4 Metailic Glasses 969	
15.9	Definitions 881		16.8.5 Nickel-Iron Alloys 911	
15.10	Problems 882	16.9	Hard Magnetic Materials 912	
СНА	PTER 16		16.9.1 Properties of Hard Magnetic Materials 912	
	etic Properties 886		16.9.2 Alnico Alloys 915	
1500			16.9.3 Rate Earth Alloys 917	
16.1 16.2	Introduction 887 Magnetic Fields and Quantities 887		16.9.4 Neodymium Iron—Boron Magnetic Alloys 917	
	16.2.1 Magnetic Fields 887 16.2.2 Magnetic Induction 889		16.9.5 Iron-Chromiam-Cobalt Magnetic Alloys 918	
	16.2.3 Magnetic Permeability 890	16.10	Ferrites 921	
	16.2.4 Magnetic Susceptibility 891		16.10.1 Magnetically Soft Ferrites 921	
16,3	Types of Magnetism # 892		16.10.2 Magnetically Hard Ferrites 925	
	16.3.1 Diamagnetism 892	16.11	Summary 925	
	16.3.2 Paramagnetism 892	16.12	Definitions 926	
	16.3.3 Ferromagnetism 893	16.13	Problems 929	
	16.3.4 Magnetic Moment of a Single Unpaired Atomic Electron 895	CUA	DTED 47	
	16.3.5 Antiferromagnetism 897		CHAPTER 17	
	16.3.6 Ferrimagnetism 897		gical Materials and Biomaterials 934	
16.4	Effect of Temperature on	17.1	Introduction 935	
	Ferromagnetism 897	17.2	Biological Materials: Bone 936	
16.5	Ferromagnetic Domains 898		17.2.1 Composition 936	

17.7.4 Nanocrystalline Ceramics 967

	17.2.2 Macrostructure 936	17.8	Composites in Biomedical *		
	17.2.3 Mechanical Properties 936		Applications 968		
	17.2.4 Biomechanics of Bone Fructure 939		17.8.1 Orthopedic Applications 968		
	17.2.5 Viscoelasticity of Bone 939		17.8.2 Applications in Dentistry 969		
	17.2.6 Bone Remodeling 940	17.9	Corrosion in Biomaterials 970		
	17.2.7 A Composite Model of Bone 940	17.10	Wear in Biomedical Implants 971		
17.3	Biological Materials: Tendons and	17.11	Tissue Engineering 975		
	Ligaments 942	17.12	Summary 976		
	17.3.1 Macrostructure and Composition 942	17.13	Definitions 977		
	17.3.2 Microstructure 942	17.14	Problems 978		
	17.3.3 Mechanical Properties 943				
	17.3.4 Structure-Property Relationship 945 17.3.5 Constitutive Modeling and	APPE	ENDIX I		
	Viscoelasticity 946	Important Properties of Selected			
	17.3.6 Ligament and Tendon Injury 948	Engin	eering Materials 983		
17.4	Biological Material: Articular Cartilage 950	APPE	NCIX II		
	17.4.1 Composition and Macrostructure 950		Properties of		
	17.4.2 Microstructure 950	Selected Elements 1040			
	17.4.3 Mechanical Properties 951				
	17.4.4 Cavillage Degeneration 952		ENDIX III		
17.5	Biomaterials: Metals in Biomedical	Ionic Radii of the Elements 1042			
	Applications 952	APPE	NDIX IV		
	17.5.1 Stainless Steels 954	Glass	Transition Temperature		
	17.5.2 Cobalt-Based Alloys 954	and Melting Temperature of			
	17.5.3 Titanium Alloys 955	Selected Polymers 1044			
	17.5.4 Some Issues in Orthopedic Application of Metals 957				
17.6	Polymers in Biomedical Applications 959		NDIX V		
17.00	17.6.1 Cardiovascular Applications of Polymers 959		ed Physical Quantities neir Units 1045		
	17.6.2 Ophthalmic Applications 960	Refere	ences for Further Study by		
	17.6.3 Drug Delivery Systems 962		er 1047		
	17.6.4 Suture Materials 962	Class	ary 1050		
	17.6.5 Orthopedic Applications 962	Glossa	ily 1030		
17.7		Answers 1062			
2000	Ceramics in Biomedical Applications 963 17.7.1 Alumina in Orthopedic Implants 964		Index 1067		
	17.7.2 Alumina in Ormopeate implants 904 17.7.2 Alumina in Dental implants 965	HINGA	1007		
	17.7.3 Ceramic Implants and Tissue Connectivity 966				