

Table of Contents

Chapter 1	Introduction	1
	Metallic Elements	1
	Price and Abundance	5
	Miscellany	7
	Problems	9
Chapter 2	Freezing	11
	Introduction	11
	Liquid Metals	11
	Nucleation	13
	Growth	20
	Ingot Structure	21
	Segregation during Freezing	23
	Zone Refining	26
	Steady State	30
	Dendritic Growth	30
	Length and Spacing of Dendrite Arms	33
	Consequences of Dendritic Growth	35
	Gas Solubility and Gas Porosity	36
	Growth of Single Crystals	38
	Eutectic Solidification	38
	Peritectic Freezing	40

Metal Glasses.....	40
Miscellany.....	43
References.....	44
Problems.....	44
Chapter 3 Diffusion.....	49
Solutions of Fick's 2nd law.....	51
Mechanisms of Diffusion.....	55
Kirkendall Effect.....	57
Special Diffusion Paths.....	59
Darken's Equation.....	61
Diffusion in Systems with More than One Phase.....	61
Miscellany.....	67
References.....	67
Problems.....	67
Chapter 4 Surface Tension and Surface Energy.....	71
Direct Measurements of Surface Energy.....	71
Measurements of Relative Surface Energies.....	74
Wetting Angles.....	75
Relation of Surface Energy to Bonding.....	76
Anisotropy of Surface Energy.....	78
Segregation to Surfaces.....	81
Appendix.....	82
Data on Various Systems.....	82
Note.....	84
Miscellany.....	84
References.....	85
Problems.....	85
Chapter 5 Solid Solutions.....	87
Types of Solid Solutions.....	87
Electron-to-Atom Ratio.....	88
Entropy of Mixing.....	90
Enthalpy of Mixing.....	91
Free Energy Change on Mixing.....	92
Solubility in Dilute Solutions.....	93
Equilibrium Vacancy and Interstitial Concentrations.....	94
Ordered vs. Random Solid Solutions.....	95
Miscellany.....	96

References	98
Problems	98
Chapter 6 Intermediate Phases	101
Hume-Rothery or Electron Phases	101
Covalent Compounds	103
Ionic Compounds	103
Interstitial Compounds	104
Laves Compounds	104
Miscellany	106
References	107
Problems	107
Chapter 7 Phase Diagrams.....	109
Review of Binary Phase Diagrams	109
Invariant Reactions.....	110
Lever Law	111
The Gibb's Phase Rule.....	111
Equalities	112
Variables.....	113
Degrees of Freedom.....	114
Ternary Phase Diagrams.....	116
Two-Phase Regions.....	117
Three-Phase Regions.....	118
Vertical Sections	119
Miscellany	121
Reference.....	122
Problems	122
Chapter 8 Dislocation Geometry and Energy	125
The Nature of Dislocations	125
Energy of a Screw Dislocation	128
Burgers Vector Notation	131
Reactions between Parallel Dislocations and Frank's Rule	132
Stress Fields around Dislocations	133
Forces on Dislocations	136
Partial Dislocations in fcc Crystals	138
Stacking Faults	140
Cross Slip.....	144

Miscellany	146
Postulation of Dislocations	146
Discovery of the Strength of Whiskers	146
References	147
Problems	148
Chapter 9 Annealing	151
General	151
Recovery	152
Recrystallization	153
Avrami Kinetics	161
Analysis of Grain Shape	164
Grain Growth	165
Limiting Grain Size	169
Summary of Grain Growth	174
Summary for the Chapter	174
Miscellany	175
References	175
Problems	175
Chapter 10 Phase Transformations	179
Classification of Solid-State Phase Changes	179
Martensitic Transformations	180
Spinodal Decomposition	184
Nucleation	186
Growth	188
Overall Kinetics	189
Precipitation from Supersaturated Solid Solution	190
Precipitation Kinetics	190
Hardening Mechanism	194
Ostwald Ripening	195
Practical Age-Hardening Treatments	196
Additional Comments	200
Aluminum-Copper Alloys	200
Habits	203
Additional Comments	204
Miscellany	206
References	206
Problems	206

Chapter 11 Aluminum and Its Alloys..... 211

 Uses..... 211

 Alloys..... 212

 Wrought Alloys 212

 Casting Alloys..... 215

 Powder-Processing..... 222

 Corrosion Resistance..... 222

 Aluminum-Lithium Alloys..... 225

 Miscellany..... 226

 References..... 230

 Problems 230

Chapter 12 Copper and Nickel Alloys 233

 Commercially Pure Copper 233

 Copper-Zinc Alloys 235

 Bronzes..... 240

 Lead Additions 241

 Copper-Nickel Alloys..... 242

 Beryllium Copper 243

 Corrosion..... 245

 Nickel-Base Alloys..... 246

 Miscellany..... 249

 References..... 250

 Problems 250

Chapter 13 Hexagonal Close-Packed Metals 251

 General..... 251

 Zinc..... 251

 Magnesium 254

 Titanium 259

 Solid-Solution Strengthening 261

 Texture Strengthening 261

 Heat Treatment 262

 Uses 263

 Zirconium..... 266

 Beryllium 267

 Miscellany..... 269

 References..... 271

 Problems 271

Chapter 14 Other Nonferrous Metals.....	273
Lead.....	273
Tin.....	273
Gold.....	274
Silver.....	274
Cobalt.....	276
Platinum Metals.....	276
Group VA and VIA metals.....	278
Tungsten.....	280
Molybdenum.....	282
Tantalum and Niobium.....	282
Rhenium.....	282
Alloys with Special Physical Properties.....	282
Metals and Alloys with Low Melting Points.....	283
Miscellaneous Metals.....	284
Miscellany.....	285
Problems.....	286
Chapter 15 Steels.....	287
Microstructures of Carbon Steels.....	287
Kinetics of Pearlite Formation.....	293
Alloying Elements in Steel.....	296
Isothermal Transformation Diagrams.....	298
Continuous Cooling Diagrams.....	305
Martensite.....	305
Special Heat Treatments.....	306
Miscellany.....	310
References.....	312
Problems.....	313
Chapter 16 Hardening of Steels.....	315
Hardenability: Jominey End-Quench Test.....	315
Ideal Diameter Calculations.....	320
Boron.....	326
Martensite and Retained Austenite.....	328
Miscellany.....	329
References.....	330
Problems.....	331

Chapter 17 Tempering and Surface Hardening.....	333
Tempering.....	333
Secondary Hardening	338
Temper Embrittlement.....	339
Carburizing.....	340
Nitriding	343
Carbo-Nitriding	344
Case Hardening without Composition Change	344
Furnace Atmospheres	344
Miscellany.....	345
References.....	345
Problems	346
Chapter 18 Low-Carbon Sheet Steels.....	349
Sheet Steels	349
Formability	350
Surface Finish.....	350
Strain Hardening	351
Strain-Rate Sensitivity	351
Anisotropy.....	352
Freedom from Strain Aging.....	352
Yield Strength.....	356
Special Grades.....	356
Coatings	357
Galvanized Grades	357
Terne Plate.....	357
Tin Plate.....	357
Phosphate Coatings.....	358
Special Concerns	358
Inclusion Shape Control.....	358
Hot Shortness	359
Miscellany.....	359
References.....	359
Problems	360
Chapter 19 Special Steels.....	363
Stainless Steels	363
Ferritic Stainless Steels.....	363
Martensitic Stainless Steels	367

- Austenitic Stainless Steels 368
- Duplex Stainless Steels..... 371
- Precipitation Hardening Stainless Steels..... 371
- Sensitization 371
- Oxidation Resistance..... 372
- Hadfield Austenitic Manganese Steel..... 373
- Maraging Steels 373
- TRIP Steels..... 373
- Tool Steels..... 374
- Silicon Steels 375
- Miscellany 376
- References 377
- Problems 378

Chapter 20 Cast Irons..... 379

- General..... 379
- White Irons 380
- Gray Irons..... 382
- Ductile Cast Iron 383
- Malleable Cast Iron 384
- Matrices 385
- Miscellany 388
- References 390
- Problems 390

Chapter 21 Welding, Brazing, and Soldering..... 393

- Welding without Melting 393
- Resistance Welding 394
- Arc Welding 395
 - Heat Distribution 398
- Torch Welding..... 400
- Metallurgy of Welding 401
- Residual Stresses and Distortion..... 403
- Braze Welding of Cast Iron 404
- Brazing and Soldering 404
- Joint Design..... 406
- Hard Facing 407
- Miscellany 407
- References 409
- Problems 409

Chapter 22 Powder Processing 411

 Powders 412

 Powder Pressing 412

 Sintering 412

 Sintering — Later Stage 415

 Liquid Phase Sintering 417

 Activated Sintering 419

 Hot Pressing 419

 Strength and Ductility 420

 Miscellany 420

 References 421

 Problems 421

Chapter 23 Corrosion 423

 Corrosion Cells 423

 Current Density 426

 Polarization 426

 Passivation 427

 Corrosion Control 430

 Rust 432

 Direct Oxidation 433

 Hydrogen Embrittlement 434

 Steels 434

 Hydride Formation 436

 Copper 436

 Miscellany 437

 References 438

 Problems 438

Chapter 24 Magnetic Materials 441

 General 441

 Magnetostatic Energy 446

 Magnetocrystalline Energy 447

 Magnetostriction 448

 Physical Units 448

 The B-H Curve 449

 Curie Temperature 451

 Bloch Walls 451

 Soft vs. Hard Magnetic Materials 451

Soft Magnetic Materials.....	453
Hard Magnetic Materials.....	456
Summary.....	460
Miscellany.....	461
References.....	461
Problems.....	461
Appendix 1 Microstructure Analysis.....	465
ASTM Grain Size Number.....	465
Linear Intercept Grain Size.....	465
Relation of Grain Boundary Area per Volume to Linear Intercept.....	467
Relation of the Number of Intersections per Area and Length of Line per Volume.....	468
Dihedral Angles.....	469
Microstructural Relationships.....	470
Two-Dimensional Relationships.....	479
Three-Dimensional Features.....	471
References.....	476
Problems.....	477
Appendix 2 Stereographic Representation of Orientations.....	479
The Stereographic Projection.....	479
Locating the $[hkl]$ Pole in the Standard Stereographic Projection of a Cubic Crystal.....	480
Problems.....	484
Appendix 3 Miller-Bravais System of Indices for Hexagonal Crystals.....	485
Planar Indices.....	485
Direction Indices.....	487
Problem.....	490
Index.....	491