CONTENTS

Preface viii

Chapter 1 INTRODUCTION 1

Chapter 2 PHASE STABILITY 4

2.1 Equilibrium in a Closed System 4
2.1.1 Effect of Temperature 7
2.1.2 Effect of Pressure 11
2.1.3 Effect of Composition 14
2.2 Order of Transformation 18
2.3 Internal Stability 20
2.3.1 Single-Phase System 20
2.3.2 Two-Phase System 22
2.3.3 Fluctuations 23
2.4 Stable, Unstable, and Metastable States 24
Problems 27
References 29
Further Reading 29
Sources of Thermodynamic Data 30

Chapter 3 INTERPHASE INTERFACES 31

3.1 Structural Defects 31
3.2 Thermodynamics of Interfaces 35
3.2.1 Surface Free Energy 35
3.2.2 Surface Tension 36
3.3 Interfaces in Solids 38
3.3.1 Coherent Interfaces 38
3.3.2 Coherent Interfaces with Strain 44
3.3.3 Semicoherent Interfaces 46
3.3.4 Incoherent Interfaces 50
3.4 Solid-Vapor Interfaces 52
3.5 Solid-Liquid and Liquid-Vapor Interfaces 53
3.6 Free Energies of Interfaces 53
3.7 Effects of Interfaces on Stability 57
3.7.1 Single-Phase System 57
3.7.2 Two-Phase System 58
3.7.3 Equilibrium Shape 60

Problems 63
References 64
Further Reading 65

Chapter 4 EMPIRICAL TRANSFORMATION KINETICS 66

4.1 Departure from Equilibrium 66
4.2 The Rates of Atomic Processes 70
4.3 Diffusion 74
4.3.1 Diffusion Mechanism 75
4.3.2 Diffusion Flux 79
4.3.3 Applications of the Flux Equation 94
4.3.4 Diffusion Data 100
4.4 The Empirical Rate Equation 105
4.5 Determination of Activation Energy 109
4.5.1 The Rate Constant Technique 109
4.5.2 The Time for Constant Fraction Technique 111
4.5.3 The Change of Slope Technique 111
4.6 Signification of the Activation Energy 115
4.7 Classification of Phase Transformations 117
Appendix The Flux Equation 122
Problems 127
References 131
Further Reading 131

Chapter 5 NUCLEATION 132

5.1 The Embryo 132
5.2 Homogeneous Nucleation 135
5.2.1 The Free Energy of Formation of the Critical Embryo 135
5.2.2 Rate of Homogeneous Nucleation 151
5.3 Heterogeneous Nucleation 158
5.3.1 The Free Energy of Formation of the Heterogeneous Critical Embryo 159
5.3.2 Rate of Heterogeneous Nucleation 168
5.4 Effect of Temperature on Nucleation 174
5.5 Transient Nucleation 175
Problems 176
References 179
Further Reading 179

Chapter 6 LIQUID-SOLID TRANSFORMATIONS 181

6.1 Introduction 181
6.2 Growth 183
6.2.1 Atomic Mechanism 183
6.2.2 Effect of Temperature Gradient 192
6.2.3 Influence of Solute Partitioning 202
6.3 Crystal Growth 206
6.4 Eutectic Solidification 208
6.5 Solidification of Castings 215
6.6 Rapid Solidification 221
6.7 Crystallization of Amorphous Materials 225
6.7.1 Reaction Sequence 225
6.7.2 Relaxation 226
6.7.3 Crystallization 227
6.8 Melting and Zone Refining 231
Appendix Heat Conduction from a Spherical Object under Steady-State Conditions 233
Problems 236
References 238
Further Reading 239

Chapter 7 DIFFUSIONAL TRANSFORAMTION IN SOLIDS: SHORT-RANGE DIFFUSION 240

7.1 Introduction 240
7.2 Polymorphic Transformation 240
7.2.1 Nucleation and Growth 242
7.2.2 Rate of Transformation 243
7.3 Massive Transformation 248
7.3.1 Kinetics 250
7.3.2 Morphology 254
7.4 Order-Disorder Transformation 256
7.4.1 Structures of Ordered Phases 260
7.4.2 Kinetics of Transformation 266
7.5 Recrystallization 272
7.5.1 Recovery 274
7.5.2 Nucleation and Growth 281
7.5.3 Rate of Recrystallization 285
7.5.4 Grain Growth 289
7.5.5 Secondary Recrystallization 292
7.5.6 Recrystallization Texture 293
Problems 295
References 297
Further Reading 299

Chapter 8 DIFFUSIONAL TRANSFORMATIONS IN SOLIDS: LONG-RANGE DIFFUSION 300

8.1 Introduction 300
8.2 Precipitation 301
8.2.1 Nucleation 302
8.2.2 Growth 307
8.2.3 Transformation Kinetics 325
8.2.4 Morphology 331
8.3 The Pearlite Reaction 333
8.3.1 Nucleation 333
8.3.2 Growth 337
8.3.3 Overall Rate 342
8.3.4 Effects of Solutes 344
8.4 Cellular Precipitation 346
8.4.1 Characteristics of Cellular Precipitation 347
8.4.2 Initiation of the Transformation 350
8.4.3 Cellular Growth by Interface Diffusion 353
8.5 Coarsening 360
8.5.1 Introduction 360
8.5.2 Growth of Precipitates 361
8.5.3 Coarsening of Cellular Precipitates 367
Problems 367
References 370
Further Reading 372

Chapter 9 SPINODAL DECOMPOSITION 373

9.1 Definition 373
9.2 Mode of Decomposition 375
9.3 Kinetics 377
9.3.1 Rate of Decomposition 377
9.3.2 Effect of Composition Gradient 381
9.3.3 Effect of Strain Energy 386
9.4 Systems Showing Spinodal Decomposition 388
9.5 Morphology 392
Appendix The Gradient Energy Coefficient 394
Problems 397
References 397
Further Reading 399

Chapter 10 MARTENSITIC TRANSFORMATION 400

10.1 Introduction 400
10.2 Characteristics 401

10.2.1 Shape Change 401
10.2.2 Temperature Insensitive Growth Rate 407
10.2.3 Constancy of Composition 408
10.2.4 Orientation Relationship 408
10.2.5 Athermal and Isothermal Kinetics 408
10.2.6 Reversibility 410
10.3 Thermodynamics 411
10.4 Nucleation 412
10.5 Growth 417
10.5.1 Mechanism of Shape Deformation 417
10.5.2 Atomic Processes at the Interface 422
10.6 Overall Transformation Kinetics 423
Appendix A List of Selected Materials showing a Martensitic Transformation 428
Problems 429
References 430
Further Reading 431

Chapter 11 TRANSFORMATIONS IN STEEL 432

11.1 Introduction 432
11.2 Effects of Alloying Elements on Stability 433
11.2.1 Austenite and Ferrite 433
11.2.2 Carbides 433
11.2.3 The Eutectoid Reaction 436
11.3 The Pearlite Reaction 437
11.4 The Bainite Reaction 439
11.4.1 Structure and Crystallography 439
11.4.2 Kinetics 442
11.5 The Martensitic Transformation 444
11.6 Overall Transformation Behavior 445
11.6.1 Isothermal Transformation 445
11.6.2 Transformation during Continuous Cooling 449
11.7 Tempering of Martensite 451
11.7.1 Precipitation of Carbides 453
11.7.2 Temper Embrittlement 459
11.7.3 Precipitation of Intermetallic Compounds 460
11.8 Spheroidization of Pearlite 461
11.9 Precipitation in Ferrite and Austenite 463
References 464
Further Reading 465

Index 466