

CONTENTS

PREFACE

xi

1 INTRODUCTION

1

- 1.1 The Importance of Metals / 1
- 1.2 Mineral Deposition / 2
- 1.3 Importance of Water / 10
- 1.4 Aqueous Processing and Utilization of Metals / 12
- 1.5 Overview of Fundamentals and Applications / 17
- References / 19
- Problems / 20

2 CHEMICAL FUNDAMENTALS OF HYDROMETALLURGY

21

- 2.1 General Reactions / 21
- 2.2 Chemical Potential / 24
- 2.3 Free Energy and Standard Conditions / 28
- 2.4 Free Energy and Nonstandard Activities / 30
- 2.5 Equilibrium / 31
- 2.6 Solubility Product / 33
- 2.7 Relationships Amongst K , pK , pK_a , and pH / 34
- 2.8 Free Energy and Nonstandard Temperatures / 36
- 2.9 Heat Generation due to Reactions / 40

2.10	Free Energy and Nonstandard Pressures / 41
2.11	Equilibrium Concentration Determinations / 41
2.12	Activities and Activity Coefficients / 42
2.13	Practical Equilibrium Problem Solving / 47
2.14	Electrochemical Reaction Principles / 52
2.15	Equilibrium and Electrochemical Equations / 56
	References / 62
	Problems / 62

3 SPECIATION AND PHASE DIAGRAMS 65

3.1	Speciation (or Ion Distribution) Diagrams / 65
3.2	Metal-Ligand Speciation Diagrams / 69
3.3	Phase Stability Diagrams / 72
	Reference / 83
	Problems / 83

4 RATE PROCESSES 84

4.1	Chemical Reaction Kinetics / 84
4.2	Biochemical Reaction Kinetics / 92
4.3	Electrochemical Reaction Kinetics / 94
4.4	Mass Transport / 106
4.5	Combined Mass Transport and Reaction Kinetics / 114
4.6	Models for Reactions Involving Particles / 117
4.7	Combined Mass Transport and Electrochemical Kinetics / 128
4.8	Crystallization Kinetics / 130
4.9	Overview of Surface Reaction Kinetics / 131
	References / 134
	Problems / 135

5 METAL EXTRACTION 137

5.1	General Principles and Terminology / 137
5.2	Bioleaching/Biooxidation / 159
5.3	Precious Metal Leaching Applications / 165
5.4	Extraction from Concentrates / 171
	References / 179
	Problems / 181

6	SEPARATION OF DISSOLVED METALS	183
6.1	Liquid–Liquid or Solvent Extraction /	184
6.2	Ion Exchange /	200
6.3	Activated Carbon Adsorption /	207
6.4	Ultrafiltration or Reverse Osmosis /	211
6.5	Precipitation /	212
	References /	214
	Problems /	215
7	METAL RECOVERY PROCESSES	218
7.1	Electrowinning /	218
7.2	Electrorefining /	229
7.3	Cementation or Contact Reduction /	232
7.4	Recovery Using Dissolved Reducing Reagents /	235
	References /	236
	Problems /	237
8	METAL UTILIZATION	239
8.1	Introduction /	239
8.2	Batteries /	240
8.3	Fuel Cells /	245
8.4	Electroless Plating /	247
8.5	Electrodeposited Coatings /	249
8.6	Electroforming /	251
8.7	Electrochemical Machining /	251
8.8	Corrosion /	253
	References /	262
	Problems /	263
9	ENVIRONMENTAL ISSUES	264
9.1	Introduction /	264
9.2	United States Environmental Policy Issues /	266
9.3	Metal Removal and Remediation Issues /	268
	References /	275
	Problems /	276

10	PROCESS DESIGN PRINCIPLES	277
10.1	Determination of Overall Objectives / 278	
10.2	Determination of Basic Flow Sheet Segments / 278	
10.3	Survey of Specific Segment Options / 279	
10.4	Overall Flow Sheet Synthesis / 285	
10.5	Procurement of Additional Information / 287	
10.6	Selected Industrial Flow Sheet Examples / 289	
	References / 310	
	Problem / 311	
11	GENERAL ENGINEERING ECONOMICS	312
11.1	The Effects of Time and Interest / 312	
11.2	Return on Investment (ROI) / 322	
11.3	Cost Estimation / 323	
11.4	Discounted Cash Flow Economic Analysis / 325	
11.7	Evaluating Financial Effects of Risk / 337	
	References / 344	
	Problems / 345	
12	GENERAL ENGINEERING STATISTICS	348
12.1	Uncertainty / 348	
12.2	Basic Statistical Terms and Concepts / 353	
12.3	The Normal Distribution / 354	
12.4	Probability and Confidence / 355	
12.5	Linear Regression and Correlation / 373	
12.6	Selecting Appropriate Statistical Functions / 375	
12.7	Hypothesis Testing / 382	
12.8	Analysis of Variance (ANOVA) / 384	
12.9	Factorial Design and Analysis of Experiments / 387	
12.10	The Taguchi Method / 390	
	References / 396	
	Problems / 397	
	APPENDIX A ATOMIC WEIGHTS	399
	APPENDIX B MISCELLANEOUS CONSTANTS	401
	APPENDIX C CONVERSION FACTORS	402

APPENDIX D	FREE ENERGY DATA	403
	References / 410	
APPENDIX E	LABORATORY CALCULATIONS	412
	E.1 Background Information / 412	
	E.2 Solution Preparation Principles / 413	
	E.3 Solution Preparation Calculations / 413	
	Problem / 415	
APPENDIX F	SELECTED IONIC SPECIES DATA	416
APPENDIX G	STANDARD HALF-CELL POTENTIALS	418
APPENDIX H	GENERAL TERMINOLOGY	420
APPENDIX I	COMMON SIEVE SIZES	423
APPENDIX J	METALS AND MINERALS	424
INDEX		429