
Contents

Chapter 1

The Scope and History of Electrochemical Engineering

1.1	Carl Wagner and the Beginning of Electrochemical Engineering Science	1
1.2	Electrochemistry and Electrochemical Engineering Science	2
1.3	Electrochemical Engineering Science and Technology Since the Mid-1960s	3
1.4	What Means Electrochemical Engineering Science and Technology Today?	5
	References	7
	Further Reading	7

Chapter 2

Basic Principles and Laws in Electrochemistry

2.1	Stoichiometry of Electrochemical Reactions	8
2.2	Faraday's Law	10
2.3	Production Rates and Current Densities	11
2.4	Ohm's Law and Electrolyte Conductivities	12
2.5	Parallel Circuits and Cells with Electrolytic Bypass and Kirchhoff's Rules	14
	Further Reading.	16

Chapter 3

Electrochemical Thermodynamics

3.1	Equilibrium Cell Potential and Gibbs Energy	17
3.2	Electrode Potentials, Reference Electrodes, Voltage Series, Redox Schemes	21
3.3	Reaction Enthalpy, Reaction Entropy, Thermoneutral Cell Voltage and Heat Balances of Electrochemical Reactions	28
3.4	Heat Balances of Electrochemical Processes	29

3.5	Retrieval of Thermodynamic Data and Activity Coefficients	31
3.6	Thermodynamics of Electrosorption.	35
	References	37

Chapter 4

Electrode Kinetics and Electrocatalysis

4.1	The Electrochemical Double Layer	39
4.2	Kinetics of Interfacial Charge Transfer	41
4.3	Electrode Kinetics of Multielectron Charge Transfer Reactions. . .	45
4.4	Thermal Activation and Activation Energies of Electrochemical Reactions	49
4.5	Electrochemical Reaction Orders	49
4.6	Current Density/Potential Correlations for Different Limiting Conditions	51
4.6.1	Micro- and Macrokinetics of Electrochemical Reactions.	51
4.6.2	Mass Transfer Controlled Current Potential Curves . . .	52
4.6.2.1	Reaction Controlled Current Voltage Curves	54
4.6.3	Charge Transfer Controlled Current Voltage Correlation.	55
4.6.4	Combined Activation and Mass Transport Control . . .	56
4.7	Reaction Controlled Current Voltage Curves	57
4.7.1	Introductory Remarks	57
4.7.2	Fast Preceding Reaction of an Electroactive Minority Species	58
4.7.3	Fast Consecutive Reactions	60
4.8	Electrocatalysis	61
4.8.1	Principles of Electrocatalysis	61
4.8.2	Heterogeneous Electrocatalysis in Cathodic Evolution and Anodic Oxidation of Hydrogen	61
4.8.2.1	The Volcano Curve	62
4.8.3	Electrocatalysis in Anodic Oxygen Evolution and Cathodic Oxygen Reduction	64
4.8.4	Redox Catalysis	66
4.9	Catalyst Morphology and Utilisation	68
4.9.1	Structural Features and Catalyst Morphology of Electrocatalysts for Gas Evolving and Gas Consuming Electrodes	68
4.9.2	Utilisation of Porous Electrocatalyst Particles.	69
4.10	Electrocatalysis in Electroorganic Synthesis.	71
4.10.1	Introduction into the Field of Electroorganic Synthesis	71
4.10.1.1	Mediated Electrochemical Conversions of Organic Substrates	71

4.10.1.2	Direct Anodic and Cathodic Electrochemical Conversions of Organic Substrates	72
4.10.2	Electrocatalytic Oxidations by Oxides of Multiply-Valent Metals	72
4.10.2.1	The Heterogeneously Catalysed Benzene Oxidation at Pb/PbO ₂ Electrodes in Sulfuric Acid	74
4.10.3	Electrocatalytic Hydrogenation and Electrocatalyzed Mediated Reduction	74
4.10.4	The Electrode Surface as Medium Catalysing Chemical Reactions of Electrogenated Reactive Organic Intermediates	75
4.10.4.1	Electrocatalytic Action of Electrosorbed Non-Reactant Species –Electrocatalysis of the Second Kind	78
4.10.5	Kinetics and Selectivity of Homogeneous Chemical Consecutive Reactions Following Charge Transfer	79
	References	80
	Further Reading	80

Chapter 5

Mass Transfer by Fluid Flow, Convective Diffusion and Ionic Electricity Transport in Electrolytes and Cells

5.1	Introduction.	81
5.2	Fluid Dynamics and Convective Diffusion	81
5.3	Fluid Dynamics of Viscous, Incompressible Media	84
5.3.1	Laminar vs Turbulent Flow	86
5.3.2	Velocity Distributions for Laminar Flow	87
5.3.2.1	Singular Electrode: Unidirectional Laminar Flow Along a Plate	87
5.3.2.2	Pair of Planar Electrodes	88
5.3.2.3	Circular Capillary Gap Cell	89
5.4	Mass Transport by Convective Diffusion	90
5.4.1	Fundamentals	90
5.4.2	Dimensionless Numbers Defining Mass Transport Towards Electrodes by Convective Diffusion	92
5.4.3	Hydrodynamic Boundary Layer and Nernst Diffusion Layer: Planar Electrodes	93
5.4.4	Mass Transport Towards a Singular Planar Electrode Under Laminar Forced Flow	95
5.4.5	Channel Flow and Mass Transfer to Electrodes of Parallel Plate Cells for Free and Forced Convection .	97
5.4.5.1	Free Convection at Isolated Planar Electrodes and between Two Vertical Electrodes	97
5.4.5.2	Convective Mass Transfer for Parallel Plate Cells with Forced Convection: Planar Plate Cells	98

5.4.5.3	Mass Transfer in Circular Capillary Gap Cells	101
5.4.6	Convective Mass Transfer Toward Rotating Electrodes	102
5.4.6.1	Rotating Cylinder	102
5.4.6.2	Rotating Disc Electrode	102
5.4.7	Mass Transfer at Gas Evolving Electrodes	103
5.4.7.1	Calculating $k_{m, \text{bubble}}$ According to the Penetration Model or Model of Periodic Boundary Layer Renewal . .	105
5.4.7.2	Calculating Bubble-Enhanced Mass Transfer According to Flow Model.	105
5.4.8	Mass Transfer in Three-Dimensional Electrodes	106
5.4.9	Summary.	107
5.5	Heat Transport	107
5.5.1	Chilton–Colburn Analogy of Mass and Heat Transfer.	107
5.5.2	General Description of Heat Generation and Heat Transfer in Electrolyzers and Fuel Cells	108
5.5.2.1	Heat Balance and Steady State-Temperature of Cells . .	109
5.6	Ionic Charge and Mass Transport in Electrolytes	110
5.6.1	Strong Electrolytes	110
5.7	Temperature Dependence of Electrolyte Conductivities	111
5.8	Molten Salt Electrolytes	113
5.9	Segregation in Stagnant Electrolytes of Binary Molten Carbonates in Fuel Cells	114
5.10	Current Density Distribution in Cells and Electrochemical Devices	117
5.11	Primary Current Density Distribution	119
5.12	Secondary Current Density Distribution.	121
5.13	Secondary Current Density Distribution and “Throwing Power” in Electrodeposition and Electrocoating	122
5.14	The Wagner Number	124
5.15	Tertiary Current Distribution	125
	References	127
	Further Reading	127

Chapter 6

Electrochemical Reaction Engineering

6.1	Introductory Remarks	128
6.2	Microkinetic Models	128
6.3	Mode of Operation	129
6.4	Electrical Control of Cells	131
6.5	Macrokinetic Models	131
6.5.1	Stirred-Batch Tank Reactor	131
6.5.2	Continuously Stirred Tank Reactor	132

6.5.3	Plug-Flow Reactor (PFR)	133
6.5.3.1	Plug Flow Electrolyzer with Uniform Current Density	135
6.5.3.2	PFR Operated at Mass Transfer Limited and Higher Current Density	135
6.5.4	Cell Cascades	136
6.5.5	Extended Modelling of Electrolyzers.	138
6.5.6	Residence-Time Distribution	139
6.5.7	The Selectivity Problem of Consecutive Reactions in Batch Reactors	142
6.6	Coupling of Electrochemical and Chemical Reactors	146
6.7	Electrolyzer Design and Chemical Yield Losses Due To Parasitic Chemical Reactions	148
6.8	Performance Criteria of Electrochemical Reactors	149
6.8.1	Fractional Conversion, X	150
6.8.2	Relative Amount of Charge- Q_r	150
6.8.3	Overall Conversion Related Yield Θ_p	150
6.8.4	Current Efficiency Φ^e	151
6.8.5	Parameters for Energy Considerations	152
	References	152
	Further Reading	152

Chapter 7

Electrochemical Engineering of Porous Electrodes and Disperse Multiphase Electrolyte Systems

7.1	Introduction.	153
7.2	Three-Dimensional Electrodes	154
7.2.1	General Considerations	154
7.2.2	Fundamental Equations	155
7.2.2.1	Nanoporous Electrode Particles	156
7.2.2.2	Microporous Electrodes	156
7.2.2.3	Packed and Fluidized Bed Electrodes	157
7.2.3	Gas Consuming Nanoporous Electrodes for Fuel Cells and Nanoporous Catalyst Particles and Layers for Gas Evolving Electrodes	157
7.2.3.1	Physical Structure of Particulate, Gas Consuming Nanoporous Gas Diffusion Electrodes	157
7.2.3.2	Physical Structure of Raney Nickel Coatings for Hydrogen Evolving Cathodes	159
7.2.3.3	Modelling Hydrogen Concentration Profiles and Catalyst Efficiencies for Hydrogen Consuming Fuel Cell Anodes or Other Gas Diffusion Electrodes.	160
7.2.3.4	Modelling of Hydrogen Concentration Profiles and Catalyst Efficiencies for Hydrogen Evolving Nanoporous Raney-Nickel Catalyst Coatings	165

7.2.4	Porous Battery Electrodes	171
7.2.5	Packed Bed and Fluidized Bed Electrodes Composed of Coarse Particles.	173
7.2.5.1	Fluidized Bed Electrodes.	178
7.3	Ionic Conductivity of Electrolytes Containing Dispersed Gas Bubbles in Gas Evolving Electrolyzers.	179
7.4	Electrolyzers with Gaseous Reactants	183
7.5	Electrochemical Liquid/Liquid Systems	186
	References	186
	Further Reading	186

Chapter 8

Electrochemical Cell and Plant Engineering

8.1	Materials Choice and Corrosion Problems.	187
8.1.1	Metals.	188
8.1.2	Carbon	192
8.2	Electrode Materials	193
8.2.1	Stainless Steel	194
8.2.2	Nickel.	194
8.2.3	Lead.	195
8.2.4	Titanium	195
8.2.5	Noble Metals.	195
8.2.6	Massive Carbon	196
8.3	Electrode Design	196
8.3.1	Gas Evolving Electrodes	196
8.3.2	Gas Consuming Electrodes, Gas Diffusion Electrodes . .	197
8.4	Separators: Membranes and Diaphragms	199
8.4.1	Membranes	201
8.4.2	Diaphragms	203
8.5	Polymeric Materials for Cell Bodies and Electrolyte Loops	203
8.6	Gaskets	205
8.7	Electrodes	206
8.7.1	Horizontal Electrodes	206
8.7.2	Membrane Electrolyzer.	207
8.8	Cell and Electrode Design	208
8.8.1	Zero Gap Electrolysis Cells.	208
8.8.2	Vertical/Horizontal Electrodes	209
8.8.3	Divided/Undivided Monopolar/Bipolar Cells and Modes of Electrolyte Flow	209
8.8.4	Special Cell Designs.	210
8.8.5	Capillary Gap Cells	216
8.8.6	Swiss Roll Cell	216
8.8.7	Cells with Three-Dimensional Electrodes	217
8.9	Power Supply for Electrochemical Plants	218

8.9.1	Rectifiers	218
8.9.2	Transformer Wiring	218
8.9.3	Further Equipment	219
	Further Reading	220

Chapter 9

Process Development

9.1	Scope and Purpose of Laboratory and Pilot Plant Measurements	221
9.2	Laboratory Methods	222
9.2.1	Steady-State Measurements of Current Density Potential Correlations	222
9.2.1.1	General Remarks	222
9.2.1.2	Measuring Devices	223
9.2.1.3	Evaluation of Rotating Disc Measurements	223
9.2.1.4	Current-Voltage Correlation for Competing Reactions by Non-Electrochemical Methods	225
9.2.1.5	The Ring Disc Electrode	226
9.2.2	Non-Steady State Methods	230
9.2.2.1	General Remarks	230
9.2.2.2	Potentiodynamic Polarisation Curves	230
9.2.2.2.1	Cyclic Voltammetry and Linear Potential Sweep Method	231
9.2.2.2.2	Initial Polarisation Curves	233
9.2.2.3	Square-Wave Pulses	233
9.2.2.4	Eliminating the IR Drop	235
9.2.2.4.1	Galvanostatic Methods	236
9.2.2.4.2	Potentiostatic Procedures	236
9.3	Pilot Plant Methods	236
9.3.1	General Considerations	236
9.3.2	Mass-Transfer Measurements	237
9.3.3	Determination of Residence-Time Distributions	238
9.4	Mathematical Modelling and Optimisation by Factorial Design of Experiments	239
9.4.1	Introduction	239
9.4.2	General Procedure for Optimum Finding by Experiment	239
9.4.3	Factorial Design of Experiments	240
9.5	Cost Analysis	243
9.5.1	Composition of Productions Costs	243
9.5.2	Total and Specific Investment Costs	244
9.5.3	Cost Optimisation with Respect to Current Density	245
9.5.4	Optimisation of Non-Selective Electrolysis Processes	248
9.5.4.1	Current Density Against Current Efficiency.	249

9.5.4.2	Temperature vs Current Efficiency	250
9.5.5	Examples Including Influences of Process Parameters on the Equipment for Non-Electrochemical Unit Operations and Corresponding Costs	250
Further Reading	251

Chapter 10

Industrial Electrodes

10.1	Catalytically Activated Electrodes.	252
10.2	Functioning, Longevity and Application of Electrocatalyst Coatings	253
10.3	Design of Industrial Electrodes	255
10.3.1	Monopolar Electrodes and Current Density Distribution on Their Surface	255
10.3.2	Electrodes for Bipolar Electrode Stacks	257
10.3.3	Gas Evolving Electrodes	258
10.4	Structural Features of Electrocatalysts for Gas Evolving and Gas Consuming Electrodes	260
10.5	Electrocatalytically Activated Dimensionally Stable Chlorine-Evolving Electrodes	260
10.5.1	Technological History	260
10.5.2	Electrocatalysis and Selectivity of Anodic Chlorine Evolution at RuO_2 -Anodes	261
10.5.3	Preparation and Formulation of the Coatings.	261
10.5.4	Improvement of Adhesion and Strength of the Coatings	261
10.5.5	Design of Cells Using DSAs	262
10.5.6	Lifetime of Dimensionally Stable Chlorine Evolving Anodes	263
10.5.7	DSAs for Chlorate and Hypochlorite Production	264
10.6	Oxygen Evolving Anodes.	265
10.6.1	Technical Processes	265
10.6.2	Electrocatalysis of Oxygen Evolution in Advanced Alkaline Water Electrolysis.	265
10.6.2.1	Coatings Containing Cobalt and Iron Oxides	265
10.6.3	Electrocatalysis of the Anodic Oxygen Evolution by Raney-Nickel Coatings	266
10.6.4	Catalyst-Coated Titanium Electrodes for Oxygen Evolution From Acid Solutions	266
10.7	Hydrogen Evolving Cathodes	268
10.7.1	Technoeconomical Significance of Cathodic Hydrogen Evolution	268
10.7.2	Electrocatalyst Coatings for Hydrogen Evolution from Alkaline Solution	268

10.7.2.1	Technically Applied Coatings	268
10.7.2.2	Nickel Sulfide Coatings	269
10.7.2.3	Raney-Nickel Coatings	269
10.7.2.3.1	Precursor Alloys and Fabrication of Coated Cathodes	269
10.7.2.3.2	Utilisation of the Catalyst in Raney-Nickel Coatings	271
10.7.2.3.3	Performance and Ageing of Raney-Nickel Coatings . . .	272
10.7.3	Coatings of Platinum Metal Oxides	273
10.7.4	Active Coatings of Flame Sprayed, Doped Nickel Oxide .	273
10.7.5	Platinum and Platinum Metal Cathodes in Membrane Water Electrolyzers	273
10.8	Fuel-Cell Electrodes	274
10.8.1	Low- and High-Temperature Fuel Cells	274
10.8.2	Structural Design of Gas-Diffusion Electrodes in Low-Temperature Fuel Cells	275
10.8.3	Oxygen Reduction Catalysts in Low-Temperature Cells	276
10.8.4	Catalysts for Anodic Hydrogen Oxidation	276
10.8.5	Properties, Preparation and Improvement of Electrocatalysts in Gas Diffusion Electrodes for Low Temperature Cells	277
10.8.5.1	Pt-Activated Active Carbon	277
10.8.5.2	Particle Size of Pt Nanocrystals on Active Carbon and Their Effective Catalytic Activity	278
10.8.5.3	Pt-Alloy Catalysts	278
10.8.6	Morphology and Structure of Complete PTFE-Bonded Active-Carbon Electrodes	279
10.8.7	Ageing of Pt-Catalysts	280
10.8.8	Electrocatalysis of Anodic Methanol Oxidation	281
10.8.8.1	Technoeconomic Significance of the Process	281
10.8.8.2	Self-Poisoning of Methanol Oxidising Pt-Catalyst by Oxidation Products of Methanol	281
10.8.8.3	Anodic Methanol Oxidation at Alloy Catalysts	281
10.8.9	Gas-Diffusion Electrodes in Membrane (PEM) Fuel Cells	282
10.8.9.1	Rationale of Developing a Method of Internal Wetting for Membrane Fuel Cell Electrodes	282
10.8.9.2	Improving Catalyst Utilisation by Ionomer Impregnation of Gas-Diffusion Electrodes	282
10.8.9.3	The Preparation of Membrane Electrode Assemblies (MEAs) for Membrane Fuel Cells	283
10.8.10	Electrodes for High-Temperature Fuel Cells	284
10.8.10.1	Stability of Electrode Structures at High Temperatures	284

10.8.11	Electrode Kinetics and Electrocatalysis in Molten-Carbonate Fuel Cells	285
10.8.11.1	Anodic Hydrogen Oxidation.	285
10.8.11.2	Cathodic Oxygen Reduction	285
10.8.12	Electrodes in Solid-Oxide Fuel Cells (SOFC)	287
10.8.12.1	Electrodes and Electrode Structure.	287
10.8.12.2	The SOFC-Anode	287
10.8.12.3	The SOFC-Cathode	288
References	289
Further Reading	289

Chapter 11

Industrial Processes

11.1	Introductory Remarks	290
11.2	Inorganic Electrolysis and Electrosynthesis	291
11.3	Chloralkali-Electrolysis	291
11.3.1	The Electrochemical Reaction.	292
11.3.2	Thermodynamics and Energy Demands.	292
11.3.3	Anodic Chlorine Evolution	293
11.3.4	The Cathodic Reaction	294
11.3.4.1	Cathodic Sodium Deposition in the Mercury Process . .	294
11.3.4.2	Cathodic Hydrogen Evolution in the Diaphragm and Membrane Process	295
11.4	Process Technologies	295
11.4.1	The Amalgam Process	295
11.4.2	The Diaphragm Process	297
11.4.3	The Membrane Process.	298
11.4.3.1	Process-Flow Sheets	300
11.4.3.2	Brine Recycling	302
11.4.4	Gas Purification and Conditioning	303
11.4.4.1	Chlorine	303
11.4.4.2	Hydrogen.	304
11.4.5	Comparison of the Three Processes	304
11.5	Hypochlorite, Chlorate and Chlorine Dioxide.	306
11.5.1	Production of Sodium Hypochlorite	306
11.5.1.1	Electrolytic Generation of Hypochlorite	306
11.5.1.2	Current Efficiency Losses	307
11.5.2	Production of Sodium Chlorate	307
11.5.2.1	Balance of Plant of Chlorate Electrosynthesis	310
11.5.2.2	Construction Materials.	311
11.5.3	Chlorine Dioxide from Sodium Chlorate.	311
11.6	Perchloric Acid, Perchlorates, Peroxidsulfates	312
11.6.1	Perchloric Acid	312
11.6.2	Sodium Perchlorate	312

11.6.3	Peroxidisulfates	313
11.7	Fluorine	315
11.8	Hydrogen by Water Electrolysis	316
11.8.1	Technoeconomic Environment	316
11.8.2	Thermodynamics and Technological Principles of Electrolytic Water Splitting	317
11.8.3	Process Technologies	318
11.8.4	Conventional Alkaline Water Electrolysis	320
11.8.4.1	Monopolar Technology	320
11.8.4.2	Bipolar Technology	320
11.8.4.3	Improved Alkaline Technologies	323
11.8.5	New Technologies	324
11.8.5.1	Membrane Water Electrolysis	324
11.8.5.2	Steam Electrolysis	324
11.8.6	Economic Implications of Technical Innovations for Alkaline Water Electrolysis	325
11.9	Electrowinning and Electrorefining of Metals	326
11.9.1	Metal Electrowinning and Refining from Aqueous Electrolytes	326
11.9.2	Copper Electrowinning and Electrorefining	330
11.9.3	Nickel Electrowinning	331
11.9.4	Nickel from the Chloride Leach Process	333
11.9.5	Nickel Refining	334
11.9.6	Zinc Electrowinning	334
11.9.7	Lead Electrorefining	335
11.10	Metal Electrowinning from Molten Salt Electrolytes	335
11.10.1	General Considerations	335
11.10.2	Aluminium Production – the Hall–Heroult Process . . .	336
11.10.2.1	The Melt	336
11.10.2.2	Electrode Reactions	338
11.10.3	The Cell	339
11.10.4	Alkali Metals from Chloride Melts	341
11.10.5	Magnesium Electrolysis	342
11.10.5.1	Production of the Feed Salt	343
11.10.5.2	Magnesium Electrolysis Cells	344
11.11	Organic Electrosynthesis Processes	345
11.11.1	General Overview	345
11.11.2	Cell Types Used in Commercial Electroorganic Synthesis	347
11.11.3	Process and Reaction Techniques of Some Examples of Industrial Organic Electrosyntheses	349
11.11.3.1	Adipodinitrile Production by the Monsanto/Baizer Process	349
11.11.3.2	Electrosynthesis of Sebacic Diesters by Kolbe Synthesis	352

11.11.3.3	Benzaldehydes by Direct Anodic Oxidation of Toluenes.	353
11.11.3.4	The Selective Anodic Oxidation of L-Sorbose in Commercial Vitamin C Synthesis	353
11.11.3.5	Anodic Formation of Perfluoro-Propylene Oxide.	355
11.12	Selected Electrochemical Procedures Outside the Chemical and Metallurgical Industries	357
11.12.1	Electrochemical Wastewater Treatment by Electrodeposition and by Electroosmosis	357
11.12.1.1	General Considerations	357
11.12.1.2	Particular Cells for Removal of Metal Ions from Effluents	358
11.12.1.3	Electrodialysis	361
11.12.2	Electrochemical Surface Treatment and Shaping of Metals	362
11.12.2.1	Electrochemical Shaping.	362
11.12.2.2	Electropolishing.	363
11.12.2.3	Electrochemical Machining (ECM).	365
11.12.2.4	Electrochemical Grinding	366
11.12.3	Electroreforming of Microdies and Microtools by the LIGA-Process	368
	References	369
	Further Reading	369

Chapter 12

Fuel Cells

12.1	Fuel Cells as Gas Supplied Batteries.	370
12.2	Theoretical Efficiency of Hydrogen/Oxygen Fuel Cells.	371
12.3	Fuel Cell Types	373
12.3.1	Low-Temperature Fuel Cells – Their Technological State	375
12.3.1.1	Phosphoric-Acid Cells	375
12.3.1.2	Membrane Cells	376
12.3.1.3	Direct and Indirect Methanol-Combusting Membrane Cells	377
12.3.1.4	Process Principles of the PAFCs and PEMFCs with Proton Conducting Electrolyte	378
12.3.2	High-Temperature Fuel Cells	379
12.3.2.1	Molten-Carbonate and Solid Oxide Fuel Cells	379
12.3.2.2	Process Schemes of MCFCs and SOFCs	379
12.3.2.3	Internal Reforming in High-Temperature Fuel Cells	380
12.3.3	Cell Technologies of MCFCs and SOFCs	381
12.3.3.1	Molten-Carbonate Fuel Cells	381
12.3.3.2	Solid Oxide Fuel Cells	382
12.3.3.3	The Westinghouse Technology	382

12.3.4	Flat-Plate Solid Oxide Cells	384
12.4	Current Voltage Curves of Different Fuel Cells	385
12.5	Fuel-Cell Systems	387
12.5.1	Phosphoric-Acid Fuel Cell / PC 25	387
12.5.2	Molten Carbonate Cells	390
12.5.2.1	ERC-2 MW Plant	390
12.5.2.2	Hot Module of MTU	390
12.5.3	Proton Exchange Membrane Cells	391
12.5.3.1	The Ballard Cell	392
12.5.3.2	De Nora's Cell	394
	Further Reading	394
	Subject Index	395



<http://www.springer.com/978-3-540-64386-9>

Electrochemical Engineering
Science and Technology in Chemical and Other
Industries

Wendt, H.; Kreysa, G.

1999, XXI, 408 p., Hardcover

ISBN: 978-3-540-64386-9