

---

# CONTENTS

---

**Contributors** xv  
**Preface** xvii  
**Preface to the First Edition** xix

## Part 1 Principles of Operation

---

### Chapter 1. Basic Concepts 1.3

---

- 1.1 Components of Cells and Batteries ¶ 1.3
- 1.2 Operation of a Cell ¶ 1.4
- 1.3 Theoretical Cell Voltage and Capacity ¶ 1.7
- 1.4 Classification of Cells and Batteries ¶ 1.9

---

### Chapter 2. Electrochemical Principles and Reactions 2.1

---

- 2.1 Introduction ¶ 2.1
- 2.2 Thermodynamic Background ¶ 2.3
- 2.3 Electrode Processes ¶ 2.5
- 2.4 Electrical Double-Layer Capacity and Ionic Adsorption ¶ 2.10
- 2.5 Mass Transport to the Electrode Surface ¶ 2.15
- 2.6 Electroanalytical Techniques ¶ 2.19

---

### Chapter 3. Factors Affecting Battery Performance 3.1

---

- 3.1 General Characteristics ¶ 3.1
- 3.2 Factors Affecting Battery Capacity ¶ 3.1

---

### Chapter 4. Battery Standardization 4.1

---

- 4.1 General ¶ 4.1
- 4.2 International Standards ¶ 4.1
- 4.3 Concepts of Standardization ¶ 4.4
- 4.4 Size, Shape, and Voltage Designations ¶ 4.4
- 4.5 Terminals ¶ 4.7
- 4.6 Service Output-Electrical Performance ¶ 4.7
- 4.7 Performance-Test Conditions ¶ 4.8
- 4.8 Markings ¶ 4.10
- 4.9 Cross-Reference of ANSI and IEC Types ¶ 4.10
- 4.10 Battery Dimensions ¶ 4.10

**Chapter 5. Battery Design**

5.1

- 5.1 General Remarks ¶ 5.1
- 5.2 Designing Out Potential Safety Problems ¶ 5.1
- 5.3 Battery Safeguards when using Discrete Cells ¶ 5.5
- 5.4 Battery Construction ¶ 5.9
- 5.5 Design of Rechargeable Batteries ¶ 5.13
- 5.6 Guidelines ¶ 5.16

**Chapter 6. Selection and Application of Batteries**

6.1

- 6.1 Major Considerations in Selecting a Battery ¶ 6.1
- 6.2 Battery Applications ¶ 6.2
- 6.3 Comparative Features and Performance Characteristics ¶ 6.4
- 6.4 Criteria for Battery Selection-Portable Equipment ¶ 6.14

**Part 2 Primary Batteries****Chapter 7. Introduction**

7.3

- 7.1 General Characteristics and Applications of Primary Batteries ¶ 7.3
- 7.2 Types and Characteristics of Primary Batteries ¶ 7.4
- 7.3 Comparison of the Performance Characteristics of Primary Battery Systems ¶ 7.7
- 7.4 Recharging Primary Batteries ¶ 7.22

**Chapter 8. Zinc-Carbon Cells (Leclanché and Zinc Chloride Cell Svstems)**

6.1

- 8.1 General Characteristics ¶ 8.1
- 8.2 Chemistry ¶ 8.2
- 8.3 Types of Cells ¶ 8.4
- 8.4 Construction ¶ 8.5
- 8.5 Cell Components ¶ 8.9
- 8.6 Performance Characteristics ¶ 8.15
- 8.7 Special Designs ¶ 8.36
- 8.8 Types and Sizes of Available Cells and Batteries ¶ 8.39

**Chapter 9. Magnesium and Aluminum Cells**

9.1

- 9.1 General Characteristics ¶ 9.1
- 9.2 Chemistry ¶ 9.2
- 9.3 Construction of Mg/MnO<sub>2</sub> Cells / 9.4
- 9.4 Performance Characteristics of Mg/MnO<sub>2</sub> Cells / 9.6
- 9.5 Sizes and Types of Mg/MnO<sub>2</sub> Cells / 9.10
- 9.6 Military Batteries ¶ 9.11
- 9.7 Other Types of Magnesium Primary Batteries ¶ 9.12
- 9.8 Aluminum Primary Cells ¶ 9.15

**Chapter 10. Alkaline-Manganese Dioxide Cells**

10.1

- 10.1 General Characteristics ¶ 10.1
- 10.2 Chemistry ¶ 10.2
- 10.3 Cell Components and Materials ¶ 10.4

- 10.4 Construction ¶ 10.8
- 10.5 Performance Characteristics ¶ 10.11
- 10.6 Battery Types and Sizes ¶ 10.23

## Chapter 11. Mercuric Oxide Cells

11.1

- 11.1 General Characteristics ¶ 11.1
- 11.2 Chemistry ¶ 11.1
- 11.3 Cell Components ¶ 11.3
- 11.4 Construction ¶ 11.5
- 11.5 Performance Characteristics of Zinc/Mercuric Oxide Cell ¶ 10.10
- 11.6 Performance Characteristics of Cadmium/Mercuric Oxide Cell ¶ 10.16
- 11.7 Cell Types and Sizes ¶ 11.19
- 11.8 Handling, Use, and Disposal of Mercury Cells ¶ 11.20
- 11.9 Applications ¶ 11.21

## Chapter 12. Silver Oxide Cells

12.1

- 12.1 General Characteristics ¶ 12.1
- 12.2 Chemistry and Components ¶ 12.1
- 12.3 Button Cell Construction ¶ 12.9
- 12.4 Performance Characteristics ¶ 12.10
- 12.5 Cell Sizes and Types ¶ 12.15

## Chapter 13. Zinc/Air Cells

13.1

- 13.1 General Characteristics ¶ 13.1
- 13.2 Chemistry ¶ 13.2
- 13.3 Construction ¶ 13.3
- 13.4 Performance Characteristics ¶ 13.6

## Chapter 14. Lithium Cells

14.1

- 14.1 General Characteristics ¶ 14.1
- 14.2 Chemistry ¶ 14.4
- 14.3 Characteristics of Lithium Primary Batteries ¶ 14.7
- 14.4 Safety and Handling of Lithium Batteries ¶ 14.15
- 14.5 Lithium/Sulfur Dioxide (Li/SO<sub>2</sub>) Cells / 14.17
- 14.6 Lithium/Thionyl Chloride (Li/SOCl<sub>2</sub>) Cells / 14.26
- 14.7 Lithium/Oxychloride Cells ¶ 14.39
- 14.8 Lithium/Manganese Dioxide (Li/MnO<sub>2</sub>) Cells / 14.48
- 14.9 Lithium/Carbon Monofluoride [Li/(CF)<sub>x</sub>] Cells / 14.59
- 14.10 Lithium/Iron Disulfide (Li/FeS<sub>2</sub>) Cells / 14.69
- 14.11 Lithium/Copper Oxide (Li/CuO) and Lithium/Copper Oxyphosphate [Li/Cu<sub>4</sub>O(PO<sub>4</sub>)<sub>2</sub>] Cells / 14.76

## Chapter 15. Solid-Electrolyte Cells

15.1

- 15.1 General Characteristics ¶ 15.1
- 15.2 Li/LiI(Al<sub>2</sub>O<sub>3</sub>)/Metal Salt Cells / 15.3
- 15.3 The Lithium/Iodine Cells ¶ 15.9
- 15.4 Other Solid-Electrolyte Cells ¶ 15.21
- 15.5 Rechargeable Solid-Electrolyte Cells ¶ 15.22

## Part 3 Reserve Batteries

---

### Chapter 16. Introduction 16.3

---

- 16.1 Classification of Reserve Batteries ¶ 16.3
- 16.2 Characteristics of Reserve Batteries ¶ 16.4

---

### Chapter 17. Magnesium Water-Activated Batteries 17.1

---

- 17.1 General Characteristics ¶ 17.1
- 17.2 Chemistry ¶ 17.2
- 17.3 Types of Water-Activated Batteries ¶ 17.3
- 17.4 Construction ¶ 17.4
- 17.5 Performance Characteristics ¶ 17.10
- 17.6 Battery Applications ¶ 17.23
- 17.7 Battery Types and Sizes ¶ 17.23

---

### Chapter 18. Zinc/Silver Oxide Reserve Batteries 16.1

---

- 18.1 General Characteristics ¶ 18.1
- 18.2 Chemistry ¶ 18.1
- 18.3 Construction ¶ 18.2
- 18.4 Performance Characteristics ¶ 18.7
- 18.5 Cells and Battery Types and Sizes / 18.13
- 18.6 Special Features and Handling ¶ 18.13
- 18.7 Cost / 18.14

---

### Chapter 19. Spin-Dependent Reserve Batteries 19.1

---

- 19.1 General Characteristics ¶ 19.1
- 19.2 Chemistry / 19.1
- 19.3 Design Considerations ¶ 19.3
- 19.4 Performance Characteristics ¶ 19.5

---

### Chapter 20. Ammonia Batteries 20.1

---

- 20.1 General Characteristics ¶ 20.1
- 20.2 Chemistry / 20.2
- 20.3 Construction ¶ 20.3
- 20.4 Performance Characteristics ¶ 20.6
- 20.5 Battery Types and Characteristics / 20.10

---

### Chapter 21. Ambient-Temperature Lithium Anode Reserve Batteries 21.1

---

- 21.1 General Characteristics ¶ 21.1
- 21.2 Chemistry ¶ 21.1
- 21.3 Construction ¶ 21.3
- 21.4 Performance Characteristics ¶ 21.11

---

### Chapter 22. Thermal Batteries 22.1

---

- 22.1 General Characteristics ¶ 22.1
- 22.2 Description of Electrochemical Systems / 22.2

- 22.3 Cell Chemistry / 22.7
- 22.4 Cell Construction / 22.10
- 22.5 Cell Stack Designs / 22.13
- 22.6 Performance Characteristics / 22.15
- 22.7 Testing and Surveillance / 22.19
- 22.8 New Developments / 22.20

## Part 4 Secondary Batteries

### Chapter 23. Introduction

23.3

- 23.1 General Characteristics and Applications of Secondary Batteries / 23.3
- 23.2 Types and Characteristics of Secondary Batteries / 23.5
- 23.3 Comparison of Performance Characteristics for Secondary Battery Systems / 23.12

### Chapter 24. Lead-Acid Batteries

24.1

- 24.1 General Characteristics / 24.1
- 24.2 Chemistry / 24.6
- 24.3 Constructional Features, Materials, and Manufacturing Methods / 24.13
- 24.4 SLI (Automotive) Batteries: Construction and Performance / 24.34
- 24.5 Deep-Cycle and Traction Batteries: Construction and Performance / 24.42
- 24.6 Stationary Batteries: Construction and Performance / 24.52
- 24.7 Charging and Charging Equipment / 24.63
- 24.8 Maintenance, Safety, and Operational Features / 24.77
- 24.9 Applications and Markets / 24.83

### Chapter 25. Sealed Lead-Acid Batteries

25.1

- 25.1 General Characteristics / 25.1
- 25.2 Chemistry / 25.2
- 25.3 Cell Construction / 25.3
- 25.4 Performance Characteristics / 25.5
- 25.5 Charging Characteristics / 25.23
- 25.6 Safety and Handling / 25.35
- 25.7 Cell Types and Sizes / 25.36

### Chapter 26. Vented Industrial Nickel-Cadmium Batteries

26.1

- 26.1 General Characteristics / 26.1
- 26.2 Chemistry / 26.3
- 26.3 Construction / 26.3
- 26.4 Performance Characteristics / 26.5
- 26.5 Charging Characteristics / 26.12
- 26.6 Manufacturers and Market Segments / 26.12
- 26.7 Applications / 26.13

### Chapter 27. Vented Sintered-Plate Nickel-Cadmium Batteries

27.1

- 27.1 General Characteristics / 27.1
- 27.2 Chemistry / 27.2

- 27.3 Construction ¶ 27.3
- 27.4 Performance Characteristics ¶ 27.5
- 27.5 Charging Characteristics ¶ 27.15
- 27.6 Maintenance Procedures ¶ 27.19
- 27.7 Reliability ¶ 27.21
- 27.8 Cell and Battery Designs ¶ 27.25

---

## **Chapter 28. Sealed Nickel-Cadmium Batteries**

28.1

- 28.1 General Characteristics ¶ 28.1
- 28.2 Chemistry ¶ 28.2
- 28.3 Cell Construction ¶ 28.3
- 28.4 Performance Characteristics / 28.5
- 28.5 Charging Characteristics ¶ 28.19
- 28.6 Special-Purpose Cells ¶ 28.25

---

## **Chapter 29. Nickel-Zinc Batteries**

29.1

- 29.1 General Characteristics / 29.1
- 29.2 Chemistry ¶ 29.1
- 29.3 Cell Components / 29.2
- 29.4 Construction ¶ 29.6
- 29.5 Performance Characteristics ¶ 29.11
- 29.6 Charging Characteristics ¶ 29.15
- 29.7 Applications ¶ 29.16
- 29.8 Special Handling ¶ 29.18

---

## **Chapter 30. Iron Electrode Batteries**

30.1

- 30.1 General Characteristics ¶ 30.1
- 30.2 Chemistry ¶ 30.1
- 30.3 Conventional Nickel-Iron Batteries ¶ 30.4
- 30.4 New Developments ¶ 30.13

---

## **Chapter 31. Silver Oxide Batteries**

31.1

- 31.1 General Characteristics ¶ 31.1
- 31.2 Chemistry ¶ 31.3
- 31.3 Cell Construction and Components ¶ 31.3
- 31.4 Performance Characteristics ¶ 31.8
- 31.5 Charging Characteristics ¶ 31.18
- 31.6 Cell Types and Sizes ¶ 31.21
- 31.7 Special Features and Handling ¶ 31.21
- 31.8 Applications ¶ 31.24
- 31.9 Recent Developments ¶ 31.27

---

## **Chapter 32. Nickel-Hydrogen Batteries**

32.1

- 32.1 General Characteristics / 32.1
- 32.2 Chemistry ¶ 32.1
- 32.3 Cell and Electrode-Stack Components ¶ 32.2
- 32.4 IPV Ni-H<sub>2</sub> Cell Construction / 32.5
- 32.5 Ni-H<sub>2</sub> Battery Construction / 32.13

- 32.6 Applications ¶ 32.17
- 32.7 Performance Characteristics ¶ 32.20
- 32.8 Advanced Designs ¶ 32.26

---

### **Chapter 33. Sealed Nickel-Metal Hydride Batteries** 33.1

- 33.1 General Characteristics ¶ 33.1
- 33.2 Chemistry ¶ 33.1
- 33.3 Construction ¶ 33.4
- 33.4 Discharge Characteristics ¶ 33.6
- 33.5 Charging Sealed Nickel-Metal Hydride Batteries ¶ 33.17
- 33.6 Cycle and Battery Life ¶ 33.24
- 33.7 Proper Use and Handling ¶ 33.26
- 33.8 Applications ¶ 33.27
- 33.9 Cell Types and Manufacturers ¶ 33.28

---

### **Chapter 34. Rechargeable Zinc/Alkaline/Manganese Dioxide Cells** 34.1

- 34.1 General Characteristics ¶ 34.1
- 34.2 Chemistry ¶ 34.2
- 34.3 Construction ¶ 34.3
- 34.4 Performance ¶ 34.4
- 34.5 Charge Methods ¶ 34.6
- 34.6 Types of Cells and Batteries ¶ 34.12

## **Part 5 Advanced Battery Systems**

---

### **Chapter 35. introduction** 35.3

- 35.1 Performance Requirements for Advanced Rechargeable Batteries / 35.3
- 35.2 Types and Characteristics of Advanced Rechargeable Battery Systems ¶ 35.7
- 35.3 Near-Term Rechargeable Batteries ¶ 35.10
- 35.4 Advanced Rechargeable Batteries-General Characteristics ¶ 35.15

---

### **Chapter 36. Rechargeable Lithium Batteries (Ambient Temperature)** 36.1

- 36.1 General Characteristics ¶ 36.1
- 36.2 Chemistry ¶ 36.4
- 36.3 Characteristics of Lithium Rechargeable Batteries ¶ 36.17
- 36.4 Characteristics of Specific Rechargeable Lithium Cells and Batteries ¶ 36.28

---

### **Chapter 37. Zinc/Bromine Batteries** 37.1

- 37.1 General Characteristics ¶ 37.1
- 37.2 Description of the Electrochemical System ¶ 37.2
- 37.3 Construction ¶ 37.4
- 37.4 Performance ¶ 37.5
- 37.5 Tradeoff Considerations ¶ 37.9
- 37.6 Safety and Hazards ¶ 37.9
- 37.7 Applications and System Designs / 37.9
- 37.8 Developments and Projections ¶ 37.13

---

**Chapter 38. Metal/Air Batteries** **38.1**

---

- 38.1 General Characteristics *¶ 38.1*
- 38.2 Chemistry *¶ 38.2*
- 38.3 Zinc/Air Batteries *¶ 38.5*
- 38.4 Aluminum/Air Batteries *¶ 38.22*
- 38.5 Magnesium/Air Batteries *¶ 38.39*
- 38.6 Lithium/Air Batteries *¶ 38.41*

---

**Chapter 39. Lithium/iron Sulfide Batteries** **39.1**

---

- 39.1 General Characteristics *¶ 39.1*
- 39.2 Description of Electrochemical System *¶ 39.2*
- 39.3 Construction *¶ 39.3*
- 39.4 Performance Characteristics *¶ 39.5*
- 39.5 Applications and Battery Designs *¶ 39.10*

---

**Chapter 40. Sodium Beta Batteries** **40.1**

---

- 40.1 General Characteristics *¶ 40.1*
- 40.2 Description of Electrochemical Systems *¶ 40.1*
- 40.3 Sodium/Sulfur Technology *¶ 40.3*
- 40.4 Sodium/Sulfur Technology Status *¶ 40.6*
- 40.5 Sodium/Sulfur Design Considerations *¶ 40.17*
- 40.6 Sodium/Metal Chloride Technology *¶ 40.23*

## **Part 6 Appendices**

---

**A. Definitions** **A.1**

---

---

**B. Standard Reduction Potential** **B.1**

---

---

**C. Electrochemical Equivalents of Battery Materials** **c.1**

---

---

**D. Standard Symbols and Constants** **D.1**

---

---

**E. Conversion Factors** **E.1**

---

---

**F. Major Battery Manufactures** **F.1**

---

---

**G. Bibliography** **G.1**

---

Index follows Appendices