

Table of Contents

Chapter 1 Electrical Fundamentals

Unit 1 Matter

1.0 Introduction	3
1.1 Matter	3
1.2 Atomic Theory	3
1.3 Law of Electrical Charges	4
1.4 Law of Atomic Charges	4
1.5 Charged Material (Static Charge).....	5
1.6 Neutralizing a Charge	6
1.7 Lightning	6
1.8 Lightning Protection	7
Unit 1–Summary	9
Unit 1–Conclusion.....	10
Unit 1–Practice Questions.....	11

Unit 2 Electron Theory

2.0 Introduction	15
2.1 Electron Orbits.....	15
2.2 Valence Electrons	15
2.3 Freeing Electrons from an Atom	16
2.4 Conductors	16
2.5 Insulators	16
2.6 Semiconductors.....	16
2.7 Atomic Bonding.....	17
2.8 Compounds.....	17
Unit 2–Summary	19
Unit 2–Conclusion.....	20
Unit 2–Practice Questions.....	21

Unit 3 Magnetism

3.0 Introduction	23
3.1 The Natural Magnet.....	23
3.2 Magnetic Polarities.....	23

3.3 Magnetic Compass.....	23
3.4 Magnetic Molecule.....	24
3.5 Magnetic Properties	24
3.6 How to Magnetize Iron	24
3.7 Permanent and Temporary Magnets	24
3.8 Demagnetizing Magnets.....	24
3.9 Magnetic Lines of Force	25
3.10 Magnetic Materials	25
3.11 Law of Attraction and Repulsion.....	25
3.12 Retentivity.....	26
3.13 Permeability	26
Unit 3–Summary	27
Unit 3–Conclusion.....	29
Unit 3–Practice Questions.....	30

Unit 4 Electricity

4.0 Introduction	33
4.1 Electric Current Flow (Electricity)	33
4.2 Electricity	33
4.3 Useful Purposes of Electricity	36
4.4 Dangers of Electricity	39
4.5 <i>National Electrical Code</i>	41
Unit 4–Summary	43
Unit 4–Conclusion.....	46
Unit 4–Practice Questions.....	47

Unit 5 Electromagnetism

5.0 Introduction	51
5.1 Electromagnetism in a Wire	51
5.2 Field Intensity	51
5.3 Field Interaction	51
5.4 Field Interaction of Loops.....	52
5.5 Electromagnetism in a Coil	52
5.6 Magnetic Core.....	53
5.7 Ampere and Turns.....	53

Unit 5–Summary 54
 Unit 5–Conclusion..... 55
 Unit 5–Practice Questions..... 56

Unit 6 Uses of Electromagnetism

6.0 Introduction 59
 6.1 Basic Electric Meters..... 59
 6.2 Electric Motors 62
 6.3 Electrical Generators..... 64
 6.4 Electromagnetic Relay..... 64
 Unit 6–Summary 67
 Unit 6–Conclusion..... 70
 Unit 6–Practice Questions..... 71
Chapter 1–Final Exam..... 73

**Chapter 2
 Basic Electricity**

Unit 7 The Electrical Circuit

7.0 Introduction 81
 7.1 The Electrical Circuit 81
 7.2 Electron Current Flow Theory 82
 7.3 Conventional Current Flow Theory 82
 7.4 Voltage (Pressure)..... 82
 7.5 Resistance 83
 7.6 Electric Current..... 84
 7.7 Power 84
 7.8 Electrical Formulas 84
 Unit 7–Summary 85
 Unit 7–Conclusion..... 86
 Unit 7–Practice Questions..... 87

Unit 8 Math

8.0 Introduction 89
 8.1 Whole Numbers 89
 8.2 Decimals 89
 8.3 Fractions 89
 8.4 Percentages..... 89
 8.5 Multiplier 90
 8.6 Percent Increase 91
 8.7 Reciprocals..... 91

8.8 Squaring a Number..... 92
 8.9 Square Root 93
 8.10 Volume 93
 8.11 Kilo..... 94
 8.12 Rounding Off 94
 8.13 Parentheses..... 95
 8.14 Testing Your Answer for Reasonableness..... 95
 Unit 8–Summary 97
 Unit 8–Conclusion..... 99
 Unit 8–Practice Questions..... 100

Unit 9 Electrical Formulas

9.0 Introduction 105
 9.1 Electrical Circuit 105
 9.2 Power Source..... 105
 9.3 Conductance 106
 9.4 Circuit Resistance..... 107
 9.5 Ohm’s Law 107
 9.6 Ohm’s Law and Alternating Current 108
 9.7 Ohm’s Law Formula Circle..... 108
 9.8 PIE Formula Circle 110
 9.9 Formula Wheel 111
 9.10 Using the Formula Wheel..... 111
 9.11 Power Losses of Conductors 112
 9.12 Cost of Power..... 113
 9.13 Power Changes with the Square of the Voltage.113
 Unit 9–Summary 116
 Unit 9–Conclusion..... 118
 Unit 9–Practice Questions..... 119
Chapter 2–Final Exam..... 123

**Chapter 3
 Basic Electrical Circuits**

Unit 10 Series Circuits

10.0 Introduction 131
 10.1 Practical Uses of the Series Circuit..... 131
 10.2 Understanding Series Calculations 132
 10.3 Series Circuit Calculations..... 135
 10.4 Power Calculations 136
 10.5 Variations 136

10.6 Series Circuit Notes.....	136
10.7 Series-Connected Power Supplies	136
Unit 10–Summary.....	138
Unit 10–Conclusion.....	140
Unit 10–Practice Questions.....	141
Unit 11 Parallel Circuits	
11.0 Introduction	143
11.1 Practical Uses of the Parallel Circuits	143
11.2 Understanding Parallel Calculations	145
11.3 Circuit Resistance.....	146
11.4 Parallel Circuit Notes	148
11.5 Parallel-Connected Power Supplies	149
Unit 11–Summary.....	150
Unit 11–Conclusion.....	152
Unit 11–Practice Questions.....	153
Unit 12 Series-Parallel Circuits	
12.0 Introduction	155
12.1 Review of Series and Parallel Circuits	155
12.2 Working With Series-Parallel Circuits	156
12.3 Voltage	157
Unit 12–Summary.....	158
Unit 12–Conclusion.....	159
Unit 12–Practice Questions.....	160
Unit 13 Multiwire Circuits	
13.0 Introduction	161
13.1 Neutral Conductor	161
13.2 Grounded Conductor	162
13.3 Current Flow on the Grounded (Neutral) Conductor	162
13.4 Balanced Systems	163
13.5 Unbalanced Current.....	163
13.6 Multiwire Branch Circuits	165
13.7 Dangers of Multiwire Circuits.....	166
13.8 NEC Requirements.....	167
Unit 13–Summary.....	169
Unit 13–Conclusion.....	171
Unit 13–Practice Questions.....	172
Chapter 3–Final Exam.....	175

Chapter 4 Electrical Systems and Protection

Unit 14 The Electrical System

14.0 Introduction	183
14.1 Current Flow.....	183
14.2 Utility Neutral Current Path	183
14.3 Utility Ground-Fault Current Path	184
14.4 Premises Neutral Current Path.....	184
14.5 Premises Ground-Fault Current Path.....	185
14.6 Utility High-Voltage Transmission Lines.....	185
14.7 Conductor Voltage Drop	185
14.8 Conductor Power Loss	186
14.9 Reducing Voltage Drop and Power Loss.....	187
14.10 Generating Plants	187
14.11 Step-Up Substation at Generating Plant.....	187
14.12 Transmission Line	188
14.13 Step-Down Substation.....	188
14.14 Primary Distribution Feeders	188
14.15 Distribution Transformer	188
14.16 Secondary Distribution Line	189
Unit 14–Summary.....	190
Unit 14–Conclusion.....	192
Unit 14–Practice Questions.....	193

Unit 15 Protection Devices

15.0 Introduction	197
Part A—Overcurrent Protection Devices	197
15.1 Overcurrent Protection.....	197
15.2 Clearing Faults	198
15.3 Overcurrent Protection Device Types	199
15.4 Fuse.....	199
15.5 Circuit Breaker Trip Elements	200
15.6 Circuit Breaker Types	200
15.7 Available Short-Circuit Current.....	201
15.8 Interrupting Rating	201
15.9 Short-Circuit Current Rating	202
15.10 Current-Limiting Protection.....	203
Part B—Ground-Fault Circuit Interrupters	203
15.11 How a GFCI Works	203

15.12 Neutral-to-Case Detection204
 15.13 Line-to-Neutral Shock Hazard204
 15.14 GFCI Fails—Circuit Remains Energized.....205
 15.15 GFCI Test Button205
Part C—Arc-Fault Circuit Interrupters205
 15.16 Arcing Definition205
 15.17 Series Versus Parallel Arc206
 15.18 AFCI and the *NEC*206
 15.19 AFCI—How They Operate207
Part D—Ground- Fault Protection of Equipment.....207
 15.20 Ground-Fault Protection of Equipment
 Definition207
 Unit 15–Summary.....208
 Unit 15–Conclusion.....212
 Unit 15–Practice Questions.....213
Chapter 4—Final Exam.....219

Chapter 5 Alternating Current

Unit 16 Alternating Current

16.0 Introduction227
 16.1 Current Flow.....227
 16.2 Why Alternating Current is Used227
 16.3 How Alternating Current is Produced228
 16.4 AC Generator.....228
 16.5 Waveform229
 16.6 Sine Wave230
 16.7 Nonsymmetrical Waveform230
 16.8 Frequency.....231
 16.9 Phase231
 16.10 Degrees.....231
 16.11 Lead or Lag.....232
 16.12 Values of Alternating Current232
 Unit 16–Summary.....234
 Unit 16–Conclusion.....236
 Unit 16–Practice Questions.....237

Unit 17 Capacitance

17.0 Introduction241
 17.1 Charged Capacitor242

17.2 Electrical Field242
 17.3 Discharging a Capacitor.....243
 17.4 Determining Capacitance243
 17.5 Uses of Capacitors244
 17.6 Phase Relationship245
 Unit 17–Summary.....246
 Unit 17–Conclusion.....247
 Unit 17–Practice Questions.....248

Unit 18 Induction

18.0 Introduction251
 18.1 Self-Induction.....251
 18.2 Induced Voltage and Applied Current251
 18.3 Conductor AC Resistance252
 18.4 Impedance.....253
 18.5 Conductor Shape.....253
 18.6 Magnetic Cores254
 18.7 Self-Induced and Applied Voltage255
 18.8 Current Flow.....255
 18.9 Phase Relationship256
 18.10 Uses of Induction.....256
 Unit 18–Summary.....257
 Unit 18–Conclusion.....259
 Unit 18–Practice Questions.....260

Unit 19 Power Factor and Efficiency

19.0 Introduction263
Part A—Power Factor.....263
 19.1 Apparent Power Volt-Ampere263
 19.2 True Power (Watts).....264
 19.3 Power Factor264
 19.4 Unity Power Factor265
 19.5 Power Factor Formulas265
 19.6 Cost of True Power.....266
 19.7 Effects of Power Factor266
Part B—Efficiency268
 19.8 Efficiency.....268
 19.9 Efficiency Formulas.....268
 Unit 19–Summary.....271
 Unit 19–Conclusion.....273

Unit 19—Practice Questions.....	274	22.1 Transformer Basics	307
Chapter 5—Final Exam.....	277	22.2 Secondary Induced Voltage	307
Chapter 6		22.3 Autotransformers	308
Motors, Generators, and Transformers		22.4 Power Losses	309
Unit 20 Motors		22.5 Harmonic Current.....	310
20.0 Introduction	285	22.6 Efficiency.....	311
Part A—Motor BASICS.....	285	22.7 Transformer Turns Ratio	311
20.1 Motor Principles	285	22.8 Transformer kVA Rating	313
20.2 Dual-Voltage AC Motors	285	22.9 Current Flow.....	313
20.3 Motor Horsepower Ratings.....	286	22.10 Current Rating	314
20.4 Motor Current Ratings.....	287	Unit 22—Summary.....	316
20.5 Calculating Motor FLA	287	Unit 22—Conclusion.....	318
20.6 Motor Starting Current.....	289	Unit 22—Practice Questions.....	319
20.7 Motor Running Current	289	Chapter 6—Final Exam.....	322
20.8 Motor Locked-Rotor Current (LRC)	289	Basic Electrical Theory	
20.9 Motor Overload Protection	289	Final Exam	329
Part B—Direct-Current Motors.....	290	Annex A—	
20.10 Direct-Current Motor Principles	290	Grounding and Bonding	
20.11 Direct-Current Motor Types	291	Introduction.....	349
20.12 Reversing the Rotation of a DC Motor	291	Understanding the Basics of Electrical Systems.....	349
Part C—Alternating-Current Motors.....	292	Understanding Electrical Shock Hazard.....	351
20.13 AC Induction Motor	292	What Determines the Severity of Electrical Shock...352	
20.14 Alternating-Current Motor Types	292	Clearing a Ground Fault.....	353
20.15 Reversing the Rotation of an AC Motor	293	Why Grounding is Often Difficult to Understand...354	
Unit 20—Summary.....	294	250.1 Scope.....	357
Unit 20—Conclusion.....	297	250.2 Definitions.....	357
Unit 20—Practice Questions.....	298	250.3 Other <i>Code</i> Sections	358
Unit 21 Generators		250.4 General Requirements for Grounding and Bonding	359
21.0 Introduction	303	250.4(A) Summary.....	365
21.1 Direct-Current Generator.....	303	250.6 Objectionable (Neutral) Current.....	365
21.2 Alternating-Current Generator	303	Index	373
21.3 Three-Phase Generator.....	304		
Unit 21—Summary.....	305		
Unit 21—Conclusion.....	305		
Unit 21—Practice Questions.....	306		
Unit 22 Transformers			
22.0 Introduction	307		