



Table of Contents

Preface	x	3.6	How to Magnetize Iron	24
Chapter 1		3.7	Permanent and Temporary Magnets	24
Electrical Fundamentals		3.8	Demagnetizing Magnets.....	25
Unit 1 Matter	3	3.9	Magnetic Lines of Force	25
Introduction	3	3.10	Magnetic Materials.....	25
1.1 Matter	3	3.11	Law of Attraction and Repulsion	25
1.2 Atomic Theory	3	3.12	Retentivity	26
1.3 Law of Electrical Charges.....	4	3.13	Permeability	26
1.4 Law of Atomic Charges	5	Unit 3—Summary	27	
Negative Atomic Charge	5	Unit 3—Conclusion	28	
Positive Atomic Charge.....	5	Unit 3—Practice Questions	29	
1.5 Charged Material (Static Charge).....	5	Unit 4 Electricity	33	
Static Voltage	6	Introduction	33	
Reducing Static Charge.....	6	4.1 Electrical Current Flow (Electricity)	33	
1.6 Neutralizing a Charge.....	6	4.2 Electricity	34	
1.7 Lightning.....	7	Chemical Activity (Electrochemistry)	34	
1.8 Lightning Protection	7	Magnetism (Magnetolectricity).....	34	
Unit 1—Summary	9	Light (Photoelectricity).....	35	
Unit 1—Conclusion	10	Thermo Energy (Thermoelectricity).....	36	
Unit 1—Practice Questions	11	Pressure (Piezoelectricity)	36	
Unit 2 Electron Theory	15	4.3 Useful Purposes of Electricity	37	
Introduction	15	Electrochemistry	37	
2.1 Electron Orbits	15	Electromagnetism	37	
2.2 Valence Electrons.....	16	Heat (Resistance)	38	
2.3 Freeing Electrons from an Atom	16	Illumination (Lighting).....	38	
2.4 Conductors.....	16	4.4 Danger of Electricity.....	39	
2.5 Insulators	17	Understanding Electrical Shock Hazard	39	
2.6 Semiconductors	17	What Determines the Severity		
2.7 Atomic Bonding.....	17	of Electrical Shock?.....	39	
2.8 Compounds.....	17	Clearing a Ground Fault.....	40	
Unit 2—Summary	19	Fire	41	
Unit 2—Conclusion	20	Electrical Arc Blast	41	
Unit 2—Practice Questions	21	4.5 National Electrical Code	42	
Unit 3 Magnetism.....	23	Unit 4—Summary	43	
Introduction	23	Unit 4—Conclusion	45	
3.1 The Natural Magnet	23	Unit 4—Practice Questions	46	
3.2 Magnetic Polarities.....	23	Unit 5 Electromagnetism	49	
3.3 Magnetic Compass.....	23	Introduction	49	
3.4 Magnetic Molecule.....	24	5.1 Electromagnetism in a Wire.....	49	
3.5 Magnetic Properties	24	5.2 Field Intensity.....	50	
		5.3 Field Interaction.....	50	
		5.4 Field Interaction of Loops	50	



5.5	Electromagnetism in a Coil.....	51	Unit 8 Math	85	
5.6	Magnetic Core.....	51	Introduction	85	
5.7	Ampere and Turns	51	8.1 Whole Numbers.....	85	
Unit 5—Summary	52	8.2 Decimal.....	85	8.3 Fractions.....	85
Unit 5—Conclusion	53	8.4 Percentages	86	8.5 Multiplier.....	86
Unit 5—Practice Questions	54	8.6 Percent Increase	87	8.7 Reciprocals	87
Unit 6 Uses of Electromagnetism.....	57	8.8 Squaring a Number	88	8.8 Square Root	89
Introduction	57	8.9 Volume.....	89	8.10 Kilo	89
6.1 Basic Electric Meters.....	57	8.11 Rounding Off.....	90	8.12 Parentheses	90
Voltmeter	58	8.13 Testing Your Answer for Reasonableness.....	91	Unit 8—Summary	92
DC Voltmeter	58	Unit 8—Conclusion	93	Unit 8—Practice Questions	94
DC Ammeter.....	58	Unit 9 Electrical Formulas.....	99	Introduction	99
Clamp-on AC Ammeter	59	9.1 Electrical Circuit	99	9.1 Power Source.....	100
Ohmmeters	60	9.2 Direct Current.....	100	Direct Current.....	100
Wheatstone Bridge.....	60	9.2 Alternating Current.....	100	Alternating Current.....	100
Megohmmeter.....	60	9.3 Conductance	100	9.3 Circuit Resistance	101
6.2 Electric Motor	60	9.4 Ohm’s Law	101	9.4 Ohm’s Law and Alternating Current.....	102
Motor Components.....	60	9.6 Direct Current.....	102	Direct Current.....	102
Understanding Motor Motion	61	9.6 Alternating Current.....	102	Alternating Current.....	102
6.3 Electrical Generator.....	62	9.7 Ohm’s Law Formula Circle.....	102	9.7 PIE Formula Circle	103
DC Generator	62	9.8 Formula Wheel	104	9.9 Using the Formula Wheel.....	104
AC Generator.....	62	9.10 Power Losses of Conductors	105	9.11 Cost of Power.....	106
6.4 Electromagnetic Relay.....	63	9.12 Power Changes with the Square of the Voltage.....	107	Power Example at 230V	107
Contacts.....	63	Power Example at 208V	107	Power Example at 240V	108
Holding Relay	64	Unit 9—Summary	109	Unit 9—Conclusion	110
Unit 6—Summary	65	Unit 9—Practice Questions	111	Chapter 2—Final Exam.....	115
Unit 6—Conclusion	67				
Unit 6—Practice Questions	68				
Chapter 1—Final Exam.....	70				
Chapter 2					
Basic Electricity					
Unit 7 The Electrical Circuit	77				
Introduction	77				
7.1 The Electrical Circuit	77				
7.2 Electron Current Flow Theory	78				
7.3 Conventional Current Flow Theory	78				
7.4 Voltage (Pressure)	78				
7.5 Resistance	79				
Conductor Resistance.....	79				
7.6 Electric Current	80				
7.7 Power.....	80				
7.8 Electrical Formulas.....	80				
Unit 7—Summary	81				
Unit 7—Conclusion	82				
Unit 7—Practice Questions	83				



Chapter 3 Basic Electrical Circuits

Unit 10 Series Circuits	123	Series Circuit Review	147
Introduction	123	Parallel Circuit Review	148
10.1 Practical Uses of the Series Circuit	123	12.2 Working Series-Parallel Circuits	148
Lighting	123	12.3 Voltage	149
Control Circuit	124	Unit 12—Summary	150
Signaling Circuit	124	Unit 12—Conclusion	151
Internal Equipment Wiring	124	Unit 12—Practice Questions	152
10.2 Understanding Series Calculations	124	Unit 13 Multiwire Circuits	153
Resistance	124	Introduction	153
Voltage	125	13.1 Neutral Conductor	153
Kirchoff's Voltage Law	125	13.2 Grounded Conductor	154
Kirchoff's Current Law	126	13.3 Current Flow on the Grounded (Neutral) Conductor	154
Power	127	2-Wire Circuit	154
10.3 Series Circuit Calculations	127	3-Wire, 120/240V, Single-Phase Circuit	154
10.4 Power Calculations	128	13.4 Balanced Systems	155
10.5 Variations	128	13.5 Unbalanced Current	155
10.6 Series Circuit Notes	128	3-Wire, 120/240V, Single-Phase Circuit	155
10.7 Series-Connected Power Supplies	128	3-Wire Circuit from a 4-wire, Three-Phase System	156
Unit 10—Summary	130	4-Wire, Three-Phase Circuit	156
Unit 10—Conclusion	131	13.6 Multiwire Branch Circuit	156
Unit 10—Practice Questions	132	2-Wire Circuit Voltage Drop	157
Unit 11 Parallel Circuits	135	Multiwire Circuit Voltage Drop	157
Introduction	135	13.7 Dangers of Multiwire Circuits	158
11.1 Practical Uses of the Parallel Circuit	135	Fire Hazard	158
Receptacle	135	Destruction of Equipment as Well as Fire Hazard	158
Lighting	135	13.8 NEC Requirements	159
Other Uses	135	Unit 13—Summary	160
11.2 Understanding Parallel Calculations	137	Unit 13—Conclusion	161
Voltage	137	Unit 13—Practice Questions	162
Kirchoff's Current Law	137	Chapter 3—Final Exam	165
Power	138		
11.3 Circuit Resistance	138	Chapter 4	
Equal Resistance Method	138	Electrical Systems and Protection	
Product-Over-Sum Method	139	Unit 14 The Electrical System	173
Reciprocal Method	140	Introduction	173
11.4 Parallel Circuit Notes	140	14.1 Current Flow	173
11.5 Parallel-Connected Power Supplies	141	14.2 Utility Neutral Current Path	173
Unit 11—Summary	142	Multipoint Neutral Ground	173
Unit 11—Conclusion	143	14.3 Utility Ground-Fault Current Path	174
Unit 11—Practice Questions	144	14.4 Premises Neutral Current Path	174
Unit 12 Series-Parallel Circuits	147	Single Point Neutral Bond	175
Introduction	147	14.5 Premises Ground-Fault Current Path	175
12.1 Review of Series and Parallel Circuits	147	Earth as Ground Fault Path for Systems 600V or Less	175



14.6	Utility High-Voltage Transmission Lines	175
14.7	Conductor Voltage Drop	175
14.8	Conductor Power Loss	176
	Current	176
14.9	Reducing Voltage Drop and Power Loss	177
	138 kV Transmission Line	177
14.10	Generating Plants	177
14.11	Step-Up Substation at Generating Plant	177
14.12	Transmission Line	178
14.13	Step-Down Substation	178
14.14	Primary Distribution Feeders	178
14.15	Distribution Transformer	178
14.16	Secondary Distribution Line	178
	Unit 14—Summary	179
	Unit 14—Conclusion	181
	Unit 14—Practice Questions	182
Unit 15	Protection Devices	185
	Introduction	185
	<i>Part A—Overcurrent Protection Devices</i>	185
15.1	Overcurrent Protection	185
	Overload	185
	Ground Fault	186
	Short Circuit	186
15.2	Clearing Faults	186
	Time—Current Curves	186
	Remove Dangerous Touch Voltage	186
15.3	Overcurrent Protection Device Types	187
15.4	Fuse	187
	Construction	187
	Overload Protection	187
	Short-Circuit and Ground-Fault Protection	187
15.5	Circuit Breaker Trip Elements	188
	Thermal Trip Element	188
	Magnetic Trip Element	188
15.6	Circuit Breaker Types	188
	Inverse-Time	188
	Adjustable-Trip	188
	Instantaneous-Trip	188
15.7	Available Short-Circuit Current	188
15.8	Interrupting Rating	189
15.9	Short-Circuit Current Rating	190
15.10	Current-Limiting Protection	190
	<i>Part B—Ground-Fault Circuit Interrupters</i>	191
15.11	How a GFCI Works	191
15.12	Neutral-to-Case Detection	191
15.13	Line-to-Neutral Shock Hazard	192
15.14	GFCI Fails—Circuit Remains Energized	192
15.15	GFCI Test Button	193
	<i>Part C—Arc-Fault Circuit Interrupter</i>	193
15.16	Arcing Definition	193
15.17	Series Versus Parallel Arc	193
	Series Arc	193
	Parallel Arc	193
15.18	AFCI and the <i>NEC</i>	194
15.19	AFCI—How They Operate	194
	<i>Part D—Ground-Fault Protection of Equipment</i>	194
15.20	Ground-Fault Protection of Equipment Definition	194
	Unit 15—Summary	195
	Unit 15—Conclusion	198
	Unit 15—Practice Questions	199
	Chapter 4—Final Exam	205
	Chapter 5 Alternating Current	
Unit 16	Alternating Current	213
	Introduction	213
16.1	Current Flow	213
16.2	Why Alternating Current is Used	213
16.3	How Alternating Current is Produced	214
16.4	AC Generator	214
16.5	Waveform	215
	Direct-Current Waveform	215
	Alternating-Current Waveform	215
16.6	Sine Wave	216
	Sinusoidal Waveform	216
	Nonsinusoidal Waveform	216
16.7	Nonsymmetrical Waveform	216
16.8	Frequency	216
16.9	Phase	217
16.10	Degrees	217
16.11	Lead or Lag	217
	Leading	217
	Lagging	217
16.12	Values of Alternating Current	218
	Instantaneous Value	218
	Peak Value	218
	Effective Value	218
	RMS Value	218
	Unit 16—Summary	219
	Unit 16—Conclusion	220
	Unit 16—Practice Questions	221

Unit 17 Capacitance	225	<i>Part A—Power Factor</i>	245
Introduction	225	19.1 Apparent Power (Volt-Ampere)	245
Capacitor Current Flow	225	19.2 True Power (Watts)	246
17.1 Charged Capacitor	225	Direct Current	246
17.2 Electrical Field	226	Alternating Current	246
17.3 Discharging a Capacitor	226	19.3 Power Factor	246
17.4 Determining Capacitance	227	19.4 Unity Power Factor	246
Plate Distance	227	19.5 Power Factor Formulas	247
Surface Area	227	19.6 Cost of True Power	248
Dielectric Strength	227	19.7 Effects of Power Factor	248
17.5 Uses of Capacitors	227	<i>Part B—Efficiency</i>	250
Electronic Power Supplies	228	19.8 Efficiency	250
17.6 Phase Relationship	228	19.9 Efficiency Formulas	250
Unit 17—Summary	229	Unit 19—Summary	252
Unit 17—Conclusion	230	Unit 19—Conclusion	253
Unit 17—Practice Questions	231	Unit 19—Practice Questions	254
Unit 18 Induction	233	<i>Chapter 5 Final Exam</i>	257
Introduction	233	Chapter 6	
18.1 Self-Induction	233	Motors, Generators, and Transformers	
18.2 Induced Voltage and Applied Current	234	Unit 20 Motors	265
Opposes Current Flow	234	Introduction	265
Aids the Current Flow	234	<i>Part A—Motor Basics</i>	265
18.3 Conductor AC Resistance	234	20.1 Motor Principles	265
Eddy Currents	235	Stator	265
Skin Effect	235	Rotor	266
18.4 Impedance	235	20.2 Dual-Voltage AC Motors	266
18.5 Conductor Shape	235	20.3 Motor Horsepower Rating	266
Current	236	20.4 Motor Current Ratings	267
Winding	236	Motor Full-Load Ampere (FLA) Rating	267
Frequency	236	Actual Motor Current	267
18.6 Magnetic Cores	236	Motor Full-Load Current (FLC) Rating	267
Core Material	236	20.5 Calculating Motor FLA	267
Core Length	236	Single-Phase	268
Core Area	236	Three-Phase	268
18.7 Self-Induced and Applied Voltage	237	20.6 Motor-Starting Current	269
18.8 Current Flow	237	20.7 Motor-Running Current	269
Inductive Reactance	237	20.8 Motor Locked-Rotor Current (LRC)	269
18.9 Phase Relationship	238	20.9 Motor Overload Protection	269
18.10 Uses of Induction	238	NEC Requirement	270
Unit 18—Summary	239	<i>Part B—Direct-Current Motors</i>	270
Unit 18—Conclusion	240	20.10 Direct-Current Motor Principles	270
Unit 18—Practice Questions	241	20.11 Direct-Current Motor Types	271
Unit 19 Power Factor and Efficiency	245	Shunt-Wound DC Motor	271
Introduction	245	Series-Wound DC Motor	271
Inductors and Capacitors	245		



20.12 Reversing the Rotation of a DC Motor.....	271	22.5 Harmonic Current.....	290
<i>Part C—Alternating-Current Motors</i>	271	22.6 Efficiency	291
20.13 AC Induction Motor.....	271	22.7 Transformer Turns Ratio	291
20.14 Alternating-Current Motor Types.....	272	22.8 Transformer kVA Rating.....	292
Squirrel-Cage Induction Motor.....	272	22.9 Current Flow	292
Synchronous Motor	272	22.10 Current Rating.....	293
Wound-Rotor Motor	272	Unit 22—Summary	295
Universal Motor	273	Unit 22—Conclusion	296
20.15 Reversing the Rotation of an AC Motor	273	Unit 22 - Practice Questions.....	297
Unit 20—Summary	274	<i>Chapter 6—Final Exam</i>	300
Unit 20—Conclusion	276	Basic Electrical Theory	
Unit 20—Practice Questions	277	Final Exam	309
Unit 21 Generators	281	Basic Electrical Theory	
Introduction	281	Final Conclusion	324
21.1 Direct-Current Generator	281	Annex A—	
Excitation Current.....	281	Grounding and Bonding	
21.2 Alternating-Current Generator	282	Introduction	325
21.3 Three-Phase Generators.....	283	Understanding the Basics of Electrical Systems.....	326
Unit 21—Summary	284	Understanding Electrical Shock Hazard.....	328
Unit 21—Conclusion	284	What Determines the Severity of Electrical Shock....	328
Unit 21—Practice Questions	285	Clearing a Ground Fault	329
Unit 22 Transformers	287	Why Grounding is Often Difficult to Understand	330
Introduction	287	250.1 Scope.....	333
22.1 Transformer Basics	287	250.2 Definitions.....	333
Primary Versus Secondary	287	250.3 Other Code Sections.....	334
Mutual Induction	287	250.4 General Requirements for Grounding and	
22.2 Secondary Induced Voltage	288	Bonding.....	335
22.3 Autotransformers	288	250.4(A) Summary	340
Step-Down Transformers.....	288	250.6 Objectionable (Neutral) Current	345
Step-Up Transformers	289	Index	347
22.4 Power Losses.....	289		
Conductor Resistance Loss	289		
Flux Leakage Loss	289		
Eddy Currents	290		
Hysteresis Losses.....	290		

