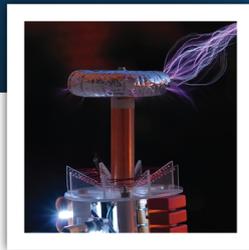
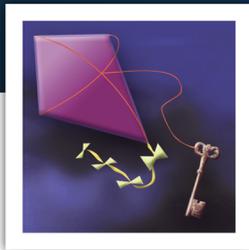
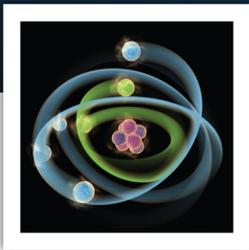


Mike Holt's Illustrated Guide to



Basic **ELECTRICAL** **THEORY**



3rd Edition

Table of Contents

Introduction	x
How to Use This Textbook	xi
About the Author	xii
About the Graphic Illustrator	xiii
Mike Holt Enterprises Team	xiv

CHAPTER 1—ELECTRICAL FUNDAMENTALS

1

Unit 1—Matter

3

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
Summary	9
Conclusion	10
Practice Questions	11

Unit 2—Electron Theory.....

15

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
Summary	19
Conclusion	20
Practice Questions	21

Unit 3—Magnetism.....

23

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
Summary	27
Conclusion	28
Practice Questions	29

Unit 4—Electricity.....

31

Introduction	31
4.1 Electric Current Flow (Electricity).....	31
4.2 Electricity.....	31
4.3 Useful Purposes of Electricity	34
4.4 Dangers of Electricity.....	37
4.5 <i>National Electrical Code</i>	39
Summary	41
Conclusion	43
Practice Questions	44

Unit 5—Electromagnetism

47

Introduction	47
5.1 Electromagnetism in a Wire	47
5.2 Field Intensity	47
5.3 Field Interaction	47
5.4 Field Interaction of Loops	48

5.5 Electromagnetism in a Coil	48	8.6 Percent Increase.....	84
5.6 Magnetic Core	49	8.7 Reciprocals.....	85
5.7 Amperes and Turns	49	8.8 Squaring a Number.....	86
Summary	50	8.9 Square Root.....	87
Conclusion	50	8.10 Volume	88
Practice Questions	51	8.11 Kilo.....	88
 		8.12 Rounding Off.....	89
Unit 6—Uses of Electromagnetism	53	8.13 Parentheses.....	89
Introduction	53	8.14 Testing Your Answer for Reasonableness.....	90
6.1 Basic Electric Meters	53	Summary	91
6.2 Electric Motors	56	Conclusion	92
6.3 Electrical Generators.....	58	Practice Questions	93
6.4 Electromagnetic Relay	58	 	
Summary	61	Unit 9—Electrical Formulas	97
Conclusion	63	Introduction	97
Practice Questions	64	9.1 Electrical Circuit.....	97
 		9.2 Power Source	97
Chapter 1 Final Exam Questions	67	9.3 Conductance	98
 		9.4 Circuit Resistance	98
CHAPTER 2—BASIC ELECTRICITY	73	9.5 Ohm’s Law	99
Unit 7—The Electrical Circuit	75	9.6 Ohm’s Law and Alternating Current.....	99
Introduction	75	9.7 Ohm’s Law Formula Circle	100
7.1 The Electrical Circuit	75	9.8 PIE Formula Circle.....	102
7.2 Electron Current Flow Theory.....	76	9.9 Formula Wheel	102
7.3 Conventional Current Flow Theory.....	76	9.10 Using the Formula Wheel	103
7.4 Voltage (Pressure).....	76	9.11 Power Losses of Conductors	104
7.5 Resistance.....	77	9.12 Cost of Power	104
7.6 Electric Current.....	78	9.13 Power Changes with the Square of the Voltage	105
7.7 Power	78	Summary	109
7.8 Electrical Formulas	78	Conclusion	110
Summary	79	Practice Questions	111
Conclusion	80	 	
Practice Questions	81	Chapter 2 Final Exam Questions	115
Unit 8—Math	83	CHAPTER 3—BASIC ELECTRICAL CIRCUITS	121
Introduction	83	Unit 10—Series Circuits	123
8.1 Whole Numbers	83	Introduction	123
8.2 Decimals	83	10.1 Practical Uses of the Series Circuit.....	123
8.3 Fractions.....	83	10.2 Understanding Series Calculations	124
8.4 Percentages.....	83	10.3 Series Circuit Calculations	127
8.5 Multiplier	84	10.4 Power Calculations	128

10.5 Variations.....	128
10.6 Series Circuit Notes	128
10.7 Series-Connected Power Supplies	128
Summary	130
Conclusion	131
Practice Questions	132
Unit 11—Parallel Circuits	135
Introduction	135
11.1 Practical Uses of the Parallel Circuits	135
11.2 Understanding Parallel Calculations	137
11.3 Circuit Resistance	138
11.4 Parallel Circuit Notes.....	140
11.5 Parallel-Connected Power Supplies.....	141
Summary	142
Conclusion	143
Practice Questions	144
Unit 12—Series-Parallel Circuits	145
Introduction	145
12.1 Review of Series and Parallel Circuits	145
12.2 Working With Series-Parallel Circuits.....	146
12.3 Voltage	147
Summary	148
Conclusion	148
Practice Questions	149
Unit 13—Multiwire Circuits	151
Introduction	151
13.1 Neutral Conductor.....	151
13.2 Grounded Conductor	152
13.3 Current Flow on the Neutral Conductor	152
13.4 Balanced Systems	153
13.5 Unbalanced Current.....	153
13.6 Multiwire Branch Circuits.....	155
13.7 Dangers of Multiwire Circuits	156
13.8 <i>NEC</i> Requirements.....	157
Summary	159
Conclusion	160
Practice Questions	161
Chapter 3 Final Exam Questions	165

CHAPTER 4—ELECTRICAL SYSTEMS AND PROTECTION	171
Unit 14—The Electrical System	173
Introduction	173
14.1 Current Flow	173
14.2 Utility Neutral Current Path.....	173
14.3 Utility Ground-Fault Current Path.....	174
14.4 Premises Neutral Current Path	174
14.5 Premises Ground-Fault Current Path	174
14.6 Utility High-Voltage Transmission Lines	175
14.7 Conductor Voltage Drop	175
14.8 Conductor Power Loss	176
14.9 Reducing Voltage Drop and Power Loss	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
Summary	180
Conclusion	181
Practice Questions	182
Unit 15—Protection Devices	185
Introduction	185
Part A—Overcurrent Protection Devices	185
15.1 Overcurrent Protection	185
15.2 Clearing Faults.....	186
15.3 Overcurrent Protection Device Types.....	187
15.4 Fuse	187
15.5 Circuit Breaker Trip Elements	188
15.6 Circuit Breaker Types.....	188
15.7 Available Short-Circuit Current.....	189
15.8 Interrupting Rating	189
15.9 Short-Circuit Current Rating.....	190
15.10 Current-Limiting Protection.....	190
Part B— Ground-Fault Circuit Interrupters	191
15.11 How a GFCI Works	191
15.12 Neutral-to-Case Detection	192
15.13 Line-to-Neutral Shock Hazard.....	192

15.14 GFCI Fails—Circuit Remains Energized	192	17.5 Uses of Capacitors	226
15.15 GFCI Test Button	193	17.6 Phase Relationship	227
Part C—Arc-Fault Circuit Interrupters	193	Summary	228
15.16 Arcing Definition	193	Conclusion	229
15.17 Series versus Parallel Arc	193	Practice Questions	230
15.18 AFCIs and the <i>NEC</i>	194	Unit 18—Induction	233
15.19 AFCIs—How They Operate	194	Introduction	233
Part D—Ground-Fault Protection of Equipment	194	18.1 Self-Induction	233
15.20 Ground-Fault Protection of Equipment Definition	194	18.2 Induced Voltage and Applied Current	234
Summary	195	18.3 Conductor AC Resistance	234
Conclusion	197	18.4 Impedance	235
Practice Questions	198	18.5 Conductor Shape	236
Chapter 4 Final Exam Questions	203	18.6 Magnetic Cores	236
 		18.7 Self-Induced and Applied Voltage	237
CHAPTER 5—ALTERNATING CURRENT	209	18.8 Current Flow	237
Unit 16—Alternating Current	211	18.9 Phase Relationship	238
Introduction	211	18.10 Uses of Induction	238
16.1 Current Flow	211	Summary	240
16.2 Why Alternating Current Is Used	211	Conclusion	241
16.3 How Alternating Current Is Produced	211	Practice Questions	242
16.4 AC Generator	212	Unit 19—Power Factor and Efficiency	245
16.5 Waveform	213	Introduction	245
16.6 Sine Wave	213	Part A—Power Factor	245
16.7 Nonsymmetrical Waveform	214	19.1 Apparent Power (Volt-Amperes)	245
16.8 Frequency	214	19.2 True Power (Watts)	246
16.9 Phase	215	19.3 Power Factor	246
16.10 Degrees	215	19.4 Unity Power Factor	246
16.11 Lead or Lag	215	19.5 Power Factor Formulas	247
16.12 Values of Alternating Current	216	19.6 Cost of True Power	248
Summary	218	19.7 Effects of Power Factor	248
Conclusion	219	Part B—Efficiency	250
Practice Questions	220	19.8 Efficiency	250
Unit 17—Capacitance	223	19.9 Efficiency Formulas	251
Introduction	223	Summary	253
17.1 Charged Capacitor	224	Conclusion	254
17.2 Electrical Field	224	Practice Question	255
17.3 Discharging a Capacitor	224	Chapter 5 Final Exam Questions	259
17.4 Determining Capacitance	225		

CHAPTER 6—MOTORS, GENERATORS, AND TRANSFORMERS 265

Unit 20—Motors 267

Introduction 267

Part A—Motor Basics 267

20.1 Motor Principles..... 267

20.2 Dual-Voltage AC Motors 267

20.3 Motor Horsepower Ratings..... 268

20.4 Motor Current Ratings..... 269

20.5 Calculating Motor FLA..... 269

20.6 Motor Starting Current 271

20.7 Motor Running Current..... 271

20.8 Motor Locked-Rotor Current (LRC) 271

20.9 Motor Overload Protection..... 271

Part B—Direct-Current Motors..... 272

20.10 Direct-Current Motor Principles..... 272

20.11 Direct-Current Motor Types 273

20.12 Reversing the Rotation of a DC Motor..... 273

Part C—Alternating-Current Motors..... 273

20.13 AC Induction Motor 273

20.14 Alternating-Current Motor Types 274

20.15 Reversing the Rotation of an AC Motor 274

Summary 276

Conclusion..... 278

Practice Questions 279

Unit 21—Generators 283

Introduction 283

21.1 Direct-Current Generator 283

21.2 Alternating-Current Generator 284

21.3 Three-Phase Generator 284

Summary 285

Conclusion..... 285

Practice Questions 286

Unit 22—Transformers 287

Introduction 287

22.1 Transformer Basics 287

22.2 Secondary Induced Voltage 287

22.3 Autotransformers 288

22.4 Power Losses 289

22.5 Harmonic Current 290

22.6 Efficiency 291

22.7 Transformer Turns Ratio 291

22.8 Transformer kVA Rating..... 293

22.9 Current Flow 294

22.10 Current Rating 294

Summary 296

Conclusion..... 297

Practice Questions 298

Chapter 6 Final Exam Questions..... 300

BASIC ELECTRICAL THEORY CONCLUSION .. 305

BASIC ELECTRICAL THEORY FINAL EXAM ... 307

ANNEX A—GROUNDING AND BONDING 323

INDEX 345

Mike Holt's Illustrated Guide to



Understanding the **NATIONAL ELECTRICAL CODE®**

Volume 1 • Articles 90 - 480



Based on the 2011 NEC®

Table of Contents

Introduction	xv
About This Textbook	xvii
How to Use the <i>National Electrical Code</i>	xix
About the Author	xxii
About the Graphic Illustrator	xxiii
Mike Holt Enterprises Team	xxiv

ARTICLE 90—INTRODUCTION TO THE NATIONAL ELECTRICAL CODE	1
90.1 Purpose of the <i>NEC</i>	1
90.2 Scope of the <i>NEC</i>	2
90.3 <i>Code</i> Arrangement	4
90.4 Enforcement	5
90.5 Mandatory Requirements and Explanatory Material	6
90.6 Formal Interpretations	7
90.7 Examination of Equipment for Product Safety	7
90.9 Units of Measurement	7
Article 90. Introduction—Practice Questions	8

CHAPTER 1—GENERAL

ARTICLE 100—DEFINITIONS	13
Definitions	13

ARTICLE 110—REQUIREMENTS FOR ELECTRICAL INSTALLATIONS

Part I. General Requirements	41
110.1 Scope	41
110.2 Approval of Conductors and Equipment	41
110.3 Examination, Identification, Installation, and Use of Equipment	41
110.4 Voltages	42
110.5 Copper Conductors	42
110.6 Conductor Sizes	42
110.7 Wiring Integrity	43
110.8 Suitable Wiring Methods	43
110.9 Interrupting Protection Rating	43
110.10 Circuit Impedance, Short-Circuit Current Rating, and Other Characteristics	45
110.11 Deteriorating Agents	45
110.12 Mechanical Execution of Work	46
110.13 Mounting and Cooling of Equipment	46

110.14 Conductor Termination and Splicing	46
110.15 High-Leg Conductor Identification	51
110.16 Arc-Flash Hazard Warning	52
110.21 Manufacturer's Markings	52
110.22 Identification of Disconnecting Means	52
110.24 Available Fault Current	52
Part II. 600V, Nominal, or Less	53
110.26 Spaces About Electrical Equipment	53
110.27 Guarding	59
110.28 Enclosure Types	59
Chapter 1. General—Practice Questions	60

CHAPTER 2—WIRING AND PROTECTION

ARTICLE 200—USE AND IDENTIFICATION OF GROUNDED CONDUCTORS

Part I. General	68
200.1 Scope	68
200.2 General	68
200.4 Grounded Conductors	68
200.6 Grounded Conductor Identification	68
200.7 Use of White or Gray Color	70
200.9 Terminal Identification	71
200.10 Identification of Terminals	71
200.11 Polarity	71

ARTICLE 210—BRANCH CIRCUITS

Part I. General Provisions	74
210.1 Scope	74
210.2 Other Articles	74
210.3 Branch-Circuit Rating	74
210.4 Multiwire Branch Circuits	74
210.5 Identification for Branch Circuits	78
210.6 Branch-Circuit Voltage Limitations	78
210.7 Multiple Branch Circuits	79
210.8 GFCI Protection	79
210.11 Branch Circuits Required	85
210.12 Arc-Fault Circuit-Interrupter Protection for Dwelling Units	87
210.18 Guest Rooms and Guest Suites	88
Part II. Branch-Circuit Ratings	88
210.19 Conductor Sizing	88
210.20 Overcurrent Protection	90

210.21 Outlet Device Rating	91	220.83 Existing Dwelling Unit Calculations.....	128
210.23 Permissible Loads.....	92	220.84 Multifamily—Optional Load Calculation	129
210.25 Branch Circuits in Buildings with Multiple Occupancies.....	93	220.85 Optional Calculation—Two Dwelling Units.....	130
Part III. Required Outlets.....	93	220.87 Determining Existing Loads.....	130
210.50 General.....	93	ARTICLE 225—OUTSIDE BRANCH CIRCUITS AND FEEDERS	131
210.52 Dwelling Unit Receptacle Outlet Requirements.....	93	Part I. General.....	131
210.60 Receptacles in Guest Rooms, Guest Suites, Dormitories, and Similar Occupancies	101	225.1 Scope	131
210.62 Show Windows	101	225.2 Other Articles	132
210.63 Heating, Air-Conditioning, and Refrigeration (HACR) Equipment	102	225.6 Minimum Size of Conductors	132
210.70 Lighting Outlet Requirements.....	103	225.7 Luminaires Installed Outdoors.....	133
ARTICLE 215—FEEDERS.....	107	225.15 Supports Over Buildings.....	133
215.1 Scope	107	225.16 Attachment.....	133
215.2 Minimum Rating	107	225.17 Masts as Support.....	133
215.3 Overcurrent Protection Sizing.....	109	225.18 Clearance for Overhead Conductors.....	133
215.4 Feeders with Common Neutral Conductor	109	225.19 Clearances from Buildings	134
215.6 Equipment Grounding Conductor.....	109	225.22 Raceways on Exterior Surfaces of Buildings or Other Structures.....	135
215.10 Ground-Fault Protection of Equipment.....	110	225.26 Trees for Conductor Support.....	136
215.12 Conductor Identification.....	110	225.27 Raceway Seal.....	136
ARTICLE 220—BRANCH-CIRCUIT, FEEDER, AND SERVICE CALCULATIONS.....	111	Part II. Buildings or Other Structures Supplied by a Feeder(s) or Branch Circuit(s).....	136
Part I. General.....	111	225.30 Number of Supplies	136
220.1 Scope	111	225.31 Disconnecting Means.....	136
220.3 Application of Other Articles	111	225.32 Disconnect Location	136
220.5 Calculations.....	111	225.33 Maximum Number of Disconnects	138
Part II. Branch-Circuit Load Calculations.....	112	225.34 Grouping of Disconnects.....	138
220.12 General Lighting	112	225.35 Access to Occupants.....	138
220.14 Other Loads—All Occupancies	113	225.36 Identified as Suitable for Service Equipment	138
220.18 Maximum Load on a Branch Circuit	116	225.37 Identification of Multiple Feeders	138
Part III. Feeder and Service Calculations.....	118	225.38 Disconnect Construction	138
220.40 General.....	118	225.39 Rating of Disconnecting Means.....	138
220.42 General Lighting Demand Factors	118	ARTICLE 230—SERVICES	140
220.43 Commercial—Show Window and Track Lighting Load	118	Part I. General.....	141
220.44 Other than Dwelling Unit—Receptacle Load.....	119	230.1 Scope	141
220.50 Motor Load	120	230.2 Number of Services	141
220.51 Fixed Electric Space-Heating Load.....	120	230.3 Not to Pass Through a Building/Structure	142
220.52 Dwelling Unit—Small-Appliance and Laundry Load	120	230.6 Conductors Considered Outside a Building.....	142
220.53 Dwelling Unit—Appliance Load.....	120	230.7 Service Conductors Separate from Other Conductors.....	142
220.54 Dwelling Unit—Electric Clothes Dryer Load	121	230.8 Raceway Seals	143
220.55 Dwelling Unit—Electric Ranges and Cooking Appliances... ..	122	230.9 Clearance from Building Openings	143
220.56 Commercial—Kitchen Equipment Load.....	124	230.10 Vegetation as Support.....	144
220.60 Noncoincident Loads	124	Part II. Overhead Service Conductors.....	144
220.61 Feeder/Service Neutral Unbalanced Load.....	124	230.23 Overhead Service Conductor Size and Rating.....	144
Part IV. Optional Calculations for Computing Feeder and Service Loads	127	230.24 Vertical Clearance for Overhead Service Conductors	145
220.82 Dwelling Unit—Optional Load Calculation.....	127	230.26 Point of Attachment	146
		230.27 Means of Attachment.....	146
		230.28 Service Masts Used as Supports.....	146

Part III. Underground Service Conductors 147
 230.31 Underground Service Conductor Size and Rating..... 147
 230.32 Protection Against Damage 147
Part IV. Service-Entrance Conductors..... 148
 230.40 Number of Service-Entrance Conductor Sets 148
 230.42 Size and Rating..... 148
 230.43 Wiring Methods..... 149
 230.46 Spliced Conductors..... 149
 230.50 Protection Against Physical Damage 149
 230.51 Cable Supports 150
 230.54 Overhead Service Locations..... 150
 230.56 High-Leg Identification..... 150
Part V. Service Equipment—General 151
 230.66 Listed as Suitable for Service Equipment 151
Part VI. Service Equipment—Disconnecting Means..... 151
 230.70 Disconnect Requirements 151
 230.71 Number of Disconnects..... 153
 230.72 Grouping of Disconnects 153
 230.76 Manual or Power Operated 154
 230.77 Indicating..... 154
 230.79 Rating of Disconnect..... 154
 230.81 Connection to Terminals..... 155
 230.82 Connected on Supply Side of the Service Disconnect 155
Part VII. Service Equipment Overcurrent Protection 156
 230.90 Overload Protection Required..... 156
 230.95 Ground-Fault Protection of Equipment 156
ARTICLE 240—OVERCURRENT PROTECTION 158
Part I. General..... 158
 240.1 Scope 158
 240.2 Definitions 159
 240.3 Protection of Equipment..... 160
 240.4 Protection of Conductors..... 160
 240.5 Protection of Flexible Cords and Fixture Wires 163
 240.6 Standard Ampere Ratings 164
 240.10 Supplementary Overcurrent Protection..... 164
 240.13 Ground-Fault Protection of Equipment..... 164
 240.15 Ungrounded Conductors 165
Part II. Location..... 166
 240.21 Overcurrent Protection Location in Circuit 166
 240.24 Location of Overcurrent Devices 170
Part III. Enclosures..... 172
 240.32 Damp or Wet Locations 172
 240.33 Vertical Position 172
Part V. Plug Fuses, Fuseholders, and Adapters 173
 240.50 General..... 173
 240.51 Edison-Base Fuses 173
 240.52 Edison-Base Fuseholders..... 173
 240.53 Type S Fuses 173

240.54 Type S Fuses, Adapters, and Fuseholders..... 173
Part VI. Cartridge Fuses and Fuseholders..... 174
 240.60 General..... 174
 240.61 Classification 174
Part VII. Circuit Breakers..... 175
 240.80 Method of Operation 175
 240.81 Indicating..... 175
 240.82 Nontamperable 175
 240.83 Markings 175
 240.85 Applications 176
ARTICLE 250—GROUNDING AND BONDING..... 177
Part I. General..... 177
 250.1 Scope 177
 250.2 Definitions 177
 250.4 General Requirements for Grounding and Bonding 179
 250.6 Objectionable Current 185
 250.8 Termination of Grounding and Bonding Conductors 189
 250.10 Protection of Fittings..... 189
 250.12 Clean Surfaces 189
Part II. System Grounding and Bonding..... 189
 250.20 Systems Required to be Grounded 189
 250.21 Ungrounded Systems—50V to Less Than 100V 190
 250.24 Service Equipment—Grounding and Bonding 190
 250.28 Main Bonding Jumper and System Bonding Jumper 195
 250.30 Separately Derived Systems—Grounding and Bonding 197
 250.32 Buildings or Structures Supplied by a Feeder or Branch Circuit..... 203
 250.34 Generators—Portable and Vehicle-Mounted..... 205
 250.35 Permanently Installed Generators..... 206
 250.36 High-Impedance Grounded Systems..... 206
Part III. Grounding Electrode System and Grounding Electrode Conductor 207
 250.50 Grounding Electrode System 207
 250.52 Grounding Electrode Types..... 208
 250.53 Grounding Electrode Installation Requirements 210
 250.54 Auxiliary Grounding Electrodes..... 215
 250.58 Common Grounding Electrode..... 216
 250.60 Lightning Protection Electrode 217
 250.62 Grounding Electrode Conductor..... 217
 250.64 Grounding Electrode Conductor Installation 218
 250.66 Sizing Grounding Electrode Conductor 220
 250.68 Termination to the Grounding Electrode..... 222
 250.70 Grounding Electrode Conductor Termination Fittings..... 223
Part IV. Grounding Enclosure, Raceway, and Service Cable Connections..... 223
 250.80 Service Raceways and Enclosures 223
 250.86 Other Enclosures 223

Part V. Bonding 224
 250.90 General..... 224
 250.92 Bonding Equipment for Services 224
 250.94 Intersystem Bonding Termination 227
 250.96 Bonding Other Enclosures 229
 250.97 Bonding Metal Parts Containing 277V and 480V Circuits ... 229
 250.102 Bonding Conductors and Jumpers 230
 250.104 Bonding of Piping Systems and Exposed Structural Metal 232
 250.106 Lightning Protection System 235
Part VI. Equipment Grounding and Equipment Grounding Conductors 236
 250.110 Fixed Equipment Connected by Permanent Wiring Methods—General 236
 250.112 Specific Equipment Fastened in Place or Connected by Permanent Wiring Methods 236
 250.114 Cord-and-Plug-Connected Equipment..... 237
 250.118 Types of Equipment Grounding Conductors 237
 250.119 Identification of Equipment Grounding Conductors 240
 250.120 Equipment Grounding Conductor Installation..... 242
 250.121 Use of Equipment Grounding Conductors 242
 250.122 Sizing Equipment Grounding Conductor 242
 250.126 Identification of Wiring Device Terminals 245
Part VII. Methods of Equipment Grounding 245
 250.130 Replacing Nongrounding Receptacles 245
 250.134 Equipment Fastened in Place or Connected by Wiring Methods 246
 250.136 Equipment Considered Grounded 247
 250.138 Cord-and-Plug-Connected Equipment..... 247
 250.140 Ranges, Ovens, and Clothes Dryers..... 247
 250.142 Use of Neutral Conductor for Equipment Grounding..... 247
 250.146 Connecting Receptacle Grounding Terminal to Metal Enclosure..... 248
 250.148 Continuity and Attachment of Equipment Grounding Conductors in Boxes 251
Part VIII. Direct-Current Systems 252
 250.166 Sizing Grounding Electrode Conductor 252
ARTICLE 285—SURGE PROTECTIVE DEVICES (SPDS) 254
Part I. General 255
 285.1 Scope 255
 285.3 Uses Not Permitted 255
 285.4 Number Required..... 255
 285.5 Listing 255
 285.6 Short-Circuit Current Rating..... 255
Part II. Installation..... 256
 285.11 Location 256
 285.12 Routing of Conductors 256

Part III. Connecting Surge protective devices..... 256
 285.23 Type 1 SPD—Line Side of Service Equipment..... 256
 285.24 Type 2 SPD—Feeder Circuits..... 256
 285.25 Type 3 SPDs—Branch Circuits..... 257
Chapter 2. Wiring and Protection—Practice Questions..... 258

CHAPTER 3—WIRING METHODS AND MATERIALS 273

ARTICLE 300—WIRING METHODS 277

Part I. General..... 277
 300.1 Scope 277
 300.3 Conductors 278
 300.4 Protection Against Physical Damage 280
 300.5 Underground Installations 283
 300.6 Protection Against Corrosion and Deterioration..... 287
 300.7 Raceways Exposed to Different Temperatures 288
 300.8 Not Permitted in Raceways 289
 300.9 Raceways in Wet Locations Above Grade 289
 300.10 Electrical Continuity 289
 300.11 Securing and Supporting..... 290
 300.12 Mechanical Continuity..... 292
 300.13 Splices and Pigtails..... 293
 300.14 Length of Free Conductors 294
 300.15 Boxes or Conduit Bodies 295
 300.16 Raceway or Cable to Open or Concealed Wiring 297
 300.17 Raceway Sizing 297
 300.18 Inserting Conductors in Raceways 299
 300.19 Supporting Conductors in Vertical Raceways..... 299
 300.20 Induced Currents in Ferrous Metal Enclosures and Raceways 300
 300.21 Spread of Fire or Products of Combustion 301
 300.22 Wiring in Ducts Not for Air Handling, Fabricated Ducts for Environmental Air, and Other Spaces For Environmental Air (Plenums) 302
 300.23 Panels Designed to Allow Access 304

ARTICLE 310—CONDUCTORS FOR GENERAL WIRING 306

Part I. General..... 306
 310.1 Scope 306
Part II. Installation..... 306
 310.10 Uses Permitted 306
 310.15 Conductor Ampacity..... 309
Part III. Construction Specification 316
 310.104 Conductor Construction and Application..... 316
 310.106 Conductors 318
 310.110 Conductor Identification 319

ARTICLE 312—CABINETS, CUTOUT BOXES, AND METER SOCKET ENCLOSURES	320
312.1 Scope.....	320
PART I. INSTALLATION	321
312.2 Damp or Wet Locations.....	321
312.3 Installed in Walls.....	321
312.4 Repairing Gaps.....	321
312.5 Enclosures.....	321
312.6 Deflection of Conductors.....	322
312.8 Enclosures With Splices, Taps, and Feed-Through Conductors.....	322
ARTICLE 314—OUTLET, DEVICE, PULL AND JUNCTION BOXES; CONDUIT BODIES; AND HANDHOLE ENCLOSURES	324
Part I. Scope and General	324
314.1 Scope.....	324
314.3 Nonmetallic Boxes.....	324
314.4 Metal Boxes.....	324
Part II. Installation	324
314.15 Damp or Wet Locations.....	324
314.16 Number of 6 AWG and Smaller Conductors in Boxes and Conduit Bodies.....	325
314.17 Conductors That Enter Boxes or Conduit Bodies.....	329
314.20 Boxes Recessed in Walls or Ceilings.....	330
314.21 Repairing Noncombustible Surfaces.....	330
314.22 Surface Extensions.....	330
314.23 Support of Boxes and Conduit Bodies.....	331
314.27 Outlet Box.....	334
314.28 Boxes and Conduit Bodies for Conductors 4 AWG and Larger.....	335
314.29 Wiring to be Accessible.....	339
314.30 Handhole Enclosures.....	339
ARTICLE 320—ARMORED CABLE (TYPE AC)	341
Part I. General	341
320.1 Scope.....	341
320.2 Definition.....	341
Part II. Installation	341
320.10 Uses Permitted.....	341
320.12 Uses Not Permitted.....	342
320.15 Exposed Work.....	342
320.17 Through or Parallel to Framing Members.....	342
320.23 In Accessible Attics or Roof Spaces.....	343
320.24 Bends.....	343
320.30 Securing and Supporting.....	343
320.40 Boxes and Fittings.....	344
320.80 Conductor Ampacity.....	345
Part III. Construction Specifications	345
320.100 Construction.....	345

320.108 Equipment Grounding Conductor.....	345
ARTICLE 330—METAL-CLAD CABLE (TYPE MC)	346
Part I. General	346
330.1 Scope.....	346
330.2 Definition.....	346
Part II. Installation	346
330.10 Uses Permitted.....	346
330.12 Uses Not Permitted.....	347
330.17 Through or Parallel to Framing Members.....	347
330.23 In Accessible Attics or Roof Spaces.....	348
330.24 Bends.....	348
330.30 Securing and Supporting.....	348
330.40 Fittings.....	349
330.80 Conductor Ampacities.....	350
Part III. Construction Specifications	350
330.108 Equipment Grounding Conductor.....	350
ARTICLE 334—NONMETALLIC-SHEATHED CABLE (TYPES NM AND NMC)	351
Part I. General	351
334.1 Scope.....	351
334.2 Definition.....	351
334.6 Listed.....	351
Part II. Installation	352
334.10 Uses Permitted.....	352
334.12 Uses Not Permitted.....	353
334.15 Exposed.....	353
334.17 Through or Parallel to Framing Members.....	354
334.23 Attics and Roof Spaces.....	354
334.24 Bends.....	355
334.30 Securing and Supporting.....	355
334.80 Conductor Ampacity.....	356
Part III. Construction Specifications	358
334.100 Construction.....	358
334.104 Conductors.....	358
334.108 Equipment Grounding Conductor.....	358
334.112 Insulation.....	358

ARTICLE 338—SERVICE-ENTRANCE CABLE (TYPES SE AND USE)	359
Part I. General	359
338.1 Scope.....	359
338.2 Definitions.....	359
Part II. Installation	359
338.10 Uses Permitted.....	359
338.12 Uses Not Permitted.....	360
338.24 Bends.....	360

ARTICLE 340—UNDERGROUND FEEDER AND BRANCH-CIRCUIT CABLE (TYPE UF) 361

Part I. General 361

340.1 Scope 361

340.2 Definition 361

340.6 Listing Requirements 361

Part II. Installation 361

340.10 Uses Permitted 361

340.12 Uses Not Permitted 362

340.24 Bends 362

340.80 Ampacity 362

340.112 Insulation 362

ARTICLE 342—INTERMEDIATE METAL CONDUIT (TYPE IMC) 363

Part I. General 363

342.1 Scope 363

342.2 Definition 363

342.6 Listing Requirements 363

Part II. Installation 363

342.10 Uses Permitted 363

342.14 Dissimilar Metals 364

342.20 Trade Size 364

342.22 Number of Conductors 364

342.24 Bends 364

342.26 Number of Bends (360°) 364

342.28 Reaming 364

342.30 Securing and Supporting 365

342.42 Couplings and Connectors 366

342.46 Bushings 367

ARTICLE 344—RIGID METAL CONDUIT (TYPE RMC) 368

Part I. General 368

344.1 Scope 368

344.2 Definition 368

344.6 Listing Requirements 368

Part II. Installation 368

344.10 Uses Permitted 368

344.14 Dissimilar Metals 369

344.20 Trade Size 369

344.22 Number of Conductors 369

344.24 Bends 369

344.26 Number of Bends (360°) 369

344.28 Reaming 370

344.30 Securing and Supporting 370

344.42 Couplings and Connectors 371

344.46 Bushings 372

Part III. Construction Specifications 372

344.130 Standard Lengths 372

ARTICLE 348—FLEXIBLE METAL CONDUIT (TYPE FMC) 373

Part I. General 373

348.1 Scope 373

348.2 Definition 373

348.6 Listing Requirements 373

Part II. Installation 373

348.10 Uses Permitted 373

348.12 Uses Not Permitted 373

348.20 Trade Size 373

348.22 Number of Conductors 374

348.24 Bends 374

348.26 Number of Bends (360°) 374

348.28 Trimming 374

348.30 Securing and Supporting 374

348.42 Fittings 375

348.60 Grounding and Bonding 375

ARTICLE 350—LIQUIDTIGHT FLEXIBLE METAL CONDUIT (TYPE LFMC) 377

Part I. General 377

350.1 Scope 377

350.2 Definition 377

350.6 Listing Requirements 377

Part II. Installation 377

350.10 Uses Permitted 377

350.12 Uses Not Permitted 377

350.20 Trade Size 377

350.22 Number of Conductors 378

350.24 Bends 378

350.26 Number of Bends (360°) 378

350.30 Securing and Supporting 378

350.42 Fittings 379

350.60 Grounding and Bonding 379

ARTICLE 352—RIGID POLYVINYL CHLORIDE CONDUIT (TYPE PVC) 380

Part I. General 380

352.1 Scope 380

352.2 Definition 380

Part II. Installation 380

352.10 Uses Permitted 380

352.12 Uses Not Permitted 381

352.20 Trade Size 382

352.22 Number of Conductors 382

352.24 Bends 382

352.26 Number of Bends (360°) 382

352.28 Trimming 382

352.30 Securing and Supporting 382

352.44 Expansion Fittings 383

352.46 Bushings	384
352.48 Joints	384
352.60 Equipment Grounding Conductor.....	384

ARTICLE 356—LIQUIDTIGHT FLEXIBLE NONMETALLIC CONDUIT (TYPE LFNC)..... 386

Part I. General	386
356.1 Scope	386
356.2 Definition	386
356.6 Listing Requirement.....	386
Part II. Installation	386
356.10 Uses Permitted	386
356.12 Uses Not Permitted	387
356.20 Trade Size	387
356.22 Number of Conductors.....	387
356.24 Bends.....	387
356.26 Number of Bends (360°).....	387
356.30 Securing and Supporting.....	387
356.42 Fittings	388
356.60 Equipment Grounding Conductor.....	388

ARTICLE 358—ELECTRICAL METALLIC TUBING (TYPE EMT)..... 389

Part I. General	389
358.1 Scope	389
358.2 Definition	389
358.6 Listing Requirement.....	389
Part II. Installation	389
358.10 Uses Permitted	389
358.12 Uses Not Permitted	390
358.20 Trade Size.....	390
358.22 Number of Conductors.....	390
358.24 Bends.....	390
358.26 Number of Bends (360°).....	391
358.28 Reaming and Threading.....	391
358.30 Securing and Supporting.....	391
358.42 Couplings and Connectors	392

ARTICLE 362—ELECTRICAL NONMETALLIC TUBING (TYPE ENT)..... 393

Part I. General	393
362.1 Scope	393
362.2 Definition	393
Part II. Installation	393
362.10 Uses Permitted	393
362.12 Uses Not Permitted	395
362.20 Trade Sizes	396
362.22 Number of Conductors.....	396
362.24 Bends.....	396
362.26 Number of Bends (360°).....	396

362.28 Trimming	396
362.30 Securing and Supporting.....	396
362.46 Bushings	397
362.48 Joints	397
362.60 Equipment Grounding Conductor.....	397

ARTICLE 376—METAL WIREWAYS..... 398

Part I. General	398
376.1 Scope	398
376.2 Definition	398
Part II. Installation	398
376.10 Uses Permitted	398
376.12 Uses Not Permitted	398
376.21 Conductors—Maximum Size	398
376.22 Number of Conductors and Ampacity	398
376.23 Wireway Sizing	399
376.30 Supports.....	399
376.56 Splices, Taps, and Power Distribution Blocks.....	399

ARTICLE 380—MULTIOUTLET ASSEMBLIES..... 401

Part I. General	401
380.1 Scope	401
Part II. Installation	401
380.10 Uses Permitted	401
380.12 Uses Not Permitted	401
380.76 Through Partitions.....	401

ARTICLE 386—SURFACE METAL RACEWAYS..... 402

Part I. General	402
386.1 Scope	402
386.2 Definition	402
386.6 Listing Requirements.....	402
Part II. Installation	402
386.10 Uses Permitted	402
386.12 Uses Not Permitted	403
386.21 Size of Conductors.....	403
386.22 Number of Conductors.....	403
386.30 Securing and Supporting.....	403
386.56 Splices and Taps.....	403
386.60 Equipment Grounding Conductor.....	403
386.70 Separate Compartments	404

ARTICLE 392—CABLE TRAYS..... 405

Part I. General	405
392.1 Scope	405
392.2 Definition	405
Part II. Installation	405
392.10 Uses Permitted	405
392.12 Uses Not Permitted	406
392.18 Cable Tray Installations	406

392.20 Cable and Conductor Installation..... 407
 392.22 Number of Conductors or Cables 407
 392.30 Securing and Supporting..... 407
 392.46 Bushed Raceway 407
 392.56 Cable Splices 407
 392.60 Equipment Grounding Conductor..... 408
 392.80 Ampacity of Conductors 409
**Chapter 3. Wiring Methods And Materials—
 Practice Questions**..... 410

**CHAPTER 4—EQUIPMENT FOR
 GENERAL USE**..... 423

**ARTICLE 400—FLEXIBLE CORDS AND FLEXIBLE
 CABLES** 425
 400.1 Scope 425
 400.3 Suitability 425
 400.4 Types of Flexible Cords and Flexible Cables..... 425
 400.5 Ampacity of Flexible Cords and Flexible Cables 425
 400.7 Uses Permitted 426
 400.8 Uses Not Permitted 427
 400.10 Pull at Joints and Terminals 428
 400.14 Protection from Damage 429
 400.23 Equipment Grounding Conductor Identification..... 429

ARTICLE 402—FIXTURE WIRES 430
 402.1 Scope 430
 402.3 Types..... 430
 402.5 Allowable Ampacity of Fixture Wires..... 430
 402.6 Minimum Size..... 430
 402.7 Raceway Size 430
 402.8 Neutral Conductor..... 431
 402.10 Uses Permitted 431
 402.11 Uses Not Permitted 431
 402.12 Overcurrent Protection..... 431

ARTICLE 404—SWITCHES 432
 404.1 Scope 432
 404.2 Switch Connections 432
 404.3 Switch Enclosures 434
 404.4 Damp or Wet Locations..... 434
 404.6 Position of Knife Switches..... 435
 404.7 Indicating..... 435
 404.8 Accessibility and Grouping 436
 404.9 Switch Faceplates..... 436
 404.10 Mounting Snap Switches 438
 404.11 Circuit Breakers Used as Switches..... 438
 404.12 Grounding of Enclosures 438
 404.14 Rating and Use of Snap Switches..... 438
 404.15 Switch Marking..... 439

**ARTICLE 406—RECEPTACLES, CORD CONNECTORS,
 AND ATTACHMENT PLUGS (CAPS)**..... 440
 406.1 Scope 440
 406.2 Definitions 440
 406.3 Receptacle Rating and Type 440
 406.4 General Installation Requirements..... 441
 406.5 Receptacle Mounting 443
 406.6 Receptacle Faceplates 444
 406.7 Attachment Plugs, Cord Connectors, and Flanged Surface
 Devices..... 445
 406.9 Receptacles in Damp or Wet Locations..... 445
 406.11 Connecting Receptacle Grounding Terminal to
 Equipment Grounding Conductor..... 447
 406.12 Tamper-Resistant Receptacles in Dwelling Units 447
 406.13 Tamper-Resistant Receptacles in Guest Rooms and
 Guest Suites 447
 406.14 Tamper-Resistant Receptacles in Child Care Facilities 447

ARTICLE 408—SWITCHBOARDS AND PANELBOARDS 448
Part I. General..... 448
 408.1 Scope 448
 408.3 Arrangement of Busbars and Conductors 448
 408.4 Field Identification 450
 408.5 Clearance for Conductors Entering Bus Enclosures 450
 408.7 Unused Openings..... 450
Part III. Panelboards 451
 408.36 Overcurrent Protection of Panelboards 451
 408.37 Panelboards in Damp or Wet Locations 452
 408.40 Equipment Grounding Conductor..... 452
 408.41 Neutral Conductor Terminations 453
Part IV. Construction Specifications..... 454
 408.54 Maximum Number of Overcurrent Devices..... 454

**ARTICLE 410—LUMINAIRES, LAMP HOLDERS, AND
 LAMPS**..... 455
Part I. General..... 455
 410.1 Scope 455
 410.2 Definitions 455
 410.6 Listing Required..... 456
Part II. Luminaire Locations..... 456
 410.10 Luminaires in Specific Locations..... 456
 410.11 Luminaires Near Combustible Material..... 458
 410.16 Luminaires in Clothes Closets 458
 410.18 Space for Cove Lighting..... 459
Part III. Luminaire Outlet Boxes and Covers 459
 410.22 Outlet Boxes to be Covered..... 459
 410.24 Connection of Electric-Discharge and LED Luminaires 459
Part IV. Luminaire Supports 460
 410.30 Supports..... 460

410.36 Means of Support	461	422.51 Cord-and-Plug-Connected Vending Machines.....	476
Part V. Grounding (Bonding)	462	422.52 Electric Drinking Fountains	476
410.44 Methods of Grounding.....	462	ARTICLE 424—FIXED ELECTRIC SPACE-HEATING	
Part VI. Wiring of Luminaires	463	EQUIPMENT	477
410.50 Polarization of Luminaires.....	463	Part I. General	477
410.62 Cord-Connected Luminaires	463	424.1 Scope	477
410.64 Luminaires as Raceways	464	424.3 Branch Circuits	477
410.68 Conductors and Ballasts	464	424.9 Permanently Installed Electric Baseboard Heaters with	
Part VIII. Installation of Lampholders	464	Receptacles.....	478
410.90 Screw-Shell Lampholders.....	464	Part III. Electric Space-Heating Equipment	478
410.96 Lampholders in Wet or Damp Locations	464	424.19 Disconnecting Means.....	478
410.97 Lampholders Near Combustible Material.....	464	Part V. Electric Space-Heating Cables	479
Part X. Recessed Luminaires	465	424.36 Clearances of Wiring in Ceilings	479
410.110 General.....	465	424.38 Area Restrictions.....	479
410.115 Thermally Protected	465	424.39 Clearance from Other Objects and Openings.....	479
410.116 Recessed Luminaire Clearances	465	424.44 Installation of Cables in Concrete or Poured	
410.117 Wiring.....	465	Masonry Floors.....	479
Part XII. Electric-Discharge Lighting	465	Part VI. Duct Heaters	479
410.130 General.....	465	424.65 Disconnect for Electric Duct Heater Controllers	479
Part XIV. Track Lighting	467	ARTICLE 430—MOTORS, MOTOR CIRCUITS, AND	
410.151 Installation.....	467	CONTROLLERS	480
410.154 Fastening.....	467	Part I. General	480
ARTICLE 411—LIGHTING SYSTEMS OPERATING AT		430.1 Scope	480
30V OR LESS	468	430.2 Definitions	480
411.1 Scope	468	430.6 Table FLC versus Motor Nameplate Current Rating.....	481
411.2 Definition	468	430.8 Marking on Controllers.....	482
411.3 Listing Required.....	468	430.9 Motor Controller Terminal Requirements	482
411.4 Specific Location Requirements.....	468	430.14 Location of Motors.....	483
411.5 Secondary Circuits.....	469	430.17 The Highest Rated Motor.....	483
ARTICLE 422—APPLIANCES	470	Part II. Conductor Size	483
Part I. General	470	430.22 Single Motor Conductor Size	483
422.1 Scope	470	430.24 Several Motors—Conductor Size	483
422.2 Definitions	470	430.28 Motor Feeder Taps	484
422.3 Other Articles	471	Part III. Overload Protection	484
Part II. Branch-Circuit Requirements	471	430.31 Overload	485
422.10 Branch-Circuit Rating	471	430.32 Overload Sizing for Continuous-Duty Motors	485
422.11 Overcurrent Protection.....	471	430.36 Use of Fuses for Overload Protection.....	486
422.12 Central Heating Equipment (Furnaces)	472	430.37 Number of Overload Devices.....	486
422.13 Storage Water Heaters	472	Part IV. Branch-Circuit Short-Circuit and Ground-Fault	
422.15 Central Vacuums.....	472	Protection	486
422.16 Flexible Cords.....	473	430.51 General.....	486
422.18 Support of Ceiling Paddle Fans.....	474	430.52 Branch-Circuit Short-Circuit and Ground-Fault	
Part III. Disconnect	474	Protection	487
422.30 General.....	474	430.55 Single Overcurrent Device.....	488
422.31 Permanently Connected Appliance Disconnects	474	Part V. Feeder Short-Circuit and Ground-Fault	
422.33 Cord-and-Plug-Connected Appliance Disconnects.....	475	Protection	489
422.34 Unit Switches as Disconnects	475	430.62 Feeder Protection.....	489

Part VI. Motor Control Circuits	490	ARTICLE 445—GENERATORS	500
430.72 Overcurrent Protection for Control Circuits	490	445.1 Scope	500
430.73 Protection of Conductors from Physical Damage	490	445.11 Marking	500
430.75 Disconnect for Control Circuits	490	445.12 Overcurrent Protection	500
Part VII. Motor Controllers	491	445.13 Ampacity of Conductors	500
430.83 Controller Rating	491	445.18 Disconnecting Means	502
430.84 Need Not Open All Conductors of the Circuit	491	445.19 Generators Supplying Multiple Loads	502
430.87 Controller for Each Motor	491	ARTICLE 450—TRANSFORMERS	503
Part IX. Disconnecting Means	491	Part I. General	503
430.102 Disconnect Requirement	491	450.1 Scope	503
430.103 Operation of Disconnect	493	450.3 Overcurrent Protection	503
430.104 Marking and Mounting	493	450.9 Ventilation	504
430.107 Readily Accessible	493	450.11 Marking	505
430.109 Disconnecting Means Rating	493	450.13 Transformer Accessibility	505
430.111 Combination Controller and Disconnect	493	450.14 Disconnecting Means	505
Part XIV. Tables	494	ARTICLE 480—STORAGE BATTERIES	506
Table 430.248 Full-Load Current, Single-Phase Motors	494	480.1 Scope	506
Table 430.250 Full-Load Current, Three-Phase Motors	494	480.2 Definitions	506
ARTICLE 440—AIR-CONDITIONING AND		480.3 Wiring and Equipment Supplied from Batteries	506
REFRIGERATION EQUIPMENT	495	480.4 Overcurrent Protection for Prime Movers	507
Part I. General	495	480.5 Disconnecting Means	507
440.1 Scope	495	480.8 Racks and Trays	507
440.2 Definitions	495	480.9 Battery Locations	507
440.3 Other Articles	495	Chapter 4. Equipment For General Use—	
440.4 Marking on Hermetic Refrigerant Motor-Compressors and		Practice Questions	509
Equipment	495	FINAL EXAM A	523
440.6 Ampacity and Rating	496	FINAL EXAM B	532
Part II. Disconnecting Means	496		
440.12 Rating and Interrupting Capacity	496		
440.13 Cord-Connected Equipment	496		
440.14 Location	496		
Part III. Overcurrent Protection	497		
440.21 General	497		
440.22 Short-Circuit and Ground-Fault Overcurrent Device Size	497		
Part IV. Conductor Sizing	498		
440.32 Conductor Size for Single Motor-Compressors	498		
Part VII. Room Air Conditioners	498		
440.62 Branch-Circuit Requirements	498		
440.63 Disconnecting Means	498		
440.64 Supply Cords	499		
440.65 Leakage Current Detector-Interrupter and Arc-Fault			
Circuit Interrupter	499		

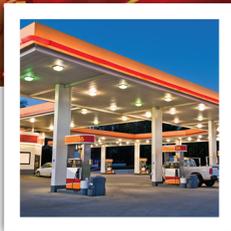
Mike Holt's Illustrated Guide to

Understanding the

NATIONAL ELECTRICAL CODE[®]



Volume 2 • Articles 500 - 820



Based on the 2011 NEC[®]

Includes over 600 Practice Questions plus 2 Final Exams

Table of Contents

Introduction	xi
About This Textbook	xiii
How to Use the <i>National Electrical Code</i>	xv
About the Author	xviii
About the Graphic Illustrator	xix
Mike Holt Enterprises Team	xx

ARTICLE 90—INTRODUCTION TO THE NATIONAL ELECTRICAL CODE	1
90.1 Purpose of the <i>NEC</i>	1
90.2 Scope of the <i>NEC</i>	2
90.3 <i>Code</i> Arrangement	4
90.4 Enforcement	5
90.5 Mandatory Requirements and Explanatory Material	6
90.6 Formal Interpretations	7
90.7 Examination of Equipment for Product Safety	7
90.9 Units of Measurement	7

PRACTICE QUESTIONS FOR ARTICLE 90—INTRODUCTION ...	8
---	---

CHAPTER 5—SPECIAL OCCUPANCIES

ARTICLE 500—HAZARDOUS (CLASSIFIED) LOCATIONS	13
500.1 Scope—Articles 500 Through 504	13
500.2 Definitions	14
500.3 Other Articles	15
500.4 General	15
500.5 Classifications of Locations	16
500.6 Material Groups	18
500.7 Protection Techniques	18
500.8 Equipment	19
500.9 Specific Occupancies	21

ARTICLE 501—CLASS I HAZARDOUS (CLASSIFIED) LOCATIONS	23
Part I. General	23
501.1 Scope	23
Part II. Wiring	23
501.10 Wiring Methods	23
501.15 Raceway and Cable Seals	25
501.20 Conductor Insulation	29
501.30 Grounding and Bonding	29
Part III. Equipment	30
501.100 Transformers and Capacitors	30

501.105 Meters, Instruments, and Relays	31
501.115 Enclosures	31
501.120 Control Transformers and Relays	31
501.125 Motors	32
501.130 Luminaires	32
501.135 Utilization Equipment	33
501.140 Flexible Cords	33
501.145 Receptacles and Attachment Plugs	34
501.150 Limited-Energy and Communications Systems	34

ARTICLE 502—CLASS II HAZARDOUS (CLASSIFIED) LOCATIONS	35
Part I. General	35
502.1 Scope	35
502.5 Explosionproof Equipment	35
Part II. Wiring	36
502.10 Wiring Methods	36
502.15 Seals	37
502.30 Grounding and Bonding	37
Part III. Equipment	38
502.115 Switches, Circuit Breakers, Motor Controllers, and Fuses ...	38
502.120 Control Transformers	39
502.125 Motors	39
502.130 Luminaires	39
502.140 Flexible Cords	40
502.145 Receptacles and Attachment Plugs	40
502.150 Limited-Energy and Communications Systems	40

ARTICLE 503—CLASS III HAZARDOUS (CLASSIFIED) LOCATIONS	43
Part I. General	43
503.1 Scope	43
503.5 General	43
Part II. Wiring	43
503.10 Wiring Methods	43
503.30 Grounding and Bonding	44
Part III. Equipment	44
503.115 Switches, Circuit Breakers, Motor Controllers, and Fuses	44
503.120 Control Transformers	45
503.125 Motors	45
503.130 Luminaires	45
503.140 Flexible Cords	45
503.145 Receptacles and Attachment Plugs	46

503.150 Limited-Energy and Communications Systems	46	525.3 Other Articles	67
ARTICLE 511—COMMERCIAL GARAGES, REPAIR, AND STORAGE	47	525.5 Overhead Conductor Clearances	67
511.1 Scope	47	525.6 Protection of Electrical Equipment.....	68
511.2 Definitions	47	Part II. Power Sources	68
511.3 Classification of Hazardous Areas	47	525.10 Services	68
511.4 Wiring and Equipment in Hazardous (Classified) Locations	50	525.11 Multiple Sources of Supply.....	68
511.7 Wiring and Equipment Above Hazardous (Classified) Locations.....	50	525.20 Wiring Methods.....	69
511.9 Seals	51	525.21 Rides, Tents, and Concessions	70
511.10 Special Equipment.....	51	525.22 Outdoor Portable Distribution or Termination Boxes.....	70
511.12 GFCI-Protected Receptacles.....	51	525.23 GFCI-Protected Receptacles and Equipment.....	70
ARTICLE 514—MOTOR FUEL DISPENSING FACILITIES	53	Part IV. Grounding and Bonding	70
514.1 Scope	53	525.30 Equipment Bonding.....	70
514.2 Definition	53	525.31 Equipment Grounding	71
514.3 Classification of Locations	53	525.32 Equipment Grounding Conductor Continuity Assurance	71
514.4 Wiring and Equipment Within Class I Locations	54	ARTICLE 547—AGRICULTURAL BUILDINGS	73
514.7 Wiring and Equipment Above Class I Locations.....	54	547.1 Scope	73
514.8 Underground Wiring	55	547.2 Definitions	73
514.9 Raceway Seal	55	547.5 Wiring Methods.....	73
514.11 Circuit Disconnect.....	56	547.8 Luminaires	75
514.13 Maintenance and Service of Dispensing Equipment	56	547.10 Equipotential Planes and Bonding of Equipotential Planes ...	75
514.16 Grounding and Bonding	56	ARTICLE 550—MOBILE HOMES, MANUFACTURED HOMES, AND MOBILE HOME PARKS	77
ARTICLE 517—HEALTH CARE FACILITIES	59	Part I. General	77
Part I. General	59	550.1 Scope	77
517.1 Scope	59	550.2 Definitions	77
517.2 Definitions	59	550.4 General Requirements	78
Part II. Wiring and Protection	60	550.13 Receptacle Outlets.....	78
517.10 Applicability	60	550.25 AFCI Protection	79
517.12 Wiring Methods.....	60	Part III. Services and Feeders	79
517.13 Grounding of Equipment in Patient Care Areas	60	550.30 Distribution Systems.....	79
517.16 Receptacles With Insulated Grounding Terminals.....	62	550.31 Allowable Demand Factors.....	79
517.18 General Care Areas	62	550.32 Disconnect	80
Part VI. Communications and Signaling Systems	63	550.33 Feeder	81
517.80 Patient Care Areas	63	ARTICLE 555—MARINAS AND BOATYARDS	83
517.81 Other-Than-Patient-Care Areas	63	555.1 Scope	83
ARTICLE 518—ASSEMBLY OCCUPANCIES	65	555.2 Definitions	83
518.1 Scope	65	555.3 Ground-Fault Protection	83
518.2 General Classifications.....	65	555.5 Transformers	83
518.3 Other Articles	65	555.7 Location of Service Equipment.....	84
518.4 Wiring Methods.....	65	555.9 Electrical Connections.....	84
ARTICLE 525—CARNIVALS, CIRCUSES, FAIRS, AND SIMILAR EVENTS	67	555.10 Electrical Equipment Enclosures	84
Part I. General Requirements	67	555.12 Load Calculations for Service and Feeder Conductors	84
525.1 Scope	67	555.13 Wiring Methods and Installation	85
525.2 Definitions	67	555.15 Grounding.....	86
		555.17 Boat Receptacle Disconnecting Means.....	86
		555.19 Receptacles	86

555.21 Motor Fuel Dispensing Stations—Hazardous (Classified)	
Locations.....	87
555.22 Repair Facilities	88
ARTICLE 590—TEMPORARY INSTALLATIONS	89
590.1 Scope	89
590.2 All Installations.....	89
590.3 Time Constraints.....	89
590.4 General.....	90
590.5 Listing of Decorative Lighting.....	92
590.6 Ground-Fault Protection for Personnel.....	92
PRACTICE QUESTIONS FOR CHAPTER 5— SPECIAL OCCUPANCIES	94
CHAPTER 6—SPECIAL EQUIPMENT	125
ARTICLE 600—ELECTRIC SIGNS AND OUTLINE LIGHTING ..	127
Part I. General	127
600.1 Scope	127
600.2 Definitions	127
600.3 Listing	127
600.4 Markings	127
600.5 Branch Circuits	128
600.6 Disconnecting Means.....	128
600.7 Grounding and Bonding	129
600.9 Location	131
600.10 Portable or Mobile Signs.....	131
600.21 Ballasts, Transformers, and Electronic Power Supplies	132
600.24 Class 2 Power Sources	132
600.33 LED Sign Illumination Systems, Secondary Wiring.....	132
ARTICLE 604—MANUFACTURED WIRING SYSTEMS	135
604.1 Scope	135
604.2 Definition.....	135
604.4 Uses Permitted	136
604.6 Construction	136
604.7 Securing and Supporting.....	136
ARTICLE 620—ELEVATORS, ESCALATORS, AND MOVING WALKS	139
Part I. General	139
620.1 Scope	139
Part III. Wiring	139
620.23 Branch Circuit for Machine Room/Machinery Space.....	139
620.24 Branch Circuit for Hoistway Pit.....	140
Part IV. Installation of Conductors	140
620.37 Wiring in Elevator Hoistways and Machine Rooms.....	140
Part VI. Disconnecting Means and Control	140
620.51 Disconnecting Means.....	140

Part VIII. Machine Rooms, Control Rooms, Machinery Spaces, and Control Spaces	141
620.85 GFCI-Protected Receptacles.....	141
ARTICLE 625—ELECTRIC VEHICLE CHARGING SYSTEM ..	143
Part I. General	144
625.1 Scope	144
625.2 Definitions	144
625.5 Listed or Labeled	144
Part III. Equipment Construction	144
625.13 Electric Vehicle Supply Equipment.....	144
625.14 Rating.....	144
625.15 Markings	145
Part IV. Control and Protection	145
625.21 Overcurrent Protection.....	145
625.23 Disconnecting Means.....	145
625.22 Personnel Protection System.....	145
Part V. Electric Vehicle Supply Equipment Locations	145
625.29 Indoor Sites	145
625.30 Outdoor Sites.....	146
ARTICLE 640—AUDIO SIGNAL PROCESSING, AMPLIFICATION, AND REPRODUCTION EQUIPMENT	147
Part I. General	147
640.1 Scope	147
640.2 Definitions	147
640.3 Locations and Other Articles	147
640.4 Protection of Electrical Equipment.....	148
640.6 Mechanical Execution of Work	148
640.7 Grounding and Bonding	150
640.9 Wiring Methods.....	150
640.10 Audio Systems Near Bodies of Water.....	150
Part II. Permanent Audio System Installations	150
640.21 Use of Flexible Cords and Flexible Cables.....	150
640.22 Wiring of Equipment Racks	151
640.23 Number of Conductors in a Raceway	151
640.25 Loudspeakers in Fire-Resistance-Rated Partitions, Walls, and Ceilings.....	151
ARTICLE 645—INFORMATION TECHNOLOGY EQUIPMENT ..	153
645.1 Scope	153
645.2 Definitions	153
645.3 Other Articles	153
645.4 Information Technology Equipment Room.....	155
645.5 Supply Circuits and Interconnecting Cables.....	155
645.6 Cables Not in Information Technology Equipment Room	157
645.7 Penetrations	157
645.10 Disconnecting Means.....	157
645.11 Uninterruptible Power Supplies (UPS).....	158
645.15 Equipment Grounding Conductor.....	158

ARTICLE 680—SWIMMING POOLS, SPAS, HOT TUBS, FOUNTAINS, AND SIMILAR INSTALLATIONS	159
Part I. General Requirements for Pools, Spas, Hot Tubs, and Fountains	159
680.1 Scope.....	159
680.2 Definitions.....	159
680.3 Other Articles.....	160
680.7 Cord-and-Plug-Connected Equipment.....	160
680.8 Overhead Conductor Clearance.....	161
680.9 Electric Water Heater.....	161
680.10 Underground Wiring.....	162
680.11 Equipment Rooms and Pits.....	162
680.12 Maintenance Disconnecting Means.....	162
Part II. Permanently Installed Pools, Outdoor Spas, and Outdoor Hot Tubs	163
680.20 General.....	163
680.21 Motors.....	163
680.22 Lighting, Receptacles, and Equipment.....	164
680.23 Underwater Luminaires.....	166
680.24 Junction Box, Transformer, or GFCI Enclosure.....	168
680.25 Feeders.....	170
680.26 Equipotential Bonding.....	170
680.27 Specialized Equipment.....	173
Part III. Storable Swimming Pools	173
680.30 General.....	173
680.31 Pumps.....	173
680.32 GFCI-Protected Receptacles.....	174
680.34 Receptacle Locations.....	174
Part IV. Spas and Hot Tubs	174
680.40 General.....	174
680.41 Emergency Switch for Spas and Hot Tubs.....	174
680.42 Outdoor Installations.....	174
680.43 Indoor Installations.....	175
680.44 GFCI Protection.....	176
Part V. Fountains	177
680.50 General.....	177
680.51 Luminaires, Submersible Pumps, and Other Submersible Equipment.....	177
680.53 Bonding.....	177
680.55 Methods of Equipment Grounding.....	178
680.56 Cord-and-Plug-Connected Equipment.....	178
680.57 Signs in or Adjacent to Fountains.....	178
680.58 GFCI-Protected Receptacles.....	178
Part VII. Hydromassage Bathtubs	178
680.70 General.....	178
680.71 GFCI Protection.....	178
680.72 Other Electrical Equipment.....	179
680.73 Accessibility.....	179
680.74 Equipotential Bonding.....	179

ARTICLE 690—SOLAR PHOTOVOLTAIC (PV) SYSTEMS..... 181

*This article is covered in *Mike Holt's Illustrated Guide to Understanding NEC Requirements for Solar Photovoltaic Systems*.

ARTICLE 695—FIRE PUMPS..... 183

695.1 Scope.....	183
695.3 Power Source(s).....	183
695.4 Continuity of Power.....	184
695.5 Transformers.....	185
695.6 Power Wiring.....	185
695.7 Voltage Drop.....	186
695.14 Control Wiring.....	186

PRACTICE QUESTIONS FOR CHAPTER 6—SPECIAL EQUIPMENT..... 188

CHAPTER 7—SPECIAL CONDITIONS..... 207

ARTICLE 700—EMERGENCY SYSTEMS..... 209

Part I. General	209
700.1 Scope.....	209
700.2 Definitions.....	209
700.3 Tests and Maintenance.....	210
700.4 Capacity.....	210
700.5 Transfer Equipment.....	210
700.7 Signs.....	211
Part II. Circuit Wiring	211
700.10 Wiring.....	211
Part III. Sources of Power	212
700.12 General Requirements.....	212
Part IV. Circuits for Lighting and Power	214
700.15 Loads on Emergency Branch Circuits.....	214
700.16 Emergency Illumination.....	214
Part VI. Overcurrent Protection	214
700.25 Accessibility.....	214
700.26 Ground-Fault Protection of Equipment.....	214
700.27 Coordination.....	214

ARTICLE 701—LEGALLY REQUIRED STANDBY SYSTEMS.. 215

Part I. General	215
701.1 Scope.....	215
701.2 Definitions.....	215
701.3 Tests and Maintenance.....	215
701.4 Capacity and Rating.....	216
701.5 Transfer Equipment.....	216
701.7 Signs.....	216
Part II. Circuit Wiring	216
701.10 Wiring.....	216

Part III. Sources of Power	216
701.12 General Requirements	216
Part IV. Overcurrent Protection	218
701.25 Accessibility	218
701.26 Ground-Fault Protection of Equipment.....	218
701.27 Coordination	218
ARTICLE 702—OPTIONAL STANDBY SYSTEMS	219
Part I. General	219
702.1 Scope	219
702.2 Definition	220
702.4 Capacity and Rating	220
702.5 Transfer Equipment	220
702.7 Signs	221
Part II. Circuit Wiring	221
702.10 Wiring	221
702.12 Outdoor Generator Sets	221
ARTICLE 725—REMOTE-CONTROL, SIGNALING, AND POWER-LIMITED CIRCUITS	223
Part I. General	223
725.1 Scope	223
725.2 Definitions	223
725.3 Other Articles	224
725.21 Electrical Equipment Behind Access Panels.....	226
725.24 Mechanical Execution of Work	226
725.25 Abandoned Cable	227
725.31 Safety-Control Equipment	228
725.35 Circuit Requirements	228
Part II. Class 1 Circuit Requirements	228
725.41 Class 1 Circuit Classifications and Power-Supply Requirements	228
725.43 Class 1 Circuit Overcurrent Protection.....	228
725.46 Class 1 Circuit Wiring Methods	229
725.48 Conductors of Different Circuits in Same Cable, Cable Tray, Enclosure, or Raceway	229
725.49 Class 1 Circuit Conductors	229
725.51 Number of Conductors in a Raceway	230
Part III. Class 2 and Class 3 Circuit Requirements	230
725.121 Power Sources for Class 2 and Class 3 Circuits.....	230
725.124 Equipment Marking.....	230
725.127 Wiring Methods on Supply Side of the Class 2 or Class 3 Power Source	230
725.130 Wiring Methods on Load Side of the Class 2 or Class 3 Power Source	231
725.136 Separation from Power Conductors.....	231
725.139 Conductors of Different Circuits in Same Cable, Enclosure, Cable Tray, or Raceway	233
725.143 Support.....	234

725.154 Applications of Class 2 and Class 3 Cables	234
Part VI. Listing Requirements	236
725.179 Listing and Marking Requirements of Class 2 and Class 3 Cables and Raceways.....	236
ARTICLE 760—FIRE ALARM SYSTEMS	239
Part I. General	239
760.1 Scope	239
760.2 Definitions	239
760.3 Other Articles	240
760.21 Access to Electrical Equipment Behind Panels Designed to Allow Access.....	241
760.24 Mechanical Execution of Work	241
760.25 Abandoned Cable	242
760.30 Fire Alarm Circuit Identification	243
760.32 Fire Alarm Circuit Cables Extending Beyond a Building	243
760.35 Fire Alarm Circuit Requirements.....	243
Part III. Power-Limited Fire Alarm (PLFA) Circuits	243
760.121 Power Sources for Power-Limited Fire Alarm Circuits.....	243
760.124 Equipment Marking.....	244
760.130 Wiring Methods on Load Side of Power-Limited Fire Alarm Power Source	244
760.136 Separation from Power Conductors.....	245
760.139 Power-Limited Fire Alarm Circuits, Class 2, Class 3, and Communications Circuits	245
760.143 Support.....	246
760.154 Applications of Power-Limited Fire Alarm Cables (PLFA)	246
Part IV. Listing Requirements	247
760.179 Listing and Marking Requirements of Power-Limited Fire Alarm Cables (PLFA)	247
ARTICLE 770—OPTICAL FIBER CABLES AND RACEWAYS	249
Part I. General	249
770.1 Scope	249
770.2 Definitions	249
770.3 Other Articles	250
770.12 Innerduct	250
770.21 Access to Electrical Equipment Behind Panels Designed to Allow Access.....	251
770.24 Mechanical Execution of Work	251
770.25 Abandoned Cable	252
770.26 Spread of Fire or Products of Combustion	252
Part II. Cables Outside and Entering Buildings	253
770.48 Unlisted Cables Entering Buildings	253
Part V. Installation Methods Within Buildings	253
770.110 Raceways for Optical Fiber Cables	253
770.113 Installation of Optical Fiber Cables, Optical Fiber Raceways, and Cable Routing Assemblies.....	254

770.133 Installation of Optical Fiber Cables 255
 770.154 Applications of Optical Fiber Cables and Raceways 256
 770.179 Listing and Marking of Optical Fiber Cables..... 256

**PRACTICE QUESTIONS FOR CHAPTER 7—
SPECIAL CONDITIONS**..... 257

**CHAPTER 8—COMMUNICATIONS
SYSTEMS**..... 273

ARTICLE 800—COMMUNICATIONS CIRCUITS 275

Part I. General..... 276

800.1 Scope 276

800.2 Definitions 276

800.18 Installation of Equipment 277

800.21 Access to Electrical Equipment Behind Panels Designed
to Allow Access..... 277

800.24 Mechanical Execution of Work 277

800.25 Abandoned Cable..... 278

800.26 Spread of Fire or Products of Combustion 278

PART II. Cables Outside and Entering Buildings..... 279

800.44 Overhead (Aerial) Communications Cables..... 279

800.47 Underground Communications Wires and Cables
Entering Buildings..... 279

800.48 Unlisted Cables Entering Buildings..... 279

800.53 Lightning Conductors..... 280

Part III. Protection..... 280

800.90 Primary Protection 280

800.93 Grounding or Interruption of Metallic Sheath Members
of Communications Cables 280

Part IV. Grounding Methods 280

800.100 Cable and Primary Protector Bonding and Grounding 280

Part V. Installation Methods Within Buildings 283

800.110 Raceways for Communications Wires and Cables 283

800.113 Installation of Communications Cables and
Communications Raceways 284

800.133 Installation of Communications Cables..... 285

800.154 Applications of Communications Cables and
Communications Raceways 286

800.156 Dwelling Unit Communications Outlet 287

Part VI. Listing Requirements 287

800.179 Listing and Marking of Communications Cables..... 287

ARTICLE 810—RADIO AND TELEVISION EQUIPMENT 289

Part I. General..... 289

810.1 Scope 289

810.3 Other Articles 290

810.4 Community Television Antenna..... 290

Part II. Receiving Equipment—Antenna Systems 291

810.12 Support of Lead-In Cables..... 291

810.13 Avoid Contact with Conductors of Other Systems 291

810.15 Metal Antenna Supports—Grounding..... 291

810.18 Clearances 291

810.20 Antenna Discharge Unit..... 292

810.21 Bonding Conductor or Grounding Electrode Conductors..... 292

**Part III. Amateur and Citizen Band Transmitting and Receiving
Antenna Systems**..... 296

810.51 Other Sections 296

810.54 Clearance on Building 296

810.57 Antenna Discharge Units..... 296

810.58 Bonding Conductor or Grounding Electrode Conductors..... 296

**ARTICLE 820—COMMUNITY ANTENNA TELEVISION
(CATV) AND RADIO DISTRIBUTION SYSTEMS**..... 297

Part I. General..... 298

820.1 Scope 298

820.2 Definitions 298

820.3 Locations and Other Articles 298

820.15 Power Limitations 299

820.21 Access to Electrical Equipment Behind Panels Designed
to Allow Access..... 299

820.24 Mechanical Execution of Work 299

820.25 Abandoned Cable..... 300

820.26 Spread of Fire or Products of Combustion 301

Part II. Coaxial Cables Outside and Entering Buildings..... 301

820.48 Unlisted Cables and Raceways Entering Building 301

Part III. Protection..... 302

820.93 Grounding of the Outer Conductive Shield of Coaxial
Cables 302

Part IV. Grounding Methods 302

820.100 Bonding and Grounding Methods 302

Part V. Installation Methods Within Buildings 305

820.110 Raceways for Coaxial Cables 305

820.113 Installation of Coaxial Cables 306

820.133 Installation of Coaxial Cables and Equipment 307

820.154 Applications of Coaxial Cables..... 308

820.179 Listing and Marking of Coaxial Cables..... 309

**PRACTICE QUESTIONS FOR CHAPTER 8—
COMMUNICATIONS SYSTEMS**..... 310

FINAL EXAM A QUESTIONS..... 319

FINAL EXAM B QUESTIONS..... 330

INDEX..... 341

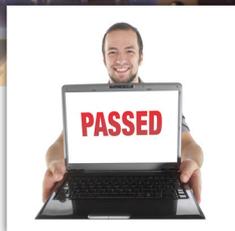
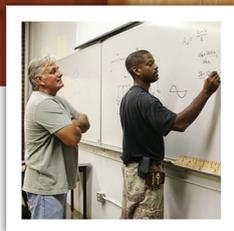
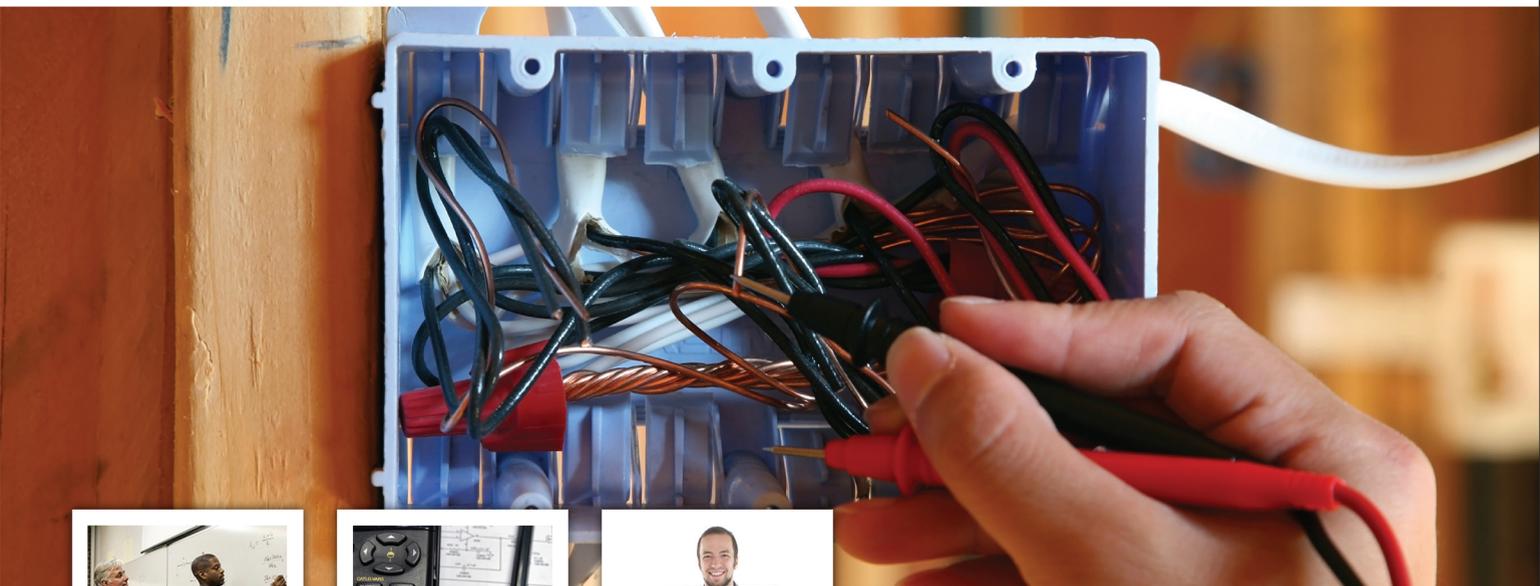
Mike Holt's Illustrated Guide to



ELECTRICAL EXAM PREPARATION

Theory • Calculations • Motor Controls • Code

Includes the NEC® Exam Practice Questions Book



Based on the 2011 NEC®

Suitable for all electrical exams based on the NEC®, such as:
AMP, ICC, Local Exam Boards, Pearson Vue, Professional Testing, Prometric, Prov, PSI

Table of Contents

Introduction	x
About This Textbook	xi
Passing Your Exam	xiv
How to Use the <i>National Electrical Code</i>	xviii
About the Author	xxi
About the Graphic Illustrator	xxii
Mike Holt Enterprises Team	xxiii

CHAPTER 1—BASIC ELECTRICAL THEORY (Essential for Journeyman and Master’s Licensing Exams)

1

UNIT 1—ELECTRICIAN’S MATH AND BASIC ELECTRICAL FORMULAS

3

Part A—Electrician’s Math	3
1.1 Whole Numbers	3
1.2 Decimals	3
1.3 Fractions	3
1.4 Percentages	4
1.5 Multiplier	4
1.6 Percent Increase	5
1.7 Reciprocals	5
1.8 Squaring a Number	6
1.9 Parentheses	7
1.10 Square Root	7
1.11 Volume	8
1.12 Kilo	8
1.13 Rounding Off	9
1.14 Testing Your Answer for Reasonableness	9
Part B—Basic Electrical Formulas	10
1.15 Electrical Circuit	10
1.16 Power Source	10
1.17 Conductance	11
1.18 Circuit Resistance	11
1.19 Ohm’s Law	12
1.20 Ohm’s Law and Alternating Current	12
1.21 Ohm’s Law Formula Circle	12
1.22 PIE Formula Circle	14
1.23 Formula Wheel	15

1.24 Using the Formula Wheel	16
1.25 Power Losses of Conductors	17
1.26 Cost of Power	17
1.27 Power Changes with the Square of the Voltage	18
Conclusion to Unit 1	20
Practice Questions for Unit 1	21
Challenge Questions for Unit 1	27

UNIT 2—ELECTRICAL CIRCUITS

29

Part A—Series Circuits	29
2.1 Practical Uses of the Series Circuit	29
2.2 Understanding Series Calculations	30
2.3 Series Circuit Calculations	33
2.4 Power Calculations	34
2.5 Variations	34
2.6 Series Circuit Notes	34
2.7 Series-Connected Power Supplies	34
Part B—Parallel Circuits	34
2.8 Practical Uses of the Parallel Circuit	35
2.9 Understanding Parallel Calculations	37
2.10 Circuit Resistance	38
2.11 Parallel Circuit Notes	40
2.12 Parallel-Connected Power Supplies	40
Part C—Series-Parallel Circuits	41
2.13 Review of Series and Parallel Circuits	41
2.14 Working With Series-Parallel Circuits	42
2.15 Voltage	42
Part D—Multiwire Branch Circuits	43
2.16 Neutral Conductor	43
2.17 Grounded Conductor	43
2.18 Current Flow on the Neutral Conductor	44
2.19 Balanced Systems	45
2.20 Unbalanced Current	45
2.21 Multiwire Branch Circuits	46
2.22 Dangers of Multiwire Branch Circuits	48
2.23 <i>NEC</i> Requirements	49
Conclusion to Unit 2	49
Practice Questions for Unit 2	51
Challenge Questions for Unit 2	57

UNIT 3—UNDERSTANDING ALTERNATING CURRENT	61	UNIT 4—MOTORS AND TRANSFORMERS	95
Part A—Understanding Alternating Current	61	Part A—Motor Basics	95
3.1 Current Flow	61	4.1 Motor Principles	95
3.2 Why Alternating Current Is Used	62	4.2 Dual-Voltage Alternating-Current Motors	96
3.3 How Alternating Current Is Produced	62	4.3 Motor Horsepower Ratings	96
3.4 Alternating-Current Generator	62	4.4 Motor Current Ratings	97
3.5 Waveform	63	4.5 Calculating Motor FLA	97
3.6 Sine Wave	64	4.6 Motor-Starting Current	98
3.7 Frequency	64	4.7 Motor-Running Current	99
3.8 Phase	64	4.8 Motor Locked-Rotor Current (LRC)	99
3.9 Degrees	65	4.9 Motor Overload Protection	99
3.10 Lead or Lag	65	4.10 Direct-Current Motor Principles	100
3.11 Values of Alternating Current	65	4.11 Direct-Current Motor Types	100
Part B—Capacitance	66	4.12 Reversing the Rotation of a Direct-Current Motor	101
3.12 Charged Capacitor	67	4.13 Alternating-Current Induction Motor	101
3.13 Electrical Field	67	4.14 Alternating-Current Motor Types	101
3.14 Discharging a Capacitor	68	4.15 Reversing the Rotation of an Alternating-Current Motor	102
3.15 Determining Capacitance	68	Part B—Transformers	102
3.16 Uses of Capacitors	69	4.16 Transformer Basics	102
3.17 Phase Relationship	69	4.17 Secondary Induced Voltage	103
Part C—Induction	70	4.18 Efficiency	103
3.18 Self-Induction	71	4.19 Transformer Turns Ratio	104
3.19 Induced Voltage and Applied Current	71	4.20 Autotransformers	106
3.20 Conductor Alternating-Current Resistance	72	4.21 Power Losses	106
3.21 Conductor Shape	72	4.22 Transformer kVA Rating	108
3.22 Magnetic Cores	73	4.23 Current Flow	108
3.23 Self-Induced and Applied Voltage	74	4.24 Current Rating	108
3.24 Inductive Reactance	75	Conclusion to Unit 4	109
3.25 Phase Relationship	75	Practice Questions for Unit 4	110
3.26 Uses of Induction	75	Challenge Questions for Unit 4	115
Part D—Power Factor	75		
3.27 Apparent Power (Volt-Amperes)	76	CHAPTER 2—NEC CALCULATIONS (Essential for Journeyman and Master’s Licensing Exams)	119
3.28 True Power (Watts)	76		
3.29 Power Factor	77	UNIT 5—RACEWAY AND BOX CALCULATIONS	121
3.30 Unity Power Factor	77	Part A—Raceway Fill	121
3.31 Power Factor Formulas	77	5.1 Understanding the <i>NEC</i> , Chapter 9 Tables	121
3.32 Cost of True Power	78	5.2 Raceway Calculations	131
3.33 Effects of Power Factor	79	5.3 Wireways	132
Part E—Efficiency	80	5.4 Tips for Raceway Calculations	135
3.34 Efficiency Formulas	81	Part B—Outlet Box Fill Calculations [314.16]	135
Conclusion to Unit 3	82	5.5 Sizing Box—Conductors All the Same Size [Table 314.16(A)]	135
Practice Questions for Unit 3	83		
Challenge Questions for Unit 3	91		

5.6 Conductor Equivalents	136	7.2 FLC versus Motor Nameplate	224
5.7 Outlet Box Sizing [314.16(B)]	139	7.3 Highest Rated Motor [430.17]	226
Part C—Pull Boxes, Junction Boxes, and Conduit Bodies	141	7.4 Branch-Circuit Conductor Size	226
5.8 Pull/Junction Box Sizing Requirements	142	7.5 Feeder Conductor Size [430.24]	229
5.9 Pull/Junction Box Sizing Tips	144	7.6 Overload Protection [430.6(A)(2) and 430.32(A)]	230
5.10 Pull Box Examples	144	7.7 Branch-Circuit Short-Circuit and Ground-Fault Protection [430.51]	236
Summary	146	7.8 Branch-Circuit Summary	239
Conclusion to Unit 5	146	7.9 Feeder Protection [430.62]	240
Practice Questions for Unit 5	147	7.10 Motor VA Calculations	241
Challenge Questions for Unit 5	152	Part B—Air-Conditioning Calculations	243
UNIT 6—CONDUCTOR SIZING AND PROTECTION CALCULATIONS	155	7.12 Scope of Article 440	243
Part A—General Conductor Requirements	155	7.13 Other Articles	243
6.1 Conductor Insulation [Table 310.104(A)]	155	7.14 Short-Circuit and Ground-Fault Protection	244
6.2 Conductor Sizing [110.6]	158	7.15 Conductor Sizing for a Single Motor-Compressor	245
6.3 Smallest Conductor Size [310.106(A)]	159	Conclusion to Unit 7	246
6.4 Conductor Size—Terminal Temperature Rating [110.14(C)]	159	Practice Questions for Unit 7	247
6.5 Conductors in Parallel	161	Challenge Questions for Unit 7	251
6.6 NEC Requirements for Conductors in Parallel [310.10(H)]	163	UNIT 8—VOLTAGE-DROP CALCULATIONS	253
6.7 Overcurrent Protection [Article 240]	165	Part A—Conductor Resistance Calculations	253
6.8 Overcurrent Protection of Conductors—General Requirements [240.4]	167	8.1 Conductor Resistance	253
6.9 Overcurrent Protection of Conductors—Specific Requirements	171	8.2 Conductor Resistance—Direct-Current Circuits [Chapter 9, Table 8]	256
Part B—Conductor Ampacity	185	8.3 Conductor Resistance—Alternating-Current Circuits	257
6.10 Conductor Ampacity	185	8.4 Alternating-Current Resistance	257
6.11 Ambient Temperature Correction Factors [Table 310.15(B)(2)(a)]	186	8.5 Alternating-Current Resistance as Compared to Direct-Current Resistance	259
6.12 Conductor Bundling Ampacity Adjustment Factors [Table 310.15(B)(3)(a)]	190	Part B—Voltage-Drop Considerations	260
6.13 Ambient and Conductor Bundling Adjustment	193	8.6 NEC Voltage-Drop Recommendations	260
6.14 Current-Carrying Conductors	195	8.7 Determining Circuit Conductors' Voltage Drop—Ohm's Law Method	262
6.15 Wireway Conductor Ampacity [376.22(B)]	197	8.8 Determining Circuit Conductors' Voltage Drop— Formula Method	262
6.16 Conductor Sizing Summary	197	8.9 Sizing Conductors to Prevent Excessive Voltage Drop	264
Part C—Article 690 Solar PV systems	198	8.10 Limiting Conductor Length to Minimize Voltage Drop	265
6.17 Maximum Voltage [690.7]	198	8.11 Limiting Current to Limit Voltage Drop	267
6.18 Circuit Sizing and Protection [690.8]	202	Conclusion to Unit 8	268
6.19 Overcurrent Protection [690.9]	209	Practice Questions For Unit 8	269
Conclusion to Unit 6	211	Challenge Questions For Unit 8	275
Practice Questions for Unit 6	212	UNIT 9—DWELLING UNIT CALCULATIONS	277
Challenge Questions for Unit 6	218	Part A—General Requirements	277
UNIT 7—MOTOR AND AIR-CONDITIONING CALCULATIONS	223	9.1 General Requirements	277
Part A—Motor Calculations	223	9.2 Voltages [220.5(A)]	278
7.1 Scope of Article 430	223	9.3 Fraction of an Ampere [220.5(B)]	278

9.4 Lighting and Receptacles 279

9.5 Cooking Equipment—Branch Circuit [Table 220.55, Note 4].... 280

Part B—Standard Method—Feeder/Service Load Calculations 283

9.6 Dwelling Unit Feeder/Service Load Calculations (Article 220, Part III) 283

9.7 Dwelling Unit Example 286

Part C—Optional Method—Feeder/Service Load Calculations.. 292

9.8 Dwelling Unit Optional Calculations [220.82]..... 292

9.9 Optional Calculation Example..... 293

Part D—Other Topics of Interest..... 294

9.10 Neutral Calculations [220.61]..... 294

9.11 Grounding and Bonding of Service Equipment..... 297

Conclusion to Unit 9..... 301

Practice Questions for Unit 9 302

Challenge Questions For Unit 9 309

CHAPTER 3—ADVANCED *NEC* CALCULATIONS (Essential for Master’s Exams) 313

UNIT 10—MULTIFAMILY DWELLING CALCULATIONS 315

10.1 Multifamily Dwelling Calculations—General..... 316

10.2 Multifamily Dwelling Calculation Examples—Standard Method..... 317

Part A—Standard Method—Feeder/Service Load Calculations 317

10.3 Multifamily Dwelling Calculations—Standard Method Example 325

Part B—Optional Method—Feeder/Service Load Calculations ... 327

10.4 Multifamily Dwelling Unit Calculations [220.84]—Optional Method 327

10.5 Multifamily—Optional Method Example 1 [220.84]..... 327

10.6 Multifamily—Optional Method Example 2 [220.84]..... 330

10.7 Two-Family Dwelling Units [220.85]..... 331

Conclusion to Unit 10..... 334

Practice Questions for Unit 10 335

Challenge Questions for Unit 10..... 340

UNIT 11—COMMERCIAL CALCULATIONS 343

Part A—General..... 343

11.1 General Requirements 343

11.2 Conductor Ampacity [Article 100]..... 343

11.3 Conductor Overcurrent Protection [240.4] 345

11.4 Voltages [220.5(A)] 347

11.5 Fractions of an Ampere [220.5(B)]..... 347

11.6 Lighting—Demand Factors [Tables 220.12 and 220.42] 347

11.7 Lighting Without Demand Factors [215.2(A) (1), 230.42(A)(1), and Table 220.12] 349

11.8 Sign Circuit [220.14(F) and 600.5] 350

11.9 Lighting—Miscellaneous 351

11.10 Multioutlet Receptacle Assembly [220.14(H)] 351

11.11 Receptacle VA Load 353

11.12 Banks and Offices—General Lighting and Receptacles [220.14(K)] 354

Part B—Examples 356

11.13 Bank/Office Building Example 356

11.14 Mobile/Manufactured Home Park [550.31]..... 358

11.15 Recreational Vehicle Park [551.73]..... 359

11.16 Marina [555.12]..... 360

Part C—Optional Method—Feeder/Service Load Calculations..... 361

11.17 New Restaurant—Optional Method [220.88] 361

Part D—Welders 362

11.18 Arc Welders 362

11.19 Resistance Welders..... 364

11.20 Light Industrial Calculation..... 365

Conclusion to Unit 11..... 367

Practice Questions for Unit 11 368

Challenge Questions for Unit 11..... 371

UNIT 12—TRANSFORMER CALCULATIONS 373

Part A—General 373

12.1 Transformer Basics 374

12.2 Secondary Induced Voltage 374

12.3 Autotransformers 375

12.4 Power Losses 376

12.5 Efficiency..... 377

12.6 Delta/Delta Connected Transformers 378

12.7 Delta/Wye Connected Transformers 381

12.8 Transformer Turns Ratio 382

12.9 Transformer kVA Rating..... 384

12.10 Current Flow 384

12.11 Line Currents 385

Part B—NEC Requirements..... 388

12.12 Transformer Overcurrent Protection 388

12.13 Primary Conductor Sizing..... 390

12.14 Secondary Conductor Sizing 391

12.15 Grounding and Bonding 394

Conclusion to Unit 12..... 397

Practice Questions for Unit 12 398

Challenge Questions for Unit 12..... 402

CHAPTER 4—MOTOR CONTROL BASICS (Journeyman and Master’s Exams in Some States) 405

UNIT 13—MOTOR CONTROL BASICS 407

Part A Basic Motor Control Concepts 407

13.1 Motor Control Language 408

13.2 Motor Control Basics..... 411

13.3 Reading a Motor Control Schematic 411

Part B Motor Control Circuits 413

13.4 2-Wire Control Circuits..... 413

13.5 3-Wire Control Circuits..... 416

13.6 3-Wire Circuit in a Wiring (Connection) Diagram..... 419

13.7 Multiple Start-Stop Pushbutton Stations..... 420

13.8 Reversing Three-Phase Motors 423

13.9 Forward and Reverse Contactors 424

13.10 Interlocking Devices..... 424

13.11 Electrical Interlock for Magnetic Reversing Controls 426

Conclusion to Unit 13..... 428

Practice Questions for Unit 13 429

Challenge Questions for Unit 13..... 432

CHAPTER 5—NEC PRACTICE QUESTIONS (Essential for all Journeyman and Master’s Exams) 435

Practice Quizzes

Practice Quiz 1—Straight Order [90–210.8] 437

Practice Quiz 1—Random Order [90–210.8]..... 446

Practice Quiz 2—Straight Order [210.8–240.54] 451

Practice Quiz 2—Random Order [90.2–240.60]..... 460

Practice Quiz 3—Straight Order [240.60–300.8] 465

Practice Quiz 3—Random Order [90.3–300.6]..... 474

Practice Quiz 4—Straight Order [300.9–344.10] 479

Practice Quiz 4—Random Order [90.2–342.26]..... 488

Practice Quiz 5—Straight Order [344.10–404.9] 493

Practice Quiz 5—Random Order [215.10–404.8]..... 502

Practice Quiz 6—Straight Order [404.9–430.87] 507

Practice Quiz 6—Random Order [210.21–430.81]..... 516

Practice Quiz 7—Straight Order [430.103–514.11] 521

Practice Quiz 7—Random Order [100–514.11]..... 530

Practice Quiz 8—Straight Order [514.13–647.4] 535

Practice Quiz 8—Random Order [200.6–640.4]..... 544

Practice Quiz 9—Straight Order [647.4–700.12] 549

Practice Quiz 9—Random Order [100–690.49]..... 559

Practice Quiz 10—Straight Order [700.15–Chapter 9] 564

Practice Quiz 10—Random Order [220.82–Chapter 9]..... 573

NEC Challenge Quizzes

Challenge Quiz 1—Article 90 through Chapter 9 579

Challenge Quiz 2—Article 90 through Chapter 9..... 588

Challenge Quiz 3—Article 90 through Chapter 9..... 597

Challenge Quiz 4—Article 90 through Chapter 9..... 606

Challenge Quiz 5—Article 90 through Chapter 9..... 616

Challenge Quiz 6—Article 90 through Chapter 9..... 625

Challenge Quiz 7—Article 90 through Chapter 9..... 634

Final NEC Exams

Final Exam 1—Questions in Random Order for
Article 90 through Annex C..... 643

Final Exam 2—Questions in Random Order for
Article 90 through Annex C..... 652