

10th Edition

# ELECTRICITY

for Refrigeration, Heating and Air Conditioning



Russell E. Smith

# CONTENTS

## Preface

vii

<b>1</b>	<b>Electrical Safety</b>	<b>1</b>
	Objectives 1 Key Terms 1 Introduction 2 1.1 Electrical Injuries 3 1.2 Dealing with Shock Victims 8 1.3 National Electrical Code® 8 1.4 Electrical Grounding 9 1.5 Circuit Protection 13 1.6 Circuit Lockout Procedures 14 1.7 Electrical Safety Guidelines 16 Summary 17 Review Questions 18	
<b>2</b>	<b>Basic Electricity</b>	<b>20</b>
	Objectives 20 Key Terms 20 Introduction 21 2.1 Atomic Theory 21 2.2 Positive and Negative Charges 23 2.3 Flow of Electrons 24 2.4 Conductors and Insulators 27 2.5 Electric Potential 27 2.6 Current Flow 29 2.7 Resistance 30 2.8 Electric Power and Energy 31 2.9 Ohm's Law 33 2.10 Calculating Electric Power 36 Summary 36 Review Questions 38	
<b>3</b>	<b>Electric Circuits</b>	<b>40</b>
	Objectives 40 Key Terms 40 Introduction 41 3.1 Basic Concepts of Electric Circuits 41 3.2 Series Circuits 43 3.3 Parallel Circuits 47 3.4 Series-Parallel Circuits 51 Summary 53 Review Questions 54	
<b>4</b>	<b>Electric Meters</b>	<b>56</b>
	Objectives 56 Key Terms 56 Introduction 57 4.1 Electric Meters 58 4.2 Ammeters 64 4.3 Voltmeters 67 4.4 Ohmmeters 69 Summary 73 Review Questions 74	
<b>5</b>	<b>Components, Symbols, and Circuitry of Air-Conditioning Wiring Diagrams</b>	<b>76</b>
	Objectives 76 Key Terms 76 Introduction 77 5.1 Loads 77 5.2 Contactors and Relays 82 5.3 Magnetic Starters 84 5.4 Switches 85 5.5 Safety Devices 88 5.6 Transformers 91 5.7 Schematic Diagrams 92 5.8 Pictorial Diagrams 93 5.9 Installation Diagrams 95 Summary 96 Review Questions 98	
<b>6</b>	<b>Reading Schematic Diagrams</b>	<b>100</b>
	Objectives 100 Key Terms 100 Introduction 101 6.1 Schematic Diagram Design 102 6.2 Reading Basic Schematic Diagrams 106 6.3 Reading Advanced Schematic Diagrams 127 Summary 150 Review Questions 151	
<b>7</b>	<b>Alternating Current, Power Distribution, and Voltage Systems</b>	<b>153</b>
	Objectives 153 Key Terms 153 Introduction 154 7.1 Basic Concepts of Alternating Current 154 7.2 Power Distribution 159 7.3 240-Volt-Single-Phase-60-Hertz Systems 160 7.4 Three-Phase Voltage Systems 162 7.5 240-Volt-Three-Phase-60-Hertz	

Delta System 163	7.6 208-Volt Three-Phase–60-Hertz Wye System 164																		
7.7 Higher-Voltage Systems 166	Summary 168	Review Questions 169																	
<b>8 Basic Electric Motors</b>	<b>171</b>																		
Objectives 171	Key Terms 171	Introduction 172	8.1 Magnetism 172	8.2 Basic Electric Motors 174	8.3 Types of Electric Motors 177	8.4 Shaded-Pole Motors 179	8.5 Capacitors 182	8.6 Split-Phase Motors 187	8.7 Permanent Split-Capacitor Motors 192	8.8 Capacitor-Start–Capacitor-Run Motors 195	8.9 Three-Phase Motors 197	8.10 Electronically Commutated Motors 199	8.11 Direct Current Brushless Motors 204	8.12 Hermetic Compressor Motors 205	8.13 Service Call Protocols 215	8.14 Service Calls 217	Summary 223	Review Questions 225	Practice Service Calls 229
<b>9 Components for Electric Motors</b>	<b>233</b>																		
Objectives 233	Key Terms 233	Introduction 234	9.1 Starting Relays for Single-Phase Motors 234	9.2 Current or Amperage Relays 235	9.3 Potential Relays 237	9.4 Solid-State Starting Relays and Devices 242	9.5 Motor Bearings 247	9.6 Motor Drives 250	9.7 Service Calls 253	Summary 258	Review Questions 260	Practice Service Calls 262							
<b>10 Contactors, Relays, and Overloads</b>	<b>265</b>																		
Objectives 265	Key Terms 265	Introduction 266	10.1 Contactors 267	10.2 Relays 271	10.3 Overloads 277	10.4 Magnetic Starters 284	10.5 Push-Button Stations 287	10.6 Service Calls 288	Summary 292	Review Questions 294	Practice Service Calls 296								
<b>11 Thermostats, Pressure Switches, and Other Electric Control Devices</b>	<b>299</b>																		
Objectives 299	Key Terms 299	Introduction 300	11.1 Transformers 301	11.2 Thermostats 303	11.3 Staging Thermostats 321	11.4 Programmable Thermostats 324	11.5 Communicating Thermostats 327	11.6 Wi-Fi Thermostats 330	11.7 Pressure Switches 333	11.8 Miscellaneous Electric Components 337	11.9 Service Calls 340	Summary 344	Review Questions 347	Practice Service Calls 350					
<b>12 Electronic Control Devices</b>	<b>354</b>																		
Objectives 354	Key Terms 354	Introduction 355	12.1 Electronic System Components 356	12.2 Basic Electronic Control Fundamentals 361	12.3 Simple Electronic Temperature Control 362	12.4 One-Function Electronic Controls 363	12.5 Electronic Timers 363	12.6 Electronic Devices for Electric Motors 365	12.7 Electronic Motor Protection Devices 365	12.8 Heat Pump Electronic Modules 368	12.9 Electronic Control Modules for Residential Gas Furnaces 371	12.10 Oil Furnace Electronic Controls 375	12.11 Troubleshooting Electronic Controls 376	Summary 376	Review Questions 378				
<b>13 Heating Control Devices</b>	<b>380</b>																		
Objectives 380	Key Terms 380	Introduction 381	13.1 Heating Fundamentals 383	13.2 Basic Heating Controls 385	13.3 Gas Heating Controls 392	13.4 Oil Heating Controls 404	13.5 Electric Heating Controls 410	13.6 Hydronic and Steam Controls 413	13.7 Service Calls 415	Summary 419	Review Questions 421	Practice Service Calls 423							
<b>14 Troubleshooting Electric Control Devices</b>	<b>426</b>																		
Objectives 426	Key Terms 426	Introduction 427	14.1 Electric Motors 427	14.2 Contactors and Relays 429	14.3 Overloads 431	14.4 Thermostats 435													

14.5 Pressure Switches 438	14.6 Transformers 439	14.7 Electric Heating Controls 440	14.8 Gas Heating Controls 442	14.9 Oil Heating Controls 453	14.10 Service Calls 456	Summary 462	Review Questions 464	Practice Service Calls 466							
<b>15</b>	<b>Residential Air-Conditioning Control Systems</b>							<b>473</b>							
Objectives 473	Key Terms 473	Introduction 474	15.1 Residential Air-Conditioning Equipment 476	15.2 Basic Residential Control Circuitry 480	15.3 Packaged Air-Conditioning Control Systems 491	15.4 Split-System Air-Conditioning Control Systems 500	15.5 Heat Pump Control Systems 505	15.6 Heat Pump Sequence of Operation 513	15.7 Advanced Residential Control Systems 518	15.8 Mini-Split Control Systems 524	15.9 Field Wiring 527	15.10 Check, Test, and Start Procedures 536	15.11 Customer Relations 538	Summary 540	Review Questions 542
<b>16</b>	<b>Installation of Heating, Cooling, and Refrigeration Systems</b>							<b>545</b>							
Objectives 545	Key Terms 545	Introduction 546	16.1 Sizing Wire 546	16.2 Disconnect Switches 554	16.3 Fusible Load Centers 558	16.4 Breaker Panels 559	16.5 Distribution Centers 562	16.6 Installing Electrical Circuits for Refrigeration, Heating, and Air-Conditioning Equipment 564	Summary 569	Review Questions 570					
<b>17</b>	<b>Commercial and Industrial Air-Conditioning Control Systems</b>							<b>572</b>							
Objectives 572	Key Terms 572	Introduction 573	17.1 Commercial and Industrial Heating and Air-Conditioning Equipment 574	17.2 Commercial and Industrial Control Circuitry 579	17.3 Commercial Condensing Unit 585	17.4 Commercial and Industrial Packaged Units 589	17.5 Air-Cooled Packaged Unit with Remote Condenser 591	17.6 Water-Cooled Packaged Units 595	17.7 Types of Total Commercial and Industrial Control Systems 596	17.8 Pneumatic Control Systems 600	17.9 Electronic Control Systems (Direct Digital Controls) 605	Summary 609	Review Questions 612		
<b>18</b>	<b>Troubleshooting Modern Refrigeration, Heating, and Air-Conditioning Control Circuitry and Systems</b>							<b>616</b>							
Objectives 616	Key Terms 616	Introduction 617	18.1 Diagnosis of Electrical Components 618	18.2 Troubleshooting Tools 620	18.3 Troubleshooting with Electrical Meters 627	18.4 Using Troubleshooting Charts 636	18.5 Hopscotching: A Useful Tool for Troubleshooting 638	18.6 Troubleshooting Control Systems 650	18.7 Service Calls 653	Summary 659	Review Questions 661	Practice Service Calls 664			
<b>Appendix A</b>								<b>668</b>							
<b>Appendix B</b>								<b>669</b>							
<b>Glossary</b>								<b>670</b>							
<b>Index</b>								<b>679</b>							

# INDEX

## A

- A (ampere), 28
- AC (alternating current). *See* Alternating current (AC)
- Advanced residential control systems, 518–524
  - advanced air-conditioning control systems, 518–519
  - zone control systems, 519–524
- Air-conditioning control systems, commercial and industrial. *See* Commercial and industrial air-conditioning control systems
- Air-conditioning control systems, residential.
  - See* Residential air-conditioning control systems
- Air-conditioning system controlled by a multistage thermostat, 131–135
- Air-conditioning system with lockout relay, 128–131
- Air-conditioning wiring diagrams, 76–97
  - contactors and relays, 82–84
  - installation diagrams, 95
  - introduction, 77
  - loads, 77–81
    - heaters, 80–81
    - motors, 78–80
    - signal lights, 81
    - solenoids, 80
  - magnetic starters, 84
  - pictorial diagrams, 93–95
  - safety devices, 88–91
  - schematic diagrams, 92–93
  - switches, 85–88
  - transformers, 91
- Air-cooled packaged units, 477
  - with remote condenser, 591–594
- Air supply sources for split-system residential systems, 503–505

Alternating current (AC), 29, 153–159

alternators, 156–157

cycles and frequency, 155–156

effective voltage, 156

inductance and reactance, 158

introduction, 154–155

phase, 156

power, 159

voltage-current systems, 156

Alternators, 156–157

Aluminum ladders conduct shock, 6

American Wire Gauge (AWG), 547

Ammeters, 64–67

clamp-on, 57

Amperage relays, 235–237

Ampere (A), 28

Analog meters, 60

Anticipators, 312

Anti-short-cycling circuitry, 583–585

Anti-short-cycling timer, 363–365

Applications

contactors, 267

parallel circuits, 47–48

programmable thermostats, 325–326

relays, 272–275

series circuits, 43–45

series-parallel circuits, 52–53

thermostats, 303–304

Arc flashes, 7–8

Atomic theory, 21–23

Atoms, 21

AWG (American Wire Gauge), 547

## B

Back electromotive force, 235

Balance point, 139

Ball bearings, 248

- Basic electricity, 20–37  
 atomic theory, 21–23  
 calculating electric power, 36  
 conductors and insulators, 27  
 current flow, 29–30  
 electric potential, 27–29  
 electric power and energy, 31–33  
 flow of electrons, 24–27  
 electricity through chemical means, 25–26  
 electricity through magnetism, 26–27  
 static electricity, 24–25  
 introduction, 21  
 Ohm's law, 33–35  
 positive and negative charges, 23–24  
 resistance, 30–31  
 Basic residential control circuitry, 480–491  
 compressor control circuits, 481  
 condenser fan motor control circuits, 481–482  
 evaporator fan motor control circuits, 482–483  
 furnace controls, 484–487  
 heat pump controls, 487–491  
 safety control circuits, 483  
 Bearings, 247–249  
 Bimetal elements, 305–306  
 Blower motor circuitry, 582–583  
 Blower units, 576  
 Breaker panels, 558–562  
 construction, 560–561  
 installation, 561–562  
 Breakers, 558  
 Broken circuit, 41  
 Burns, 5
- C**
- Cad cell, 406–407  
 Cad cell oil burner primary controls, 406–408  
 Calculations  
 current, resistance, and voltage  
 parallel circuits, 49–51  
 series circuits, 46–47  
 electric power, 36  
 voltage drop, 552–554  
 Capacitive reactance, 158  
 Capacitors, 182–187  
 troubleshooting, 183–186  
 two types used in the industry, 182–183
- Capacitor-start–capacitor-run motors, 195–197  
 operation, 195  
 troubleshooting, 195–197  
 Capacitor-start motors, 191  
 Capacity control, 579  
 Capacitor-start–induction-run motor, 191  
 Cardiopulmonary resuscitation (CPR), 8  
 Check, test, and start procedures, 536–537  
 Chemical means, 25–26  
 Circuit breakers, 13  
 Circuit lockout procedures, 14–16  
 Circuit protection, 13–14  
 Circuits, electric, 40–53  
 basic concepts, 41–43  
 introduction, 41  
 parallel circuits, 47–51  
 applications, 47–48  
 calculations for current, resistance, and voltage, 49–51  
 characteristics, 48–49  
 safety controls, condensing unit, 589  
 series circuits, 43–47  
 applications, 43–45  
 calculations for current, resistance, and voltage, 46–47  
 characteristics, 45–46  
 series-parallel circuits, 51–53  
 applications, 52–53  
 Clamp-on ammeter, 57  
 Closed circuit, 41  
 Coils, 269–270  
 Combustion chamber, 120  
 Commercial and industrial air-conditioning control systems, 572–611  
 air-cooled packaged unit with remote condenser, 591–594  
 commercial and industrial control circuitry, 579–585  
 anti-short-cycling circuitry, 583–585  
 blower motor circuitry, 582–583  
 compressor motor controls, 580–581  
 condenser fan motor circuitry, 583  
 water chiller control circuitry, 581–582  
 water-cooled condenser interlocks, 583

- commercial and industrial heating and air-conditioning equipment, 574–579  
blower units, 576  
commercial and industrial condensing units, 575  
commercial and industrial packaged units, 575–576  
hot water boilers, 576–577  
water chillers, 577–579  
commercial and industrial packaged units, 589–590  
commercial condensing unit, 585–589  
circuit safety controls, 589  
compressor circuits, 585–587  
condenser fan motor circuits, 587–589  
electronic control systems (direct digital controls), 605–609  
introduction, 573–574  
pneumatic control systems, 600–605  
types of total commercial and industrial control systems, 596–600  
water-cooled packaged units, 595–596  
Commercial freezers, 116–118  
Commercial refrigeration system with pump-down cycle, 144–150  
Communicating thermostats, 327–330  
Compounds, 22  
Compressor circuits, 585–587  
Compressor control circuits, 481  
Compressor motor controls, 580–581  
Condenser fan motor circuits, 583  
Condenser fan motor control circuits, 481–48  
Condensing unit, 476, 500–503, 585–589  
circuit safety controls, 589  
commercial and industrial air-conditioning control systems, 585–589  
circuit safety controls, 589  
compressor circuits, 585–587  
condenser fan motor circuits, 587–589  
compressor circuits, 585–587  
condenser fan motor circuits, 587–589  
Conductors, 4, 23, 27  
Construction  
breaker panels, 560–561  
electronically commutated motors (ECMs), 200–202  
relays, 275–276  
Contactors, 82–84, 267–271, 429  
applications, 267  
coils, 269  
contacts, 269  
operation, 267–269  
troubleshooting, 270–271  
Contacts, 269  
Continuity, 69  
Control circuit, 43  
Control circuitry, commercial and industrial air-conditioning control systems, 579–585.  
See also Commercial and industrial air-conditioning control systems  
anti-short-cycling circuitry, 583–585  
blower motor circuitry, 582–583  
compressor motor controls, 580–581  
condenser fan motor circuitry, 583  
water chiller control circuitry, 581–582  
water-cooled condenser interlocks, 583  
Control circuitry, residential air-conditioning systems, 480–491. See also Residential air-conditioning control systems  
compressor control circuits, 481  
condenser fan motor control circuits, 481–48  
evaporator fan motor control circuits, 482–483  
furnace controls, 484–487  
heat pump controls, 487–491  
safety control circuits, 483  
Control devices, electric. See Electric control devices  
Control devices, electronic. See Electronic control devices  
Control devices, heater. See Heating control devices  
Controlling elements of thermostats, 304–308  
Control loop, 597  
Control relay, 128  
Control wiring, 527, 532–535  
CPR (cardiopulmonary resuscitation), 8  
Current, 29  
Current flow, 29–30  
Current or amperage relays, 235–237  
operation, 235–236  
troubleshooting, 237  
Current overload, 282  
Current-sensing lockout relay (CSLR), 643

Cut-in pressure, 335  
 Cut-out pressure, 335  
 Cycles, 155

**D**

DC (direct current), 29, 154  
 brushless motors, 204–205  
 De-energized, 83  
 Defrost controls, 508–511  
 Defrost cycle, 139  
 Dehumidifiers, 107–108  
 Delay-on-make and break timers, 363  
 Delta system, 163–164  
 Delta winding, 198  
 Diagrams  
     air-conditioning. See Air-conditioning wiring diagrams  
     electrical wiring diagrams, 620–624  
         as troubleshooting tool, 620–624  
     factual diagrams, 95  
     fault isolation diagrams, 636  
     installation diagrams, 95  
     line diagrams, 93  
     pictorial diagrams, 93–95  
     schematic diagrams. See Schematic diagrams  
     wiring. See Wiring diagrams

Differential (of a pressure switch), 335

Digital meters, 60  
 Digital thermostat, 308

Diodes, 358

Direct current (DC), 29, 154  
 brushless motors, 204–205

Direct digital control systems, 605–609

Direct drive, 250

Disconnect switches, 85, 554–558  
 enclosures, 556

fusible and nonfusible switches, 557–558

Distribution centers, 562–564

Double insulated tools, 11

**E**

ECM (electronically commutated motor) savings  
 green technology, 204

Effective voltage, 156

Electrical grounding, 9–12

Electrical injuries, 3–8

Electrical meters, 620

Electrical resistance heater, 384  
 Electrical safety, 1–17  
 circuit lockout procedures, 14–16  
 circuit protection, 13–14  
 electrical grounding, 9–12  
 electrical injuries, 3–8  
 guidelines, 16–17  
 introduction, 2–3  
 National Electrical Code (NEC), 8–9  
 safety devices, 88–91  
 shock victims, dealing with, 8  
 Electrical shock, 3–6, 8  
 Electrical wiring diagrams, 620–624  
     for air-conditioning, 76–97  
     contactors and relays, 82–84  
     installation diagrams, 95  
     introduction, 77  
     loads, 77–81  
         heaters, 80–81  
         motors, 78–80  
         signal lights, 81  
         solenoids, 80  
     magnetic starters, 84  
     pictorial diagrams, 93–95  
     safety devices, 88–91  
     schematic diagrams, 92–93  
     switches, 85–88  
     transformers, 91  
 Electric circuits, 40–53  
     basic concepts, 41–43  
     introduction, 41  
     parallel circuits, 47–51  
         applications, 47–48  
         calculations for current, resistance, and voltage, 49–51  
         characteristics, 48–49  
     series circuits, 43–47  
         applications, 43–45  
         calculations for current, resistance, and voltage, 46–47  
         characteristics, 45–46  
     series-parallel circuits, 51–53  
         applications, 52–53  
 Electric control devices  
     humidistats, 337  
     oil safety switches, 337–338

- pressure switches, 87–88, 333–337, 390–392  
high-pressure switches, 334–335  
low-pressure switches, 335  
notations and terms, 335–336  
troubleshooting, 336–337
- solenoid valves, 339–340
- thermostats. *See Thermostats*
- time clocks, 339
- time-delay relays, 338–339
- troubleshooting, 426–463
- Electric energy, 32
- Electric heating controls, 410–412
- Electricity, basic concepts of, 20–37  
atomic theory, 21–23  
calculating electric power, 36  
conductors and insulators, 27  
current flow, 29–30  
electric potential, 27–29  
electric power and energy, 31–33  
flow of electrons, 24–27  
electricity through chemical means, 25–26  
electricity through magnetism, 26–27  
static electricity, 24–25
- introduction, 21
- Ohm's law, 33–35
- positive and negative charges, 23–24
- resistance, 30–31
- Electric meters, 56–73, 620  
ammeters, 64–67  
basic principles, 58–59  
differences among meters, 60–63  
introduction, 57–58  
ohmmeters, 69–73  
voltmeters, 67–69
- Electric motors, basic, 78–80, 171–224  
capacitors, 182–187  
troubleshooting, 183–186  
two types used in the industry, 182–183
- capacitor-start–capacitor-run motors, 195–197  
operation, 195  
troubleshooting, 195–197
- direct current brushless motors, 204–205
- electronically commutated motors (ECMs),  
199–204  
construction, 200–202  
operation, 202–203
- troubleshooting, 203
- hermetic compressor motors, 205–215  
operation, 206–207  
terminal identification, 207–208  
troubleshooting, 208–215
- introduction, 172, 174–176
- loads, 78–80, 427
- magnetism, 172–174  
induced magnetism, 173–174  
magnetic field, 173
- permanent split-capacitor motors, 192–195  
operation, 194  
troubleshooting, 194–195
- service calls, 215–223  
examples, 217–223  
protocol, 215–217
- shaded-pole motors, 179–182  
operation, 180–181  
reversing, 181  
troubleshooting, 181–182
- split-phase motors, 187–192  
capacitor-start–induction-run motor, 191  
enclosed type, 192  
open type, 191–192  
operation, 189–190  
resistance-start–induction-run motor, 187–189  
troubleshooting, 190
- three-phase motors, 197–199  
operation, 197–198  
troubleshooting, 198–199
- types of, 177–179  
motor dimensions, 179  
motor speed, 177  
motor strength, 177  
open and enclosed motors, 178–179
- Electric motors, components of, 233–259  
bearings, 247–249  
ball bearings, 248  
sleeve bearings, 249
- current or amperage relays, 235–237  
operation, 235–236  
troubleshooting, 237
- drives, 250–253  
direct drive, 250  
V-belt, 251–253
- introduction, 234

- Electric motors, components of (continued)  
potential relays, 237–241  
operation, 237–239  
troubleshooting, 239–241  
service calls, 253–258  
solid-state starting relays and devices, 242–247  
operation, 246–247  
troubleshooting, 247  
starting relays for single-phase motors, 234–235  
Electric potential, 27–29  
Electric power and energy, 31–33  
Electric pressure, 28  
Electrodes, 25  
Electrolytes, 25  
Electromagnet, 173  
Electromotive force, 3, 28  
Electronically commutated motors (ECMs), 199–204  
construction, 200–202  
operation, 202–203  
troubleshooting, 203  
Electronic control devices, 354–377  
basic electronic control fundamentals, 361–362  
electronic control modules for residential gas furnaces, 371–374  
electronic devices for electric motors, 365  
electronic motor protection devices, 365–367  
multifunction electronic motor protectors, 367  
overload protection, 366  
phase reversal protector, 367  
single-phase protection, 367  
electronic system components, 356–360  
diodes and rectifiers, 358–359  
LEDs, 360  
semiconductors, 357–358  
thermistors, 360  
transistors, 359  
triacs, 360  
electronic timers, 363–365  
anti-short-cycling timer, 363–365  
delay-on-make and break timers, 363  
heat pump electronic modules, 368–370  
introduction, 355–356  
oil furnace electronic controls, 375  
one-function electronic controls, 363  
simple electronic temperature control, 362  
troubleshooting electronic controls, 376  
Electronic control systems, 605–609  
Electronic elements, 307–308  
Electronic gas furnace control modules, 371  
Electronic modules, 356  
Electronic motor overloads, 366  
Electronic motor protection devices, 365–367  
multifunction electronic motor protectors, 367  
overload protection, 366  
phase reversal protector, 367  
single-phase protection, 367  
Electronic self-diagnostic feature, 627  
Electronic system components, 356–360  
diodes and rectifiers, 358–359  
LEDs, 360  
semiconductors, 357–358  
thermistors, 360  
transistors, 359  
triacs, 360  
Electronic timers, 363–365  
anti-short-cycling timer, 363–365  
delay-on-make and break timers, 363  
Electrons, 21–22  
flow of, 24–27  
Elements, 21  
Enclosed motors, 178–179  
Energized, 83  
Energy efficiency ratings  
green technology, 476  
Energy-efficient motors  
green technology, 178  
Evaporator fan motor control circuits, 482–483
- F**
- Factory-installed wiring, 527  
Factual diagrams, 95  
Fan-coil unit, 479  
Fan controls, 385–389  
Fan switches, 386  
Fault isolation diagram, 636  
Field of force, 28  
Field wiring, 527–535  
control wiring, 532–535  
power wiring, 527–530  
wire and fuse sizing, 530–532  
Flux, 173  
Free electrons, 23

Freezers, commercial, 116–118  
Frequency, 155–156  
Full-load amperage (FLA), 235  
Furnace controls, 484–487  
Fuses, 13, 89, 277, 557–559  
Fusible and nonfusible switches, 557–558  
Fusible disconnect switch, 557  
Fusible load centers, 558–559

## G

Gas furnaces, 118  
with standing pilot, 118–122  
Gas heat electric air-conditioning packaged unit control system, 492–498  
Gas heating controls, 392–404  
direct ignition burner control system, 398–400  
integrated furnace control boards, 400–404  
intermittent pilot burner control system, 395–398  
standing pilot burner control system, 392–395  
Gas packs, 477  
Gas valves, 392  
Green technology  
ECM (electronically commutated motor) savings, 204  
energy efficiency ratings, 476  
energy-efficient motors, 178  
hybrid heat pump system, 507  
mercury disposal, 320  
multistage equipment, 321  
PCBs (polychlorinated biphenyls), 187  
programmable thermostats, 327  
variable-speed compressors, 206  
zoned air-conditioning systems, 522  
Ground, 9  
Ground fault circuit interrupter (GFCI), 11  
Grounding adapter, 10

## H

Heater, 80–81  
Heater loads, 80–81  
Heating anticipators, 312  
Heating control devices, 380–420  
basic heating controls, 385–392  
fan controls, 385–389  
limit switches, 389–390  
pressure switches, 390–392

electric heating controls, 410–412  
gas heating controls, 392–404  
direct ignition burner control system, 398–400  
integrated furnace control boards, 400–404  
intermittent pilot burner control system, 395–398  
standing pilot burner control system, 392–395  
heating fundamentals, 383–385  
hydronic and steam controls, 413–414  
introduction, 381–383  
oil heating controls, 404–410  
cad cell oil burner primary controls, 406–408  
stack switch oil burner primary controls, 408–410  
service calls, 415–419  
Heating fundamentals, 383–385  
Heat pump, 135, 323–324, 477  
control module, 368  
control systems, 487–491, 505–513  
defrost controls, 508–511  
heat pump electrical components, 508  
reversing valves, 508  
supplementary heat, 511–513  
electrical components, 508  
electronic module, 368–370  
hybrid heat pump system, 507  
sequence of operation, 513–518  
with solid-state defrost board, 135–144  
Hermetic compressor motors, 205–215  
operation, 206–207  
terminal identification, 207–208  
troubleshooting, 208–215  
Higher-voltage systems  
advantages, 166  
disadvantages, 166  
277/480-volt system, 166–167  
High-pressure switches, 334–335  
Hopscotching, 638–650  
Hot surface ignition, 398  
Hot water boilers, 576–577  
HSPF (Heating Seasonal Performance Factor), 476  
Humidistats, 337  
Hybrid heat pump system  
green technology, 507  
Hydronic and steam controls, 413–414

**I**  
Ignition module, 371, 396

Impedance, 158

Induced magnetism, 173–174

Inductance, 158

Inductive loads, 269, 277

Inductive reactance, 158

Industrial air conditioning and control systems.  
See Commercial and industrial air-conditioning control systems

Injuries, electrical, 3–8. See also Safety

Installation and service instructions, 625

Installation diagrams, 95

Installation of heating, cooling, and refrigeration systems, 545–569

breaker panels, 559–562

construction, 560–561

installation, 561–562

disconnect switches, 554–558

enclosures, 556

fusible and nonfusible switches, 557–558

distribution centers, 562–564

fusible load centers, 558–559

installing electrical circuits for refrigeration, heating, and air-conditioning equipment, 564–569

introduction, 546

sizing wire, 546–554

calculating voltage drop, 552–554

factors to consider in wiring, 547

voltage drop, 547–552

wire size, 547

wire-sizing charts, 552

Insulators, 27

Interlock, 581

Internal compressor overloads, 280

## K

Kilowatthours (kWh), 32

## L

Label, 93

Ladders, 6

Law of electric charges, 23

Light commercial air-conditioning control system with a control relay, 127–128

Light-emitting diode (LED), 360

Limit switch, 120, 389–390

Line break and pilot duty overloads, 277–283

Line diagram, 93

Line-voltage control system, 107

Line-voltage thermostat, 304, 308–309

Live electrical circuit, 2

Loads, 77–81

heaters, 80–81

motors, 78–80

signal lights, 81

solenoids, 80

Loads, resistive, 269, 277

Locked rotor amperage (LRA), 235

Lockout relay, 128

Low-pressure switch, 335

Low-voltage control system, 104, 118–120

Low-voltage thermostats, 304, 309–316

## M

Made circuit, 41

Magnetic field, 58, 173

Magnetic overload, 89, 282

Magnetic relay, 235

Magnetic starters, 84, 284–287

troubleshooting, 286–287

types of magnetic starter overloads and their operation, 286

Magnetism, 26–27, 172–174

induced magnetism, 173–174

magnetic field, 173

Matter, 21

Measurable resistance, 69

Mechanical linkage, 270

Mercury disposal

green technology, 320

Meters, electric, 56–73, 620

ammeters, 64–67

basic principles, 58–59

differences among meters, 60–63

introduction, 57–58

ohmmeters, 69–73

voltmeters, 67–69

Microfarad, 183

Mini-split control systems, 525–527

Molecules, 21

Motors. *See* Electric motors, basic; Electric motors, components of

Multifunction electronic motor protectors, 367

Multistage equipment

green technology, 321

Multistage thermostat, 131

## N

National Electrical Code (NEC), 8–9, 546

National Fire Protection Association, 8

Negative and positive charges, 23–24

Neutrons, 22

Nonconductive ladders, 6

Nonfusible disconnect switch, 557

Noninductive loads, 277

Normally closed contacts, 83

"Normally," meaning of, 83

Normally open contacts, 83

Nucleus, 21

## O

Ohmmeters, 60, 69–73

Ohm's law, 33–35

Ohm ( $\Omega$ ), 28

Oil furnace electronic controls, 375

Oil heating controls, 404–410

  cad cell oil burner primary controls, 406–408

  stack switch oil burner primary controls, 408–410

Oil safety switch, 337–338

One-function electronic controls, 363

Open and enclosed motors, 178–179

Open circuit, 41

Opens (open circuits), 69

Overloads, 277–284

  fuses, 277

  line break and pilot duty overloads, 277–283

  protection, 366

  troubleshooting, 284

## P

Packaged air-conditioning control systems,

  491–500

  commercial and industrial, 589–590

  gas heat electric air-conditioning packaged unit  
    control system, 492–498

  packaged air-conditioning unit control systems,  
    492

  packaged heat pump control systems,  
    498–500

Packaged air-conditioning equipment, 122–127,  
  476–479

Packaged units, 476

Parallel circuits, 47–51

  applications, 47–48

  calculations for current, resistance, and voltage,  
    49–51

  characteristics, 48–49

PCBs (polychlorinated biphenyls)  
  green technology, 187

Peak voltage, 156

Permanent magnet, 173

Permanent split-capacitor motors, 192–195  
  operation, 194

  troubleshooting, 194–195

Phase, 156

Phase reversal protector, 367

Pictorial diagrams, 93–95

Pilot, 381

Pilot assembly, 396

Pilot duty device, 89

Pilot duty overload, 278, 281–283

Plugs, 10

Pneumatic control systems, 600–605

Pole, 83

Polychlorinated biphenyls (PCBs)  
  Green technology, 187

Positive and negative charges, 23–24

Potential difference, 28

Potential relays, 237–241

  operation, 237–239

  troubleshooting, 239–241

Power, 159

Power circuits, 47

Power distribution, 159–160

Power factor, 31, 159

Power wiring, 527–530

Pressure elements, 306–307

Pressure switches, 87–88, 333–337, 390–392,  
  438

  high-pressure switches, 334–335

  low-pressure switches, 335

  notations and terms, 335–336

  troubleshooting, 336–337

Primary control, 405  
 Programmable thermostats, 324–327  
     applications, 325–326  
     green technology, 327  
     installation, 326–327  
     programming the electronic digital programmable thermostat, 327  
 Protons, 22  
 Pump, heat. *See* Heat pump  
 Pump-down control system, 144  
 Push-button stations, 287–288  
 Push-button switch, 85

**R**

Range (of a control), 335  
 Reactance, 158  
 Reactance, capacitive, 158  
 Reading advanced schematic diagrams, 127–150.  
     *See also* Schematic diagrams, reading  
 Reading basic schematic diagrams, 106–127. *See also* Schematic diagrams, reading  
 Rectifiers, 358–359  
 Relays, 82–84, 271–277, 429  
     applications, 272–275  
     construction, 275–276  
     operation, 271–272  
     troubleshooting, 277  
 Residential air-conditioning control systems, 473–541  
     advanced residential control systems, 518–524  
         advanced air-conditioning control systems, 518–519  
         zone control systems, 519–524  
     basic residential control circuitry, 480–491  
         compressor control circuits, 481  
         condenser fan motor control circuits, 481–48  
         evaporator fan motor control circuits, 482–483  
         furnace controls, 484–487  
         heat pump controls, 487–491  
         safety control circuits, 483  
     check, test, and start procedures, 536–537  
     customer relations, 538–540  
     equipment, 476–480  
         packaged air-conditioning equipment, 476–479  
         split air-conditioning systems, 479–480

field wiring, 527–535  
     control wiring, 532–535  
     power wiring, 527–530  
     wire and fuse sizing, 530–532  
 heat pump control systems, 505–513  
     defrost controls, 508–511  
     heat pump electrical components, 508  
     reversing valves, 508  
     supplementary heat, 511–513  
 heat pump sequence of operation, 513–518  
 introduction, 474–475  
 mini-split control systems, 525–527  
 packaged air-conditioning control systems, 491–500  
     gas heat electric air-conditioning packaged unit control system, 492–498  
     package air-conditioning unit control systems, 492  
     packaged heat pump control systems, 498–500  
 split-system air-conditioning control systems, 500–505  
     air supply sources for split-system residential systems, 503–505  
     basic condensing units, 500–503  
 Residential gas furnaces, electronic control modules for, 371–374  
 Resistance, 30–31  
     measurable, 69  
 Resistance-start–induction-run motor, 187–189  
 Resistive load, 269, 277  
 Reversing shaded-pole motors, 181  
 Reversing valve, 135, 505, 508  
 Rotors, 174  
 Running capacitor, 183

## S

Safety, electrical, 1–17  
     circuit lockout procedures, 14–16  
     circuit protection, 13–14  
     electrical grounding, 9–12  
     electrical injuries, 3–8  
     guidelines, 16–17  
     introduction, 2–3  
     National Electrical Code (NEC), 8–9  
     safety devices, 88–91  
     shock victims, dealing with, 8

- Safety control circuits, 483  
Schematic diagrams, 92–93  
design, 102–106  
reading, 100–150  
advanced schematic diagrams, 127–150  
air-conditioning system controlled by a multistage thermostat, 131–135  
air-conditioning system with lockout relay, 128–131  
basic schematic diagrams, 106–127  
commercial freezer, 116–118  
commercial refrigeration system with pump-down cycle, 144–150  
dehumidifier, 107–108  
gas furnace with standing pilot, 118–122  
heat pump with solid-state defrost board, 135–144  
introduction, 101–102  
light commercial air-conditioning control system with a control relay, 127–128  
packaged air-conditioning unit, 122–127  
reading advanced schematic diagrams, 127–150  
reading basic schematic diagrams, 106–127  
schematic diagram design, 102–106  
simple window air conditioner, 108–113  
walk-in cooler, 113–116  
Seasonal energy efficiency ratio (SEER), 32, 476  
Semiconductors, 357–358  
Sequencer, 410  
Series circuits, 43–47  
applications, 43–45  
calculations for current, resistance, and voltage, 46–47  
characteristics, 45–46  
Series-parallel circuits, 51–53  
applications, 52–53  
Service calls, 288–292  
electric motors, components of, 253–258  
examples, 217–223  
heating control devices, 415–419  
protocol, 215–217  
thermostats, 340–344  
Set point, 108  
Shaded-pole motors, 179–182  
operation, 180–181  
reversing, 181  
troubleshooting, 181–182  
Shock victims, dealing with, 8  
Short cycles, 128  
Shorts (short circuits), 69  
Signal lights, 81  
Simple electronic temperature control, 362  
Simple window air conditioner, 108–113  
Sine wave, 154  
Single-phase current, 156  
Single-phase protection, 367  
Sizing wire, 546–554  
calculating voltage drop, 552–554  
factors to consider in wiring, 547  
voltage drop, 547–552  
wire size, 547  
wire-sizing charts, 552  
Sleeve bearings, 249  
Snap action, 305  
Solenoid, 80  
Solenoid loads, 80  
Solenoid valves, 339–340  
Solid state, 357  
Solid-state starting relays and devices, 242–247  
operation, 246–247  
troubleshooting, 247  
Spark ignition, 398  
Speed of electric motors, 177  
Split-air-conditioning systems, 476, 479–480  
Split-phase motors, 187–192  
capacitor-start–induction-run motor, 191  
enclosed type, 192  
open type, 191–192  
operation, 189–190  
resistance-start–induction-run motor, 187–189  
troubleshooting, 190  
Split system, 475  
Split-system air-conditioning control systems, 500–505  
air supply sources for split-system residential systems, 503–505  
basic condensing units, 500–503  
Squirrel cage rotor, 176

- Stack switch, 406  
Stack switch oil burner primary controls, 408–410  
Staging thermostats, 321–324  
heat pumps, 323–324  
operation and types, 322–323  
staging system, 321–322  
Starting capacitors, 182  
Starting relay, 234  
for single-phase motors, 234–235  
Start procedure (check, test, and start), 536–537  
Star winding, 198  
Static electricity, 24–25  
Stators, 174  
Steam and hydronic controls, 413–414  
Strength of electric motors, 177  
Supplementary heat, 511–513  
Switches, 85–88  
Systems, voltage, 160–167  
higher-voltage systems, 166–167  
advantages, 166  
disadvantages, 166  
277/480-volt system, 166–167  
three-phase voltage systems, 162–163  
240-volt-single-phase–60-Hertz systems, 160–162  
240-volt-three-phase–60-Hertz delta system, 163–164  
208-volt-three-phase–60-Hertz wye system, 164–166
- T**
- Terminal identification, in hermetic compressor motors, 207–208  
Test procedure (check, test, and start procedures), 536–537  
Thermal overload, 89  
Thermistors, 357, 360  
Thermocouple, 392–394  
Thermostats, 87, 303–320, 435  
applications, 303–304  
communicating thermostats, 327–330  
controlling elements of thermostats, 304–308  
installation, 316–319  
line-voltage thermostats, 308–309  
low-voltage thermostats, 309–316  
miscellaneous electric components, 337–340  
humidistats, 337  
oil safety switch, 337–338  
solenoid valves, 339–340  
time clock, 339  
time-delay relay, 338–339  
pressure switches, 333–337  
high-pressure switches, 334–335  
low-pressure switches, 335  
notations and terms, 335–336  
troubleshooting, 336–337  
programmable thermostats, 324–327  
applications, 325–326  
installation, 326–327  
programming the electronic digital programmable thermostat, 327  
service calls, 340–344  
staging thermostats, 321–324  
heat pumps, 323–324  
operation and types, 322–323  
staging system, 321–322  
troubleshooting, 319–320  
wi-fi thermostats, 330–333  
Three-phase current, 156  
Three-phase motors, 197–199  
operation, 197–198  
troubleshooting, 198–199  
Three-phase voltage systems, 162–163  
Three-prong plug, 10  
Throw, 85  
Time clocks, 339  
Time-delay relay, 338–339  
Timers, delay-on-make and break, 363  
Timers, electronic, 363–365  
anti-short-cycling timer, 363–365  
delay-on-make and break timers, 363  
Torque, 172  
Total commercial and industrial control systems, 596–600  
Transformers, 91, 301–303  
operation, 301–301  
sizing, 302–303  
troubleshooting, 303  
Transistors, 359  
Triacs, 360

- Troubleshooting, 426–463, 616–660  
capacitors, 183–186  
capacitor-start–capacitor-run motors, 195–197  
contactors, 270–271  
contactors and relays, 429–431  
coil, 430  
contacts, 429–430  
mechanical linkage, 430–431  
control systems, 650–653  
industrial systems, 652–653  
residential systems, 652  
current or amperage relays, 237  
electrical components, 618–620  
contactors and relays, 619–620  
motors, 619  
other electrical devices, 620  
switches, 619  
electrical meters, 627–636  
electric heating controls, 440–442  
electric motors, 427–429  
electronically commutated motors (ECMs), 203  
electronic controls, 376  
gas heating controls, 442–453  
direct ignition control systems, 449  
gas valves, 443–446  
integrated furnace control, 449–453  
intermittent pilot systems, 446–448  
hermetic compressor motors, 208–215  
hopscotching: a useful tool for troubleshooting, 638–650  
introduction, 427, 617–618  
magnetic starters, 286–287  
oil heating controls, 453–456  
cad cell primary controls, 455–456  
stack switch primary controls, 453–455  
overloads, 284, 431–435  
circuit breaker, 432  
fuse, 431  
internal overloads, 434–435  
line voltage overload, 432  
pilot duty overload, 432–434  
permanent split-capacitor motors, 194–195  
potential relays, 239–241  
pressure switches, 336–337, 438–439  
refrigeration, heating, and air-conditioning  
control circuitry and systems, 616–660  
relays, 277  
service calls, 456–462, 653–659  
shaded-pole motors, 181–182  
solid-state starting relays and devices, 247  
split-phase motors, 190  
thermostats, 319–320, 435–437  
line-voltage thermostat, 436  
low-voltage thermostat, 436–437  
three-phase motors, 198–199  
tools for, 620–627  
electrical meters, 620  
electrical wiring diagrams, 620–624  
electronic self-diagnostic feature, 627  
installation and service instructions, 625  
troubleshooting charts, 625–627, 636–638  
transformers, 439–440  
Troubleshooting tree, 636
- V**
- Variable-speed compressors  
green technology, 206  
Varistor, 357  
V-belt, 251  
V-belt drive, 251–253  
V-belt motors, 251–253  
Voltage, 28  
Voltage-current systems, 156  
Voltage drop, 46  
sizing wire, 547–552  
Voltage spikes, 361  
Voltage systems, 160–167  
208-volt-three-phase-60-Hertz wye system, 164–166  
240-volt-single-phase-60-Hertz systems, 160–162  
240-volt-three-phase-60-Hertz delta system, 163–164  
higher-voltage systems, 166–167  
advantages, 166  
disadvantages, 166  
277/480-volt system, 166–167  
three-phase voltage systems, 162–163  
Voltmeters, 60, 67–69  
Volt-ohm-milliammeters, 57  
Volt (V), 28

**W**

- Walk-in cooler, 113–116
- Water chillers, 577–579
  - control circuitry, 581–582
- Water-cooled condenser interlocks, 583
- Water-cooled condensing units, 583
- Water-cooled packaged units, 477, 595–596
- Water source heat pump, 477–478
- Watts (W), 31
- Wi-fi thermostats, 330–333
- Window air conditioner, simple, 108–113
- Wire, sizing, 546–554
  - calculating voltage drop, 552–554
  - factors to consider in wiring, 547
  - voltage drop, 547–552
  - wire size, 547
    - wire-sizing charts, 552
- Wire and fuse sizing, 530–532
- Wiring, field, 527–535
  - control wiring, 532–535
  - power wiring, 527–530
  - wire and fuse sizing, 530–532

- Wiring diagrams, for air-conditioning, 76–97
  - contactors and relays, 82–84
  - installation diagrams, 95
  - introduction, 77
  - loads, 77–81
    - heaters, 80–81
    - motors, 78–80
    - signal lights, 81
    - solenoids, 80
  - magnetic starters, 84
  - pictorial diagrams, 93–95
  - safety devices, 88–91
  - schematic diagrams, 92–93
  - switches, 85–88
  - transformers, 91
- Wye system, 164

**Z**

- Zone control systems, 519–524
- Zoned air-conditioning systems
  - green technology, 522