

**Delmar's
Standard Textbook of**
ELECTRICITY

Seventh Edition

Stephen L. Herman

The book cover features a dark blue background with a complex, glowing pattern of blue and yellow-orange lightning bolts. The lightning bolts are most intense in the lower half, where they appear as bright, branching structures. The upper half is darker, with more subtle, wispy lightning patterns. Two horizontal bands of semi-transparent, grey, geometric shapes (resembling a sawtooth or zigzag pattern) are positioned above and below the main text area. The text is centered and reads:

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Standard Textbook of

ELECTRICITY



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Delmar's Standard Textbook of Electricity,
7th edition
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Library of Congress Control Number: 2018965691

ISBN: 978-1-337-90034-8

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Printed in the United States of America
Print Number: 01 Print Year: 2019

CONTENTS

Preface	xvii
Introduction: Electrical Occupations	xxiii
SECTION 1	
Safety, Basic Electricity, and Ohm's Law	2
SAFETY OVERVIEW	
S-1 General Safety Rules	4
S-2 Effects of Electric Current on the Body	5
S-3 On the Job	6
S-4 Protective Clothing	10
S-5 Ladders and Scaffolds	13
S-6 Fires	16
S-7 Ground-Fault Circuit Interrupters	18
S-8 Arc-Fault Circuit Interrupters (AFCIs)	20
S-9 Grounding	24
UNIT 1	
Atomic Structure	29
1-1 Early History of Electricity	30
1-2 Atoms	31
1-3 The Law of Charges	35
1-4 Structure of the Atom	36
1-5 Electron Orbits	37
1-6 Valence Electrons	38
1-7 The Bump Theory	40
1-8 Power Sources	43
1-9 Insulators	44
1-10 Semiconductors	44
1-11 Molecules	44
1-12 Methods of Producing Electricity	46
1-13 Electrical Effects	47
UNIT 2	
Electrical Quantities and Ohm's Law	50
2-1 The Coulomb	51
2-2 The Ampere	51
2-3 The Electron Flow Theory	52
2-4 The Conventional Current Flow Theory	52
2-5 Speed of Current	54
2-6 Basic Electric Circuits	55
2-7 The Volt	57
2-8 The Ohm	58

2–9	The Watt	60
2–10	Other Measures of Power	61
2–11	Ohm’s Law	62
2–12	Metric Prefixes	67

UNIT 3

Static Electricity **73**

3–1	Static Electricity	74
3–2	Charging an Object	76
3–3	The Electroscope	76
3–4	Static Electricity in Nature	79
3–5	Nuisance Static Charges	81
3–6	Useful Static Charges	81

UNIT 4

Magnetism **86**

4–1	The Earth Is a Magnet	87
4–2	Permanent Magnets	88
4–3	The Electron Theory of Magnetism	88
4–4	Magnetic Materials	90
4–5	Magnetic Lines of Force	91
4–6	Electromagnetics	92
4–7	Magnetic Measurement	95
4–8	Magnetic Polarity	97
4–9	Demagnetizing	97
4–10	Magnetic Devices	98

UNIT 5

Resistors **103**

5–1	Uses of Resistors	104
5–2	Fixed Resistors	105
5–3	Color Code	109
5–4	Standard Resistance Values of Fixed Resistors	113
5–5	Power Ratings	114
5–6	Variable Resistors	115
5–7	Schematic Symbols	118

SECTION 2

Basic Electric Circuits **122**

UNIT 6

Series Circuits **123**

6–1	Series Circuits	124
6–2	Voltage Drops in a Series Circuit	124
6–3	Resistance in a Series Circuit	126
6–4	Calculating Series Circuit Values	127

6–5	Solving Circuits	128
6–6	Voltage Dividers	139
6–7	The General Voltage Divider Formula	140
6–8	Voltage Polarity	141
6–9	Using Ground as a Reference	142
UNIT 7		
Parallel Circuits		149
7–1	Parallel Circuit Values	150
7–2	Parallel Resistance Formulas	153
UNIT 8		
Combination Circuits		173
8–1	Combination Circuits	174
8–2	Solving Combination Circuits	174
8–3	Simplifying the Circuit	175
SECTION 3		
Meters and Wire Sizes		200
UNIT 9		
Measuring Instruments		201
9–1	Analog Meters	202
9–2	The Voltmeter	204
9–3	Multirange Voltmeters	205
9–4	Reading a Meter	207
9–5	The Ammeter	210
9–6	Ammeter Shunts	211
9–7	Multirange Ammeters	213
9–8	The Ayrton Shunt	214
9–9	AC Ammeters	218
9–10	Clamp-On Ammeters	221
9–11	DC–AC Clamp-On Ammeters	223
9–12	The Ohmmeter	225
9–13	Shunt-Type Ohmmeters	227
9–14	Digital Meters	228
9–15	The Low-Impedance Voltage Tester	231
9–16	The Oscilloscope	232
9–17	The Wattmeter	242
9–18	Recording Meters	244
9–19	Bridge Circuits	245
UNIT 10		
Using Wire Tables and Determining Conductor Sizes		250
10–1	The American Wire Gauge (AWG)	251
10–2	Using the <i>NEC</i> Charts	253

10–3	Factors That Determine Ampacity	255
10–4	Correction Factors	257
10–5	Calculating Conductor Sizes and Resistance	262
10–6	Calculating Voltage Drop	271
10–7	Parallel Conductors	273
10–8	Testing Wire Installations	275

SECTION 4

Small Sources of Electricity	282
-------------------------------------	------------

UNIT 11

Conduction in Liquids and Gases	283
--	------------

11–1	The Ionization Process: Magnesium and Chlorine	284
11–2	Other Types of Ions	286
11–3	Electroplating	287
11–4	Electrolysis	288
11–5	Conduction in Gases	288
11–6	Ionization in Nature	292

UNIT 12

Batteries and Other Sources of Electricity	294
---	------------

12–1	History of the Battery	295
12–2	Cells	296
12–3	Cell Voltage	297
12–4	Primary Cells	298
12–5	Secondary Cells: Lead-Acid Batteries	306
12–6	Other Secondary Cells	313
12–7	Series and Parallel Battery Connections	315
12–8	Other Small Sources of Electricity	317

UNIT 13

Magnetic Induction	327
---------------------------	------------

13–1	Electromagnetic Induction	328
13–2	Fleming's Left-Hand Generator Rule	330
13–3	Moving Magnetic Fields	331
13–4	Determining the Amount of Induced Voltage	331
13–5	Lenz's Law	333
13–6	Rise Time of Current in an Inductor	335
13–7	The Exponential Curve	336
13–8	Inductance	338
13–9	R-L Time Constants	339
13–10	Induced Voltage Spikes	341

SECTION 5	
Basics of Alternating Current	348
UNIT 14	
Basic Trigonometry and Vectors	349
14–1 Right Triangles	350
14–2 The Pythagorean Theorem	351
14–3 Sines, Cosines, and Tangents	353
14–4 Formulas	356
14–5 Practical Application	356
UNIT 15	
Alternating Current	367
15–1 Advantages of AC	368
15–2 AC Waveforms	368
15–3 Sine Wave Values	375
15–4 Resistive Loads	381
15–5 Power in an AC Circuit	382
15–6 Skin Effect in AC Circuits	383
SECTION 6	
Alternating Current (AC) Circuits Containing Inductance	388
UNIT 16	
Inductance in AC Circuits	389
16–1 Inductance	390
16–2 Inductive Reactance	393
16–3 Schematic Symbols	396
16–4 Inductors Connected in Series	397
16–5 Inductors Connected in Parallel	398
16–6 Voltage and Current Relationships in an Inductive Circuit	399
16–7 Power in an Inductive Circuit	400
16–8 Reactive Power	401
16–9 Q of an Inductor	402
UNIT 17	
Resistive-Inductive Series Circuits	409
17–1 R-L Series Circuits	410
17–2 Impedance	411
17–3 Total Current	414
17–4 Voltage Drop Across the Resistor	414
17–5 Watts	415
17–6 Calculating the Inductance	416
17–7 Voltage Drop Across the Inductor	416
17–8 Total Voltage	416

17–9	Calculating the Reactive Power	416
17–10	Calculating the Apparent Power	418
17–11	Power Factor	420
17–12	Angle Theta	421

UNIT 18

Resistive-Inductive Parallel Circuits **434**

18–1	Resistive-Inductive Parallel Circuits	435
18–2	Calculating Circuit Values	435

SECTION 7

AC Circuits Containing Capacitors **454**

UNIT 19

Capacitors **455**

19–1	Capacitors	456
19–2	Electrostatic Charge	459
19–3	Dielectric Constant	462
19–4	Capacitor Ratings	462
19–5	Capacitors Connected in Parallel	464
19–6	Capacitors Connected in Series	464
19–7	Capacitive Charge and Discharge Rates	465
19–8	RC Time Constants	466
19–9	Applications for Capacitors	468
19–10	Nonpolarized Capacitors	468
19–11	Polarized Capacitors	471
19–12	Variable Capacitors	473
19–13	Capacitor Markings	474
19–14	Temperature Coefficients	476
19–15	Ceramic Capacitors	476
19–16	Dipped Tantalum Capacitors	476
19–17	Film Capacitors	477
19–18	Testing Capacitors	478

UNIT 20

Capacitance in AC Circuits **484**

20–1	Connecting the Capacitor into an AC Circuit	485
20–2	Capacitive Reactance	486
20–3	Calculating Capacitance	487
20–4	Voltage and Current Relationships in a Pure Capacitive Circuit	488
20–5	Power in a Pure Capacitive Circuit	490
20–6	Quality of a Capacitor	491
20–7	Capacitor Voltage Rating	492
20–8	Effects of Frequency in a Capacitive Circuit	492
20–9	Series Capacitors	494
20–10	Parallel Capacitors	497

UNIT 21		
Resistive-Capacitive Series Circuits		504
21-1	Resistive-Capacitive Series Circuits	505
21-2	Impedance	506
21-3	Total Current	507
21-4	Voltage Drop Across the Resistor	507
21-5	True Power	507
21-6	Capacitance	508
21-7	Voltage Drop Across the Capacitor	508
21-8	Total Voltage	508
21-9	Reactive Power	508
21-10	Apparent Power	510
21-11	Power Factor	511
21-12	Angle Theta	511
UNIT 22		
Resistive-Capacitive Parallel Circuits		521
22-1	Operation of RC Parallel Circuits	522
22-2	Calculating Circuit Values	523
SECTION 8		
AC Circuits Containing Resistance-Inductance-Capacitance		536
UNIT 23		
Resistive-Inductive-Capacitive Series Circuits		537
23-1	RLC Series Circuits	538
23-2	Series Resonant Circuits	548
UNIT 24		
Resistive-Inductive-Capacitive Parallel Circuits		556
24-1	RLC Parallel Circuits	557
24-2	Parallel Resonant Circuits	566
UNIT 25		
Surge, Spike, and Lightning Protection		577
25-1	Surges and Spikes	578
25-2	Capacitors	579
25-3	Capacitor Charge Rate	580
25-4	Inductors	581
25-5	Isolation Transformers	583
25-6	Electrical Noise	583
25-7	Metal-Oxide Varistor (MOV)	585
25-8	Thermal Fuses	587
25-9	Surge Protector Ratings	588
25-10	Lightning Arresters	590

SECTION 9**Three-Phase Power****594****UNIT 26****Three-Phase Circuits****595**

26–1	Three-Phase Circuits	596
26–2	Wye Connections	597
26–3	Delta Connections	600
26–4	Three-Phase Power	603
26–5	Watts and VARs	603
26–6	Three-Phase Circuit Calculations	604
26–7	Load 3 Calculations	611
26–8	Load 2 Calculations	612
26–9	Load 1 Calculations	612
26–10	Alternator Calculations	613
26–11	Power Factor Correction	614

SECTION 10**Transformers****622****UNIT 27****Single-Phase Transformers****623**

27–1	Single-Phase Transformers	624
27–2	Isolation Transformers	625
27–3	Autotransformers	647
27–4	Transformer Polarities	650
27–5	Voltage and Current Relationships in a Transformer	654
27–6	Testing the Transformer	656
27–7	Transformer Nameplates	656
27–8	Determining Maximum Current	658
27–9	Transformer Impedance	658

UNIT 28**Three-Phase Transformers****670**

28–1	Three-Phase Transformers	671
28–2	Closing a Delta	676
28–3	Three-Phase Transformer Calculations	677
28–4	Open-Delta Connection	682
28–5	Single-Phase Loads	683
28–6	Closed Delta with Center Tap	686
28–7	Closed Delta without Center Tap	687
28–8	Delta–Wye Connection with Neutral	687
28–9	T-Connected Transformers	688
28–10	Scott Connection	691
28–11	Zig-Zag Connection	691
28–12	Six-Phase Transformer Connections	692

28–13	The Double-Delta Connection	694
28–14	The Double-Wye Connection	695

SECTION 11

DC Machines

700

UNIT 29

DC Generators

701

29–1	What Is a Generator?	702
29–2	Armature Windings	710
29–3	Brushes	711
29–4	Pole Pieces	711
29–5	Field Windings	712
29–6	Series Generators	714
29–7	Shunt Generators	716
29–8	Compound Generators	720
29–9	Compounding	721
29–10	Countertorque	722
29–11	Armature Reaction	724
29–12	Setting the Neutral Plane	727
29–13	Paralleling Generators	728

UNIT 30

DC Motors

733

30–1	DC Motor Principles	734
30–2	Shunt Motors	737
30–3	Series Motors	739
30–4	Compound Motors	740
30–5	Terminal Identification for DC Motors	742
30–6	Determining the Direction of Rotation of a DC Motor	743
30–7	Speed Control	745
30–8	The Field-Loss Relay	747
30–9	Horsepower	748
30–10	Brushless DC Motors	750
30–11	Converters	753
30–12	Permanent Magnet Motors	754
30–13	The Right-Hand Motor Rule	760

SECTION 12

AC Machines

764

UNIT 31

Three-Phase Alternators

765

31–1	Three-Phase Alternators	766
31–2	The Rotor	769
31–3	The Brushless Exciter	770

31–4	Alternator Cooling	770
31–5	Frequency	773
31–6	Output Voltage	774
31–7	Paralleling Alternators	775
31–8	Sharing the Load	777
31–9	Field-Discharge Protection	777

UNIT 32

Three-Phase Motors **780**

32–1	Three-Phase Motors	781
32–2	The Rotating Magnetic Field	781
32–3	Connecting Dual-Voltage Three-Phase Motors	793
32–4	Squirrel-Cage Induction Motors	799
32–5	Wound-Rotor Induction Motors	820
32–6	Synchronous Motors	823
32–7	Selsyn Motors	829

UNIT 33

Single-Phase Motors **836**

33–1	Single-Phase Motors	837
33–2	Split-Phase Motors	837
33–3	Resistance-Start Induction-Run Motors	840
33–4	Capacitor-Start Induction-Run Motors	847
33–5	Dual-Voltage Split-Phase Motors	848
33–6	Determining the Direction of Rotation for Split-Phase Motors	851
33–7	Capacitor-Start Capacitor-Run, or Permanent Split Capacitor, Motors	852
33–8	Shaded-Pole Induction Motors	854
33–9	Multispeed Motors	858
33–10	Repulsion-Type Motors	859
33–11	Construction of Repulsion Motors	860
33–12	Repulsion-Start Induction-Run Motors	863
33–13	Repulsion-Induction Motors	865
33–14	Single-Phase Synchronous Motors	865
33–15	Stepping Motors	867
33–16	Universal Motors	874

UNIT 34

Motor Installation **886**

34–1	Motor Full-Load Current	887
34–2	Single-Phase AC Motors	887
34–3	Three-Phase Motors	889
34–4	Determining Conductor Size for a Single Motor	890
34–5	Termination Temperature	890
34–6	Overloads	892
34–7	Sizing Overload Heaters for Large Motors	897
34–8	Motor Starter Size	900
34–9	Short-Circuit Protection	900
34–10	Multiple Motor Calculations	910

UNIT 35	
Harmonics	916
35–1 What Are Harmonics?	917
APPENDIX A	
Identifying the Leads of a Three-Phase, Wye-Connected, Dual-Voltage Motor	927
APPENDIX B	
AC Formulas	930
APPENDIX C	
Greek Alphabet	941
APPENDIX D	
Metals	942
APPENDIX E	
Scientific Notation	944
APPENDIX F	
Answers to Practice Problems	948
Glossary	966
Index	978

PREFACE

Intended Use

Delmar's Standard Textbook of Electricity, 7th edition, is intended for students in electrical trade programs at high schools and community colleges, as well as those in industry training. It assumes that the reader has had no prior knowledge of electricity but also provides enough comprehensive coverage to be used as a reference tool for experienced electricians.

Subject and Approach

The content itself is presented as a blend of the practical and theoretical. It not only explains the different concepts relating to electrical theory but also provides many practical examples of how to do many of the common tasks the industrial electrician must perform. An extensive art program containing full color photographs and line drawings, as well as the inclusion of practical exercises for the student, also serve to further clarify theoretical concepts.

Design of Text

The subject matter has been divided into 35 separate units—each designed to “stand alone.” The “stand-alone” concept permits the information to be presented in almost any sequence the instructor desires, as teaching techniques vary from one instructor to another. The information is also presented in this manner to allow students and instructors quick reference on a particular subject.

Math Level

The math level has been kept to basic algebra and trigonometry, and Appendix B contains a section of electrical formulas—all divided into groups that are related to a particular application. Unit 14 of the text provides an introduction to basic trigonometry and vectors for those students weak in the subject.

A Note about Calculations

Delmar's Standard Textbook of Electricity, 7th edition, like all other scientific texts, contains numerous mathematical equations and calculations. Students often become concerned if their answers to problems are not exactly the same as the solutions given in the text. The primary reason for a discrepancy is the rounding off of values. Different scientific calculators carry out numbers to different places, depending on the manufacturer and model. Some calculators carry numbers to 8 places, some to 10 places, and some to 12 places. There may also be times when numbers that are reentered into the calculator are carried to only 2 or 3 decimal places of accuracy. For example, the numbers shown below will be multiplied with a calculator that carries numbers out to 8 places of accuracy:

$$3.21 \times 34.6 \times 4.32 \times 0.021 \times 3.098 \times 0.467$$

The answer is 14.577480.

The same problem will again be multiplied, but this time each answer will be reentered before it is multiplied by the next number. Each time the answer is reentered, it will be rounded off to 3 places after the decimal. If the fourth number after the decimal is 5 or greater, the third decimal place will be rounded up. If the fourth number is less than 5, it will be rounded down. The answer is 14.577405.

The same set of numbers will again be multiplied, but this time each answer will be reentered after rounding off the number to one place after the decimal. The answer is 14.617100.

Notice that all three answers are different, but all three are essentially correct. The most accurate answer is 14.577480, and the least accurate answer is 14.617100. Although these answers may look substantially different, they are within approximately 1% of each other.

Another consideration is problems that contain multiple steps. The more steps it takes to solve a problem, the more chance there is for inaccuracy. In most instances in this text, the answers were left in the display of the calculator, which permits the greatest degree of accuracy. When numbers had to be re-entered, they were taken to 3 places of accuracy. When you work a problem in this text and your answer is different, consider the degree of difference before concluding that your answer is incorrect.

New to This Edition

The seventh edition of *Delmar's Standard Textbook of Electricity* continues to remain true to the comprehensive nature and visually appealing style that are its trademark features but will now offer more emphasis on the practical approach to electrical theory. New to this edition:

- Updated graphics.
- Extended coverage of batteries to include AGM batteries.
- Added coverage of three-phase transformers to include connections for six-phase transformer connections.
- The previous-edition unit on filters has been revised to include more practical applications concerning surge, spike, and lightning protection.
- A new unit on motor installation in accord with the *NEC*. The unit concerns conductor selection, fuse or circuit-breaker sizing, and overload heater selection.

Features of the Text

• “Safety Overview”

At the beginning of Section I, Safety Overview provides information on general safety rules, personal protective equipment, potential job hazards, lock-out/tag-out procedures, GFCI, Grounding—and more! Students are acquainted with the all important safety concerns applicable to working in a lab and on the work site.

• “Cautions”

Author highlights text where students should be aware of potential risks in working with various types of electrical equipment.

CAUTION

The ammeter, unlike the voltmeter, is a very low-impedance device. The ammeter is used to measure current and must be connected in series with the load to permit the load to limit the current flow (Figure 9-13).

• **Math Presentation**

Section on vectors in Unit 16 is presented earlier in the text in Unit 14, *Basic Trigonometry*, providing a foundation for students as they work through math equations.

356 SECTION 5 Basics of Alternating Current

EXAMPLE 14-3
Using the same triangle (Figure 14-7), determine the number of degrees in angle Y.

SOLUTION
In this example, the lengths of the hypotenuse and the adjacent side are known. The cosine function can be used to find the angle:

$$\cosine \angle Y = 0.643$$

To find what angle corresponds to the cosine of 0.643, use the trigonometric tables in Appendices A and B or the COS function of a scientific calculator:

$$COS^{-1} \text{ or ARC COS } 0.643 = 50^\circ$$

14-4 Formulas

Some formulas that can be used to find the angles and lengths of different sides follow:

$$Adj. = \cos \angle \theta \times Hyp.$$

$$Opp = \sin \angle \theta \times Hyp.$$

$$Opp. = Adj. \times \tan \angle \theta$$

14-5 Practical Application

Although the purpose of this unit is to provide preparation for the study of AC circuits, basic trigonometry can provide answers to other problems that may be encountered on the job. Assume that it is necessary to know the height of a tall building (Figure 14-8). Now assume that the only tools available to make this measurement are a 1-foot ruler, a tape measure, and a scientific calculator. To make the measurement, find a relatively flat area in the open sunlight. Hold the ruler upright and measure the shadow cast by the sun (Figure 14-9). Assume the length of the shadow to be 7.5 inches. Using the length of the shadow as one side of a right triangle and the ruler as the other side, the angle

• **“Why You Need to Know”**

This element at the beginning of each unit explains to students the importance of learning the material presented in each unit, and how it may apply to actual job situations.

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UNIT
33 Single-Phase Motors

Key Terms
Centrifugal switch
Compensating winding
Conductive compensation
Consequent-pole motor
Encoder
Holtz motor
Inductive compensation
Multispeed motors
Neutral plane
Repulsion motor
Run winding
Servo motor
Shaded-pole induction motor

Why You Need to Know
Single-phase motors are used almost exclusively in residential applications and to operate loads that require fractional horsepower motors in industrial and commercial locations. Many of these motors you will recognize from everyday life and may have wondered how they work. Unlike three-phase motors, there are many different types of single-phase motors and they do not all operate on the same principle. There are some that operate on the principle of a rotating magnetic field, but others do not. Some single-phase motors are designed to operate at more than one speed. This unit

- presents several different types of single-phase motors and explains how they operate.
- explains how to determine the appropriate motor to be used under a given situation by evaluating the operating principles of each.

• **“Practical Applications”**

Word problems step the students through potential situations on the job and encourage them to develop critical thinking skills.

PRACTICAL APPLICATIONS

Industry often employs the use of an electromagnet to pick up metal objects. These large magnets are called round horseshoe magnets. They contain a center core surrounded by an outer core. A direct current winding of magnetic wire is wound around the center core. An illustration of a round horseshoe magnet that has been cut in half is shown in Figure 4-21. When direct current flows through the winding, the magnetic field produces the polarities as shown. The dimensions of the magnet are shown in Figure 4-22. It is assumed that the magnetic field developed has a flux density of 2 webers per square inch. Determine the maximum pulling force of the magnet.

• **Text Design**

A fresh design creates a text that makes it even easier to navigate through content, serving to facilitate learning for students.

• **New, Up-to-Date Art**

Approximately 110 new four-color photos and line illustrations combined bring text up to date, keeping students aware of the latest technology in the industry.

• **Dedication to Technical Accuracy and Consistency**

Text was thoroughly reviewed for technical accuracy and consistency, ensuring existing errors were corrected, enabling students to readily grasp more difficult concepts.

Supplement Package

- **Lab-Volt Manual** provides experiments for students to test and troubleshoot key concepts presented in the text, using Lab-volt equipment. (Order #: 978-1-111-53916-0).
- **The Complete Laboratory Manual for Electricity**, by Steve Herman. This manual is designed to be conducted with common lab equipment. (Order #: 978-1-133-67382-8).

MindTap

MindTap is well beyond an eBook, a homework solution or digital supplement, a resource center website, a course delivery platform, or a Learning Management System. MindTap is a new personal learning experience that combines all your digital assets—readings, multimedia, activities, and assessments—into a singular learning path to improve student outcomes.

Instructor Site

An Instructor Companion website containing supplementary material is available. This site contains an Instructor Guide, an image gallery of text figures, chapter presentations done in PowerPoint, and testing powered by Cognero.

Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to:

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1. Go to <http://login.cengage.com> and log in using the instructor e-mail address and password.
2. Enter author, title, or ISBN in the **Add a title to your bookshelf** search.
3. Click **Add to my bookshelf** to add instructor resources.
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Delmar Online Training Simulation: Electricity

Delmar Online Training Simulation: Electricity is an immersive simulation that offers electrical students a learning path from basic electrical concepts to real world electrical applications. It features a variety of engaging simulation activities including interactive wiring diagrams and practical exercises like wiring a lighting branch circuit in a realistic 3D setting.



Certain Units in this text will display the Delmar Online Training Simulation: Electricity icon at the end of the unit and will specify which modules in the simulation contain activities related to that unit.

The interactive wiring diagrams are visually powerful and illustrate how electricity flows in a system. Students can use a realistic multimeter to measure voltage, amperage, and resistance and rapidly increase their understanding of practical electrical concepts. There are also extensive animations and tutorials to gradually build student confidence with challenging topics.

The lighting branch simulations are realistic and will give students the practical context to understand common electrical tasks. Students will have to choose cable types and wire individual conductors to make the circuits work properly. Circuits include a variety of single pole and 3-way switches.

Printed Access Code ISBN: 978-1-305-26447-2 or Instant Access Code ISBN: 978-1-305-26445-8 available for instant purchase on www.cengagebrain.com.

A Note about the Lab Manuals

Two laboratory manuals are available to The Standard Textbook of Electricity: *Experiments in Electricity for Use with Lab-Volt EMS Equipment* and *The Complete Laboratory Manual for Electricity, 4E*, provide extensive opportunities for students to apply what they have learned. Both manuals contain multiple hands-on experiments for selective units of the textbook and have been extensively field-tested to ensure that all the experiments will work as planned. The engineers at Lab-Volt conducted each of the experiments in *Experiments in Electricity for Use with Lab-Volt EMS Equipment*, and, following their testing, Lab-Volt has endorsed this manual. It is the manual they recommend to their customers. *The Complete Laboratory Manual for Electricity* was field-tested at the Shreveport-Bossier Regional Technical School under the direction of Richard Cameron.

ABOUT THE AUTHOR

Stephen L. Herman has been both a teacher of industrial electricity and an industrial electrician for many years. His formal training was obtained at Catawba Valley Technical College in Hickory, North Carolina. Mr. Herman has worked as a maintenance electrician for Superior Cable Corp. and as a class “A” electrician for National Liberty Pipe and Tube Co. During those years of experience, Mr. Herman learned to combine his theoretical knowledge of electricity with practical application. The books he has authored reflect his strong belief that a working electrician must have a practical knowledge of both theory and experience to be successful.

Mr. Herman was the Electrical Installation and Maintenance instructor at Randolph Technical College in Asheboro, North Carolina, for 9 years. After a return to industry, he became the lead instructor of the Electrical Technology Curriculum at Lee College in Baytown, Texas. He retired from Lee College after 20 years of service and, at present, resides in Pittsburg, Texas, with his wife. He continues to stay active in the industry, write, and update his books.

ACKNOWLEDGMENTS

The author and publisher would like to express thanks to those reviewers who provided insightful feedback throughout the development of this text:

James Blackett, Thomas Nelson Community College, Hampton, VA

Oscar Buschinelli, Centre for Skills Development and Training, Burlington, ON, Canada

James Cipollone, Antelope Valley Community College, Lancaster, CA

Eduardo Del Toro, MacArthur High School/Independent Electrical Contractors, San Antonio, TX
Anne Koering, Clark College, Vancouver, WA
Randy Ludington, Guilford Community College, Greensboro, NC
Robert B. Meyers, Jr., Harrisburg Area Community College, Harrisburg, PA
J.C. Morrow, Hopkinsville Community College, Hopkinsville, KY
Quinton Phillips, Athens Area Vocational Technical Institute, Athens, GA
Larry Pogoler, LA Trade Tech College, Los Angeles, CA
Rick Reardon, Eastern Maine Community College, Bangor, ME
Dean Senter, Pratt Community College, Pratt, KS
Justin Shores, Antelope Valley Community College, Lancaster, CA
Elmer Tepper, Gateway Community College, Phoenix, AZ
Raul Vasquez, Independent Electrical Contractors, San Antonio, TX
Kevin Weigman, Northeast Wisconsin Technical College, Green Bay, WI

INTRODUCTION

ELECTRICAL OCCUPATIONS

ORGANIZATION OF THE INDUSTRY

The electrical industry is one of the largest in the United States and Canada. In 2008, electricians held about 692,000 jobs. Electrical contracting firms employed about 65% of the wage and salaried workers. The remainder worked as electricians in other related industries. About 9% of the electricians were self-employed. The opportunity for employment and advancement as an electrician is one of the highest of any industry. Basically, the entire country runs on electricity. Industry, commercial locations, and homes all employ electricity as the main source of power. It has been estimated that between 2008 and 2018 the need for qualified electricians will increase at a rate of about 12%. That represents an annual increase of over 8000 electricians over the next 10 years. The lay-off rate of electricians is one of the lowest of any occupation. If industry operates, it will require electricians to keep it running.

Electrical Personnel

Electricians can generally be divided into several categories, depending on their specific area of employment. Each of these categories may require special skills.

- ♦ **Construction**

Electricians working in the construction industry generally require a basic knowledge of electrical theory and an extensive knowledge of *National Electrical Code*® requirements and wiring practices. Electricians in the construction area can generally be divided into helpers, journeymen, and masters. Many states require tests for journeymen and master levels.

- ♦ **Industrial Electricians**

Industrial electricians are generally concerned with maintaining equipment that has already been installed. Electricians in an industrial environment require an extensive knowledge of electrical theory and *National Electrical Code*® requirements for installation of motors, capacitor banks, and transformers. Industrial electricians should also possess a basic knowledge of electronics and electronic devices. Modern industry employs many electronic devices, such as variable frequency drives, solid state controls for direct current motors, and programmable logic controllers. Another area of concern for most industrial electricians is motor controls. Motor control systems are generally either relay logic or electronic in the form of programmable logic controllers or distributive control systems.

- ♦ **Instrumentation Technicians**

Instrumentation technicians calibrate and maintain devices that sense such quantities as temperature, pressure, liquid level, flow rate, and others. These people should have an extensive knowledge of electrical theory, especially as it pertains to low-voltage and closed-loop systems.

- ♦ **Related Industries**

The fields related to the electrical industry are too numerous to mention but include air conditioning and refrigeration, aircraft electronics, automotive, cable TV, broadcast media, energy and utilities, and home appliance and repair, as well as many, many others. The opportunity for employment in the electrical field is almost unlimited.

Union and Nonunion Employees

The largest percentage of electricians are nonunion employees. Many construction electricians receive training at various trade and technical schools. Some employers also sponsor apprenticeship programs. Apprenticeship-type programs generally require the electrician to work on the job as well as attend classes. The advantage to apprenticeship training is that it permits a person to earn money while he or she attends class. The disadvantage is that it can create an extremely busy schedule. Most industrial electricians, and those in related fields, require special training at a trade or technical school.

The largest electrician's union is the International Brotherhood of Electrical Workers (IBEW). The construction electricians who belong to the IBEW generally receive apprenticeship-type training for an organization called the National Joint Apprenticeship Training Committee (NJATC). Union electricians who work in related fields generally belong to unions organized for their particular industry, such as United Auto Workers or United Steel Workers.

Apprentices, whether union or nonunion, attend classes several hours a week and work on the job under the supervision of a journeyman. Most journeymen have completed their apprenticeship training and a set number of hours of practical work, and are required to pass an examination to become a journeyman. Journeymen work under the supervision of a master electrician. The master is ultimately responsible for the work performed and is answerable to the architect or owner. Most states require not only that a master pass a very rigorous examination but also be bonded for a particular sum of money, depending on the size of the job he or she bids on.

Ethics

Probably the greatest document concerning ethical behavior was given to a man named Moses on top of a mountain several thousand years ago and is called the Ten Commandments. Ethics are the principles by which behavior is judged to be right or wrong. There is an old saying stating that the best advertisement is word of mouth. This type of advertisement, however, can be a two-edged sword. People who do poor work, charge for work that was not done, make promises that are never kept, and cheat people at every opportunity gain a reputation that eventually catches up with them.

People who do an honest day's work for an honest wage, keep promises, and deal fairly with other people gain a reputation that will lead to success. Many years ago I worked for a man who had a business of rebuilding engines. He charged about twice the going rate of any other person in town and had more business than he could handle. I once asked him how he could charge more than anyone else and still have more business than anyone else. His answer was simple. He said, "There are two ways by which a business can be known. One is as the cheapest in town and the other is as the best in town. I'm the best in town." Most people are willing to pay more for a person that has a reputation for doing quality work and dealing honestly with customers.

Appearance

Appearance plays a major role in how a person is perceived. The old saying that first impressions are the most important is true. This doesn't mean that formal office attire is required to make a good impression on a prospective customer, but a professional person is expected to look professional. A person who wears clean work clothes and drives a relatively clean vehicle makes a much better impression than someone who shows up in filthy clothes with shirttail hanging out and pants sagging almost to the knees.

Communication

Communication skills are extremely important on any job. These skills can be divided into several areas such as speaking, listening, and writing.

Speaking: Speaking well is probably one of the most important skills for obtaining a successful career in any field. Generally, one of the first impressions you make concerns your ability to speak properly. Even though slang is widely used among friends, family, and the media, a person who uses proper English gives the impression of being educated, informed, and professional.

The ability to speak also involves communicating with people on the job, whether that person is a journeyman or an employer. The ability to explain clearly how a job was done or why it was done a certain way is also important, as it is often necessary to communicate with people who have no knowledge of the electrical field. The ability to explain to a homeowner why a receptacle or switch should or should not be placed in a particular location is important.

Listening: Listening is probably the most understated skill concerning communication. You should not only listen to what a person wants but also make sure you *understand* what he or she is saying. Not understanding what a person wants can lead to extremely costly mistakes. The most costly work is that which has to be redone because of a misunderstanding. An example of how misunderstandings can lead to costly mistakes is shown in *Figure Occupations 1*.

Writing: Many jobs require the electrician to fill out work reports that can include a description of the job, the materials used, and the time required to complete the job. This is especially true of a person in charge of other workers, such as a journeyman.

Maintenance electricians in an industrial environment generally submit a report on the maintenance performed on a particular machine. The report commonly includes the particular machine, the problem encountered, the materials necessary for repair, and the time spent in troubleshooting and repair.

Working on a Team

Teamwork is essential on most construction jobs. The typical construction job may include people that pour the concrete foundation; carpenters; brick masons; stone masons; plumbers; landscapers; people that install flooring and carpet; air-conditioning and refrigeration contractors; and, of course, electricians. One of the key elements to a successful team effort is communication. If conduit is to be run under the slab, it is better to communicate with the people doing the foundation and inform them that conduit needs to be run before the slab is poured.

Be respectful of other trades. If an electrical outlet box is in the way of a sewer line, the plumber may ask that it be moved. It is much easier to move an outlet box than it is to reroute a sewer line. If electrical boxes are to be placed in an outside brick wall, ask the brick mason how he would like the box to be placed. A little respect for other trades plus communication can solve many problems before they happen.

If possible, help other people. If you are already in an attic and the air-conditioning contractor asks whether you would be willing to do a small job that would save him time and effort, it is good working relations to do so. Grudges and hard feelings do not happen in a work setting where kindness is practiced.

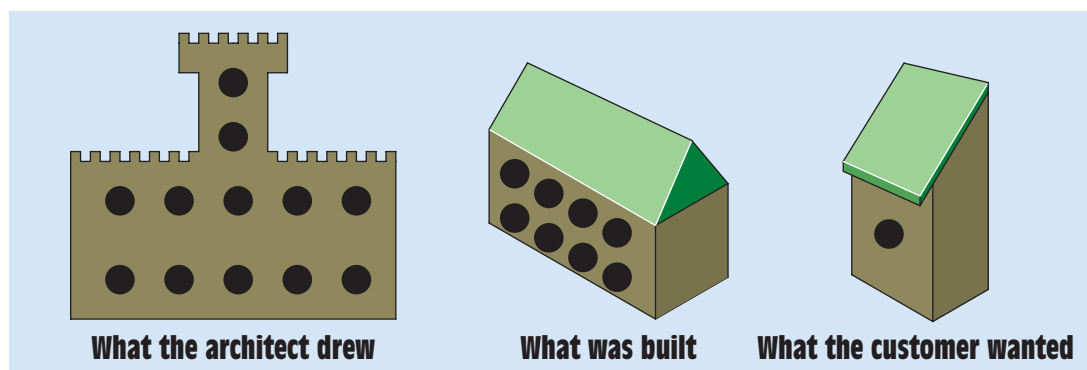


FIGURE OCCUPATIONS 1 Listening to the customer can save money and time.

Building Codes

Many cities, counties, and states have their own building codes that supersede the *National Electrical Code*[®]. The *National Electrical Code*[®] is law only if the local authority has adopted it as law. Always check local codes before beginning a construction project. Local codes often specify the manner in which wiring is to be installed and the size or type of wire that must be used for a particular application.

Green Building

“Green building” basically means making buildings more energy efficient. This can encompass many areas of the construction such as using “low E” energy-efficient windows, adding extra insulation, adding solar collectors to assist the water heater, and installing solar panels and/or wind generators to assist the electrical service. For the electrician, it may be installing larger wire than necessary to help overcome voltage drop, or installing energy-efficient appliances such as heat pump-type water heaters. These water heaters use about half the amount of power of a standard electric water heater. Energy-efficient appliances are generally identified by an Energy Star label. Energy Star is a government-backed symbol awarded to products that are considered energy efficient. Energy Star was established to reduce greenhouse gas emissions and other pollutants caused by inefficient use of energy, and to aid consumers in identifying and purchasing energy-efficient products that will save money without sacrificing performance, features, or comfort.

Before a product can receive an Energy Star label, it must meet certain requirements set forth in Energy Star product specifications:



FIGURE OCCUPATIONS 2 Solar water heaters mounted on a roof.

- Product categories must produce significant energy savings nationwide.
- Qualified products must deliver the features and performance demanded by customers as well as increase energy efficiency.
- If the qualified product cost more than a conventional, less-efficient counterpart, purchasers must be able to recover their investment in increased energy efficiency through utility bill savings, within a reasonable period of time.
- Energy efficiency must be achievable through broadly available, nonproprietary technologies offered by more than one manufacturer.
- Product energy consumption and performance must be measurable and verified with testing.
- Labeling should effectively differentiate products and be clearly visible to purchasers.

Solar Energy

One of the primary sources of green energy is solar power. Solar energy is the primary source of heating water in many countries and can be as simple as a dark colored container mounted on the roof of a structure, *Figure Occupations 2*.

Other types of solar water heaters involve a solar collector, a special tank that contains a heat exchanger, and related equipment, *Figure Occupations 3*. Most of these types of water heaters contain backup electric heating elements for cloudy weather when the solar collector cannot supply enough energy to heat the water.

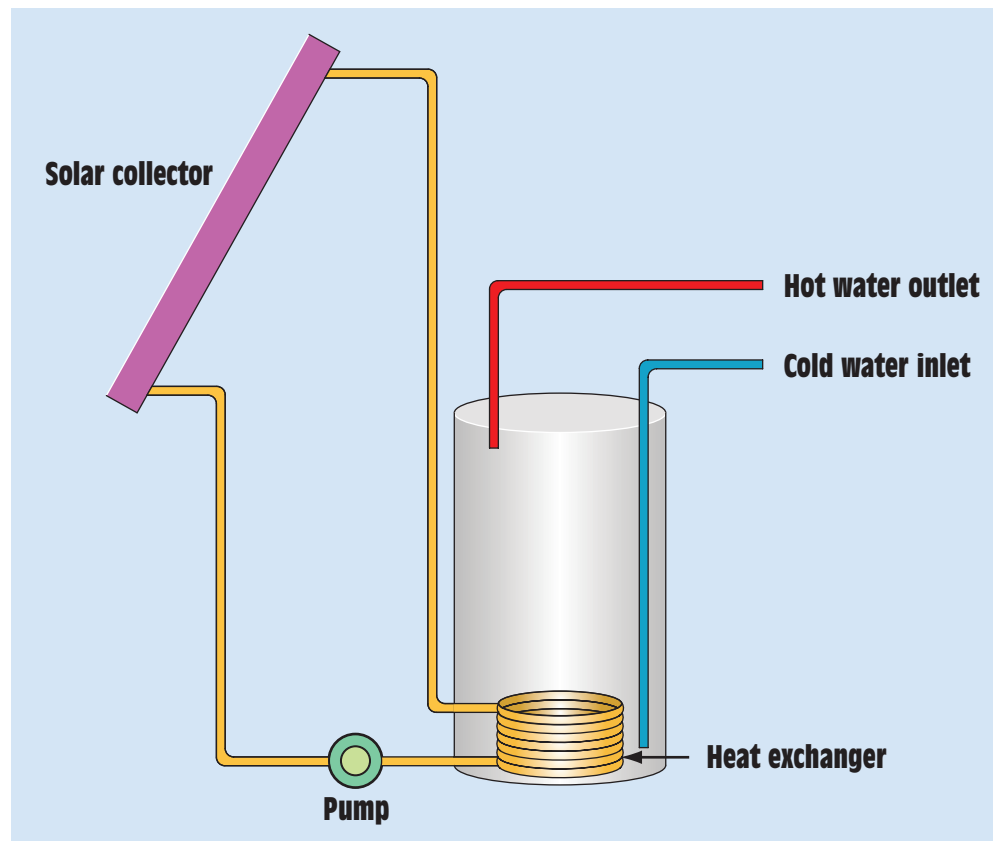


FIGURE OCCUPATIONS 3 Some solar water heaters use a solar panel and special tank with a heat exchanger.

Some solar systems generate electricity and are generally called PV (photovoltaic) systems. In these types of systems solar panels are mounted on the roof of a dwelling or in an open area on the ground, *Figure Occupations 4*. Photovoltaic cells generate direct current, which must be changed into alternating current by an inverter, *Figure Occupations 5*. The home remains connected to the utility company at all times. The solar panels augment the incoming power to help reduce the energy supplied by the utility company. There are various methods of supplying power to the utility company, depending on the requirements of the utility company and state laws. Some systems cause the electric meter to run backward during times that the solar panels are producing more energy than is being supplied by the utility company. Other systems require the use of two separate meters, *Figure Occupations 6*. One records the amount of power supplied by the utility company and the other records the amount of power supplied by the solar cells. The utility company then purchases the power from the homeowner or in some cases gives the homeowner credit for the amount of power generated. Other systems employ batteries to store the electricity produced by the solar panels. An uninterruptable power supply (UPS) converts the direct current into alternating current. In the event of a power failure, the UPS continues to supply power from the storage batteries.

The amount of electricity produced by the solar panels is directly proportional to the intensity of sunlight striking the panels. The graph shown in *Figure Occupations 7* illustrates the power output over a 24-hour period. The information was gathered during the month of March. Solar cells have a very long life span, generally considered to be 50 years or more. Most manufacturers of solar panels cover the cells with a material that is designed to remain clear in direct sunlight and is strong enough to withstand the average hail storm. Solar panels connect cells in series and parallel to obtain the desired voltage and current capacity.



FIGURE OCCUPATIONS 4 Solar panels are often mounted on the roof or in an open area.



FIGURE OCCUPATIONS 5 Inverter changes the direct current produced by the solar cells into alternating current.



FIGURE OCCUPATIONS 6 One meter records the power supplied by the utility company, and another records the amount of power supplied by the solar panels.