

Delmar's Standard Textbook of

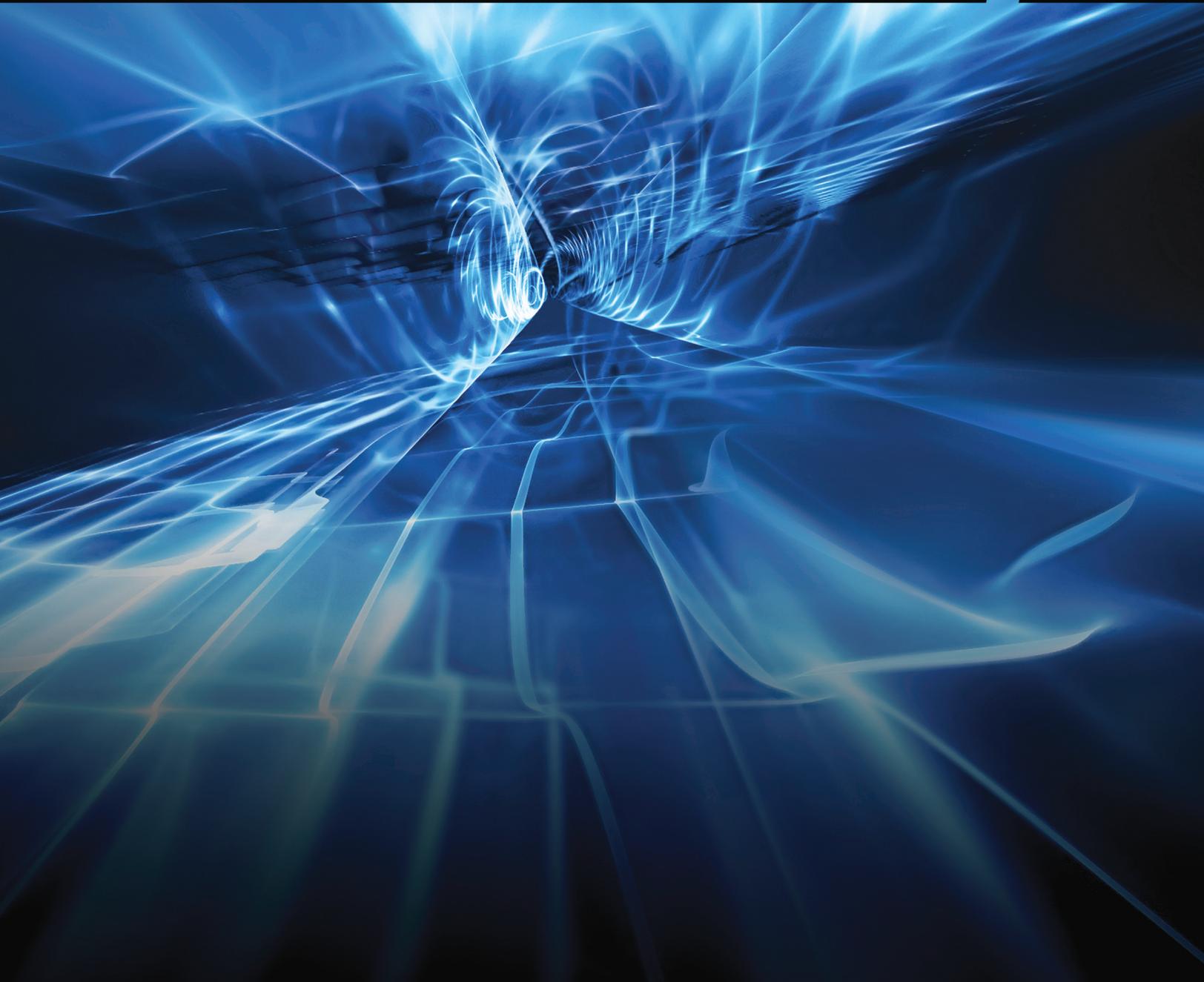
Sixth Edition  
**Electricity**



Stephen L. Herman

Delmar's Standard Textbook of

# Electricity





Delmar's Standard Textbook of

Sixth Edition  
**Electricity**

Stephen L. Herman



Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

**Delmar's Standard Textbook of Electricity,  
Sixth Edition**

Stephen L. Herman

Senior Vice President, GM Skills & Product  
Planning: Dawn Gerrain

Product Team Manager: James DeVoe

Senior Director Development: Marah Bellegarde

Senior Product Development Manager:  
Larry Main

Senior Content Developer: John Fisher

Product Assistant: Andrew Ouimet

Vice President Marketing Services:  
Jennifer Baker

Market Manager: Linda Kuper

Senior Production Director: Wendy A. Troeger

Production Director: Andrew Crouth

Senior Content Project Manager:  
Kara A. DiCaterino

Senior Art Director: David Arsenault

Senior Art Director: Bethany Casey

Technology Project Manager: Joe Pliss

Cover Image(s): © SphinxHK/Shutterstock.com

© gyn9037/Shutterstock.com

© jakit17/Shutterstock.com

© Zffoto/Shutterstock.com

Interior Design Images:

© Zffoto/Shutterstock.com

© 2016, 2011 Cengage Learning

WCN: 02-200-203

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored, or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at  
**Cengage Learning Customer & Sales Support, 1-800-354-9706**

For permission to use material from this text or product,  
submit all requests online at [www.cengage.com/permissions](http://www.cengage.com/permissions)  
Further permissions questions can be e-mailed to  
[permissionrequest@cengage.com](mailto:permissionrequest@cengage.com)

Library of Congress Control Number: 2014940608

ISBN: 978-1-285-85270-6

**Cengage Learning**20 Channel Center Street  
Boston, MA 02210  
USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at:

**[www.cengage.com/global](http://www.cengage.com/global)**

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Cengage Learning, visit **[www.cengage.com](http://www.cengage.com)**Purchase any of our products at your local college store or at our preferred online store **[www.cengagebrain.com](http://www.cengagebrain.com)****Notice to the Reader**

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer. The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities described herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions. The publisher makes no representations or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or part, from the readers' use of, or reliance upon, this material.

Printed in the United States of America

Print Number: 01 Print Year: 2014

**To my wife, Debbie, God's gift to me.**

Preface	xix
Introduction: Electrical Occupations	xxv
<b>SECTION 1</b>	
<b>Safety, Basic Electricity, and Ohm's Law</b>	<b>2</b>
<b>SAFETY OVERVIEW</b>	
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	17
S-8 Arc-Fault Circuit Interrupters (AFCIs)	20
S-9 Grounding	25
<b>UNIT 1</b>	
<b>Atomic Structure</b>	<b>30</b>
1-1 Early History of Electricity	31
1-2 Atoms	32
1-3 The Law of Charges	35
1-4 Structure of the Atom	37
1-5 Electron Orbits	38
1-6 Valence Electrons	40
1-7 The Bump Theory	42
1-8 Power Sources	45
1-9 Insulators	46
1-10 Semiconductors	47
1-11 Molecules	47
1-12 Methods of Producing Electricity	48
1-13 Electrical Effects	49
<b>UNIT 2</b>	
<b>Electrical Quantities and Ohm's Law</b>	<b>52</b>
2-1 The Coulomb	53
2-2 The Ampere	53
2-3 The Electron Flow Theory	54
2-4 The Conventional Current Flow Theory	54
2-5 Speed of Current	55
2-6 Basic Electric Circuits	58
2-7 The Volt	60
2-8 The Ohm	61
2-9 The Watt	63

2-10	Other Measures of Power	64
2-11	Ohm's Law	66
2-12	Metric Prefixes	70

### UNIT 3

#### Static Electricity **75**

3-1	Static Electricity	76
3-2	Charging an Object	78
3-3	The Electroscope	78
3-4	Static Electricity in Nature	81
3-5	Nuisance Static Charges	83
3-6	Useful Static Charges	83

### UNIT 4

#### Magnetism **88**

4-1	The Earth Is a Magnet	89
4-2	Permanent Magnets	90
4-3	The Electron Theory of Magnetism	90
4-4	Magnetic Materials	92
4-5	Magnetic Lines of Force	93
4-6	Electromagnetics	94
4-7	Magnetic Measurement	97
4-8	Magnetic Polarity	98
4-9	Demagnetizing	99
4-10	Magnetic Devices	100

### UNIT 5

#### Resistors **105**

5-1	Uses of Resistors	106
5-2	Fixed Resistors	107
5-3	Color Code	111
5-4	Standard Resistance Values of Fixed Resistors	115
5-5	Power Ratings	116
5-6	Variable Resistors	117
5-7	Schematic Symbols	120

### SECTION 2

#### Basic Electric Circuits **124**

### UNIT 6

#### Series Circuits **125**

6-1	Series Circuits	126
6-2	Voltage Drops in a Series Circuit	126

6-3	Resistance in a Series Circuit	128
6-4	Calculating Series Circuit Values	128
6-5	Solving Circuits	130
6-6	Voltage Dividers	141
6-7	The General Voltage Divider Formula	142
6-8	Voltage Polarity	143
6-9	Using Ground as a Reference	144

## UNIT 7

### Parallel Circuits **150**

7-1	Parallel Circuit Values	151
7-2	Parallel Resistance Formulas	154

## UNIT 8

### Combination Circuits **173**

8-1	Combination Circuits	174
8-2	Solving Combination Circuits	174
8-3	Simplifying the Circuit	175

## UNIT 9

### Kirchhoff's Laws, Thevenin's, Norton's, and Superposition Theorems **198**

9-1	Kirchhoff's Laws	199
9-2	Thevenin's Theorem	205
9-3	Norton's Theorem	208
9-4	The Superposition Theorem	211

## SECTION 3

### Meters and Wire Sizes **222**

## UNIT 10

### Measuring Instruments **223**

10-1	Analog Meters	224
10-2	The Voltmeter	226
10-3	Multirange Voltmeters	227
10-4	Reading a Meter	229
10-5	The Ammeter	232
10-6	Ammeter Shunts	233
10-7	Multirange Ammeters	235
10-8	The Ayrton Shunt	236
10-9	AC Ammeters	240
10-10	Clamp-On Ammeters	243

10–11 DC–AC Clamp-On Ammeters	245
10–12 The Ohmmeter	247
10–13 Shunt-Type Ohmmeters	249
10–14 Digital Meters	250
10–15 The Low-Impedance Voltage Tester	253
10–16 The Oscilloscope	254
10–17 The Wattmeter	264
10–18 Recording Meters	266
10–19 Bridge Circuits	267

## UNIT 11

### Using Wire Tables and Determining Conductor Sizes **272**

11–1 The American Wire Gauge (AWG)	273
11–2 Using the <i>NEC</i> Charts	275
11–3 Factors That Determine Ampacity	277
11–4 Correction Factors	279
11–5 Calculating Conductor Sizes and Resistance	285
11–6 Calculating Voltage Drop	294
11–7 Parallel Conductors	296
11–8 Testing Wire Installations	299

## SECTION 4

### Small Sources of Electricity **306**

## UNIT 12

### Conduction in Liquids and Gases **307**

12–1 The Ionization Process: Magnesium and Chlorine	308
12–2 Other Types of Ions	310
12–3 Electroplating	311
12–4 Electrolysis	312
12–5 Conduction in Gases	312
12–6 Ionization in Nature	316

## UNIT 13

### Batteries and Other Sources of Electricity **318**

13–1 History of the Battery	319
13–2 Cells	320
13–3 Cell Voltage	321
13–4 Primary Cells	323
13–5 Secondary Cells: Lead-Acid Batteries	330
13–6 Other Secondary Cells	336
13–7 Series and Parallel Battery Connections	338
13–8 Other Small Sources of Electricity	340

**UNIT 14****Magnetic Induction 350**

14-1	Electromagnetic Induction	351
14-2	Fleming's Left-Hand Generator Rule	353
14-3	Moving Magnetic Fields	354
14-4	Determining the Amount of Induced Voltage	354
14-5	Lenz's Law	356
14-6	Rise Time of Current in an Inductor	358
14-7	The Exponential Curve	359
14-8	Inductance	361
14-9	R-L Time Constants	362
14-10	Induced Voltage Spikes	364

**SECTION 5****Basics of Alternating Current 372****UNIT 15****Basic Trigonometry and Vectors 373**

15-1	Right Triangles	374
15-2	The Pythagorean Theorem	375
15-3	Sines, Cosines, and Tangents	377
15-4	Formulas	380
15-5	Practical Application	380

**UNIT 16****Alternating Current 391**

16-1	Advantages of AC	392
16-2	AC Waveforms	392
16-3	Sine Wave Values	399
16-4	Resistive Loads	405
16-5	Power in an AC Circuit	406
16-6	Skin Effect in AC Circuits	407

**SECTION 6****Alternating Current (AC) Circuits Containing Inductance 412****UNIT 17****Inductance in AC Circuits 413**

17-1	Inductance	414
17-2	Inductive Reactance	417
17-3	Schematic Symbols	420
17-4	Inductors Connected in Series	421

17-5 Inductors Connected in Parallel	422
17-6 Voltage and Current Relationships in an Inductive Circuit	423
17-7 Power in an Inductive Circuit	425
17-8 Reactive Power	426
17-9 Q of an Inductor	427

## UNIT 18

### Resistive-Inductive Series Circuits **434**

18-1 R-L Series Circuits	435
18-2 Impedance	436
18-3 Total Current	439
18-4 Voltage Drop Across the Resistor	439
18-5 Watts	440
18-6 Calculating the Inductance	441
18-7 Voltage Drop Across the Inductor	441
18-8 Total Voltage	441
18-9 Calculating the Reactive Power	441
18-10 Calculating the Apparent Power	443
18-11 Power Factor	445
18-12 Angle Theta	446

## UNIT 19

### Resistive-Inductive Parallel Circuits **460**

19-1 Resistive-Inductive Parallel Circuits	461
19-2 Calculating Circuit Values	461

## SECTION 7

### AC Circuits Containing Capacitors **480**

## UNIT 20

### Capacitors **481**

20-1 Capacitors	482
20-2 Electrostatic Charge	485
20-3 Dielectric Constant	488
20-4 Capacitor Ratings	488
20-5 Capacitors Connected in Parallel	490
20-6 Capacitors Connected in Series	490
20-7 Capacitive Charge and Discharge Rates	491
20-8 RC Time Constants	492
20-9 Applications for Capacitors	494

20–10	Nonpolarized Capacitors	494
20–11	Polarized Capacitors	496
20–12	Variable Capacitors	499
20–13	Capacitor Markings	500
20–14	Temperature Coefficients	502
20–15	Ceramic Capacitors	502
20–16	Dipped Tantalum Capacitors	502
20–17	Film Capacitors	503
20–18	Testing Capacitors	504

## UNIT 21

### Capacitance in AC Circuits **511**

21–1	Connecting the Capacitor into an AC Circuit	512
21–2	Capacitive Reactance	513
21–3	Calculating Capacitance	514
21–4	Voltage and Current Relationships in a Pure Capacitive Circuit	515
21–5	Power in a Pure Capacitive Circuit	517
21–6	Quality of a Capacitor	518
21–7	Capacitor Voltage Rating	519
21–8	Effects of Frequency in a Capacitive Circuit	519
21–9	Series Capacitors	521
21–10	Parallel Capacitors	524

## UNIT 22

### Resistive-Capacitive Series Circuits **531**

22–1	Resistive-Capacitive Series Circuits	532
22–2	Impedance	533
22–3	Total Current	534
22–4	Voltage Drop Across the Resistor	534
22–5	True Power	534
22–6	Capacitance	535
22–7	Voltage Drop Across the Capacitor	535
22–8	Total Voltage	535
22–9	Reactive Power	535
22–10	Apparent Power	537
22–11	Power Factor	538
22–12	Angle Theta	538

## UNIT 23

### Resistive-Capacitive Parallel Circuits **548**

23–1	Operation of RC Parallel Circuits	549
23–2	Calculating Circuit Values	550

<b>SECTION 8</b>	
<b>AC Circuits Containing Resistance-Inductance-Capacitance</b>	<b>564</b>
<b>UNIT 24</b>	
<b>Resistive-Inductive-Capacitive Series Circuits</b>	<b>565</b>
24-1 RLC Series Circuits	566
24-2 Series Resonant Circuits	576
<b>UNIT 25</b>	
<b>Resistive-Inductive-Capacitive Parallel Circuits</b>	<b>585</b>
25-1 RLC Parallel Circuits	586
25-2 Parallel Resonant Circuits	595
<b>UNIT 26</b>	
<b>Filters</b>	<b>607</b>
26-1 Broadband Tuning	608
26-2 Low-Pass Filters	609
26-3 High-Pass Filters	612
26-4 Bandpass Filters	614
26-5 Band-Rejection (Notch) Filters	615
26-6 T Filters	616
26-7 PI-Type Filters	618
26-8 Crossover Networks	618
<b>SECTION 9</b>	
<b>Three-Phase Power</b>	<b>622</b>
<b>UNIT 27</b>	
<b>Three-Phase Circuits</b>	<b>623</b>
27-1 Three-Phase Circuits	624
27-2 Wye Connections	625
27-3 Delta Connections	628
27-4 Three-Phase Power	631
27-5 Watts and VARs	631
27-6 Three-Phase Circuit Calculations	632
27-7 Load 3 Calculations	639
27-8 Load 2 Calculations	639
27-9 Load 1 Calculations	640
27-10 Alternator Calculations	641
27-11 Power Factor Correction	641

**SECTION 10****Transformers 650****UNIT 28****Single-Phase Transformers 651**

28-1	Single-Phase Transformers	652
28-2	Isolation Transformers	653
28-3	Autotransformers	675
28-4	Transformer Polarities	678
28-5	Voltage and Current Relationships in a Transformer	682
28-6	Testing the Transformer	684
28-7	Transformer Nameplates	685
28-8	Determining Maximum Current	685
28-9	Transformer Impedance	685

**UNIT 29****Three-Phase Transformers 698**

29-1	Three-Phase Transformers	699
29-2	Closing a Delta	704
29-3	Three-Phase Transformer Calculations	705
29-4	Open-Delta Connection	711
29-5	Single-Phase Loads	711
29-6	Closed Delta with Center Tap	715
29-7	Closed Delta without Center Tap	715
29-8	Delta-Wye Connection with Neutral	716
29-9	T-Connected Transformers	717
29-10	Scott Connection	719
29-11	Zig-Zag Connection	720

**SECTION 11****DC Machines 726****UNIT 30****DC Generators 727**

30-1	What Is a Generator?	728
30-2	Armature Windings	736
30-3	Brushes	738
30-4	Pole Pieces	738
30-5	Field Windings	738
30-6	Series Generators	741
30-7	Shunt Generators	742
30-8	Compound Generators	747

30-9	Compounding	748
30-10	Counter torque	751
30-11	Armature Reaction	751
30-12	Setting the Neutral Plane	754
30-13	Paralleling Generators	755

## UNIT 31

### DC Motors **760**

31-1	DC Motor Principles	761
31-2	Shunt Motors	764
31-3	Series Motors	766
31-4	Compound Motors	767
31-5	Terminal Identification for DC Motors	769
31-6	Determining the Direction of Rotation of a DC Motor	770
31-7	Speed Control	773
31-8	The Field-Loss Relay	774
31-9	Horsepower	775
31-10	Brushless DC Motors	777
31-11	Converters	780
31-12	Permanent Magnet Motors	781
31-13	The Right-Hand Motor Rule	787

## SECTION 12

### AC Machines **792**

## UNIT 32

### Three-Phase Alternators **793**

32-1	Three-Phase Alternators	794
32-2	The Rotor	796
32-3	The Brushless Exciter	798
32-4	Alternator Cooling	799
32-5	Frequency	800
32-6	Output Voltage	801
32-7	Paralleling Alternators	802
32-8	Sharing the Load	804
32-9	Field-Discharge Protection	805

## UNIT 33

### Three-Phase Motors **808**

33-1	Three-Phase Motors	809
33-2	The Rotating Magnetic Field	809
33-3	Connecting Dual-Voltage Three-Phase Motors	822
33-4	Squirrel-Cage Induction Motors	827

33-5 Wound-Rotor Induction Motors	849
33-6 Synchronous Motors	852
33-7 Selsyn Motors	858

## UNIT 34

### Single-Phase Motors **865**

34-1 Single-Phase Motors	866
34-2 Split-Phase Motors	866
34-3 Resistance-Start Induction-Run Motors	869
34-4 Capacitor-Start Induction-Run Motors	876
34-5 Dual-Voltage Split-Phase Motors	877
34-6 Determining the Direction of Rotation for Split-Phase Motors	880
34-7 Capacitor-Start Capacitor-Run Motors	881
34-8 Shaded-Pole Induction Motors	883
34-9 Multispeed Motors	887
34-10 Repulsion-Type Motors	888
34-11 Construction of Repulsion Motors	889
34-12 Repulsion-Start Induction-Run Motors	892
34-13 Repulsion-Induction Motors	894
34-14 Single-Phase Synchronous Motors	894
34-15 Stepping Motors	896
34-16 Universal Motors	903

## UNIT 35

### Harmonics **915**

35-1 What Are Harmonics?	916
--------------------------	-----

## APPENDIX A

Identifying the Leads of a Three-Phase, Wye-Connected, Dual-Voltage Motor	926
---	-----

## 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	964
Index	977

*Tables 310.15(B)(16), 310.15(B)(17), 310.15(B)(18), 310.15(B)(2)(a), and 310.15(B)(3)(a)* are reprinted with permission from NFPA 70-2014<sup>®</sup>, the *National Electrical Code*<sup>®</sup> Copyright © 2013, National Fire Protection Association, Quincy, Massachusetts 02269. This reprinted material is not the complete and official position of the NFPA, on the referenced subject, which is represented only by the standard in its entirety.

## Intended Use

*Delmar's Standard Textbook of Electricity*, 6th 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 15 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*, 6th 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 sixth 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:

- + *Coverage of AC servo motors*
- + *Coverage of AC torque motors*
- + *Updated photographs*
- + *Extended coverage of motor nameplate data*
- + *Extended coverage of RL time constants*
- + *Extended coverage of AC waveforms*
- + *“Electrical Occupations” contains information about electrical personnel, building codes, and solar and wind energy.*

### 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 10–13). ■

• **Math Presentation**

Section on vectors in Unit 17 is presented earlier in the text in Unit 15, *Basic Trigonometry*, providing a foundation for students as they work through math equations.

**EXAMPLE 15-3**

Using the same triangle (*Figure 15-7*), 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:

$$\text{cosine } \angle Y = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{cosine } \angle Y = \frac{9}{14}$$

$$\text{cosine } \angle Y = 0.643$$

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:

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

**15-4 Formulas**

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

$$\sin \angle \theta = \frac{O}{H}$$

$$\cos \angle \theta = \frac{A}{H}$$

$$\tan \angle \theta = \frac{O}{A}$$

$$\text{Adj.} = \cos \angle \theta \times \text{Hyp.}$$

$$\text{Adj.} = \frac{O}{\tan \angle \theta}$$

$$\text{Opp} = \sin \angle \theta \times \text{Hyp.}$$

$$\text{Opp.} = \text{Adj.} \times \tan \angle \theta$$

$$\text{Hyp.} = \frac{O}{\sin \angle \theta}$$

$$\text{Hyp.} = \frac{A}{\cos \angle \theta}$$

**15-5 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 15-8*). 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 15-9*). Assume the length of the shadow to be 7.5 inches. Using the length of the

• **“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.

## Single-Phase Motors

**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.

**Outline**

- 34-1 Single-Phase Motors
- 34-2 Split-Phase Motors
- 34-3 Resistance-Start Induction-Run Motors

UNIT

# 34

**Key Terms**

Centrifugal switch  
Compensating winding  
Conductive compensation

✦ **“Practical Applications”**

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

**PRACTICAL APPLICATIONS**

An office building uses a bank of 63 lead-acid cells connected in series with a capacity of 80 amp-hours each to provide battery backup for their computers. The lead-acid cells are to be replaced with nickel-metal hydride cells with a capacity of 40 amp-hours each. How many nickel-metal hydride cells will be required to replace the lead-acid cells and how should they be connected? ■



✦ **DVD Correlation**

Units are highlighted where material can be viewed on the accompanying DVD series, providing another source of learning for the student:

***DC Electrical Theory, AC Electrical Theory, Single-Phase Transformers & Electrical Machines, Three-Phase Circuits & Electrical Machines***

✦ **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).

✦ **Instructor Resource (CD-ROM for Instructors)**

(Order #: 978-1-305-26977-4).

Instructor Guide contains answers to all review questions and practical applications contained within the text, as well as practice exams.

✦ **PowerPoint** presentations provide a thorough review of all major concepts presented in each unit, featuring four-color photos and line illustrations from the text. The sixth edition contains numerous PowerPoint presentations.

✦ **Unit testbanks** contain approximately 700 questions for instructors to test student knowledge as they progress through the text. Allows instructors to edit the exams and add their own questions.

✦ **Image Library** consists of all the images from the text in electronic format, allowing instructors to create their own classroom presentations.

✦ **Instructors Guide & Solutions to Lab-Volt Manual** is in Word format.

To access additional course materials including CourseMate, please visit [www.cengagebrain.com](http://www.cengagebrain.com). At the CengageBrain.com home page, search for the ISBN of your title (from the back cover of your book) using the search box at the top of the page. This will take you to the product page where these resources can be found.

- ✦ **A DVD Set** brings important concepts to life through easy-to-understand explanations and examples, professional graphics and animations, and a necessary emphasis on safety. Videos run approximately 20 minutes. The DVDs are interactive and provide test questions and remediation.

*DC Electrical Theory DVD (4 videos)* includes Basic Electricity, Series & Parallel Circuits, Combination Circuits, and Small Sources of Electricity.

*AC Electrical Theory DVD (5 videos)* includes Alternating Current, Inductance, Capacitors, Capacitors in AC Circuits, and Series Circuits.

*Single-Phase Transformers & Electrical Machines DVD (4 videos)* includes Single-Phase Transformers; DC Machines; Single-Phase Motors, Part I; Single-Phase Motors, Part II.

*Three-Phase Circuits & Electrical Machines DVD (4 videos)* includes Three-Phase Circuits; Three-Phase Transformers; Three-Phase Motors, Part I; Three-Phase Motors, Part II.

## 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:*

- ✦ author, edit, and manage test bank content from multiple Cengage Learning solutions
- ✦ create multiple test versions in an instant
- ✦ deliver tests from your LMS, your classroom, or wherever you want

Contact Cengage Learning or your local sales representative to obtain an instructor account. Accessing an Instructor Companion Website from SSO Front Door

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.
4. At the Product page, click the **Instructor Companion site** link.

## 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.

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.

Delmar Online Training Simulation | **Electricity**

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.

## PREFACE

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](http://www.cengagebrain.com).

### A Note about the Lab Manuals

The two laboratory manuals, entitled *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 each unit 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 the sixth edition of this text:

James Blackett, Thomas Nelson Community College, Hampton, VA  
James Cipollone, Antelope Valley Community College, Lancaster, CA  
Eduardo Del Toro, MacArthur High School/Independent Electrical Contractors, San Antonio, TX  
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  
Larry Pogoler, LA Trade Tech College, Los Angeles, CA  
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

## 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*<sup>®</sup> 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*<sup>®</sup> 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*.

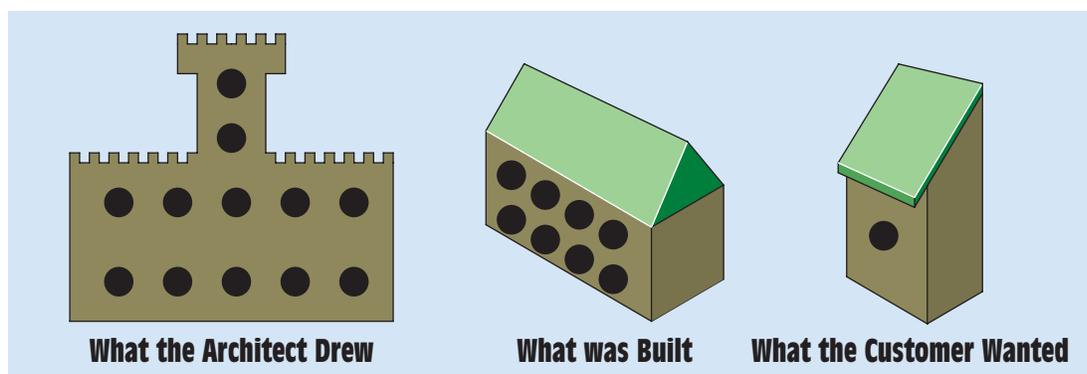
**Writing:** Many jobs require the electrician to fill out work reports that can include a description of the job, the materials used, and the time required to complete the job. This is especially true of a person in charge of other workers, such as a journeyman.

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



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

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.

## Building Codes

Many cities, counties, and states have their own building codes that supersede the *National Electrical Code*<sup>®</sup>. The *National Electrical Code*<sup>®</sup> 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:

- ✦ 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

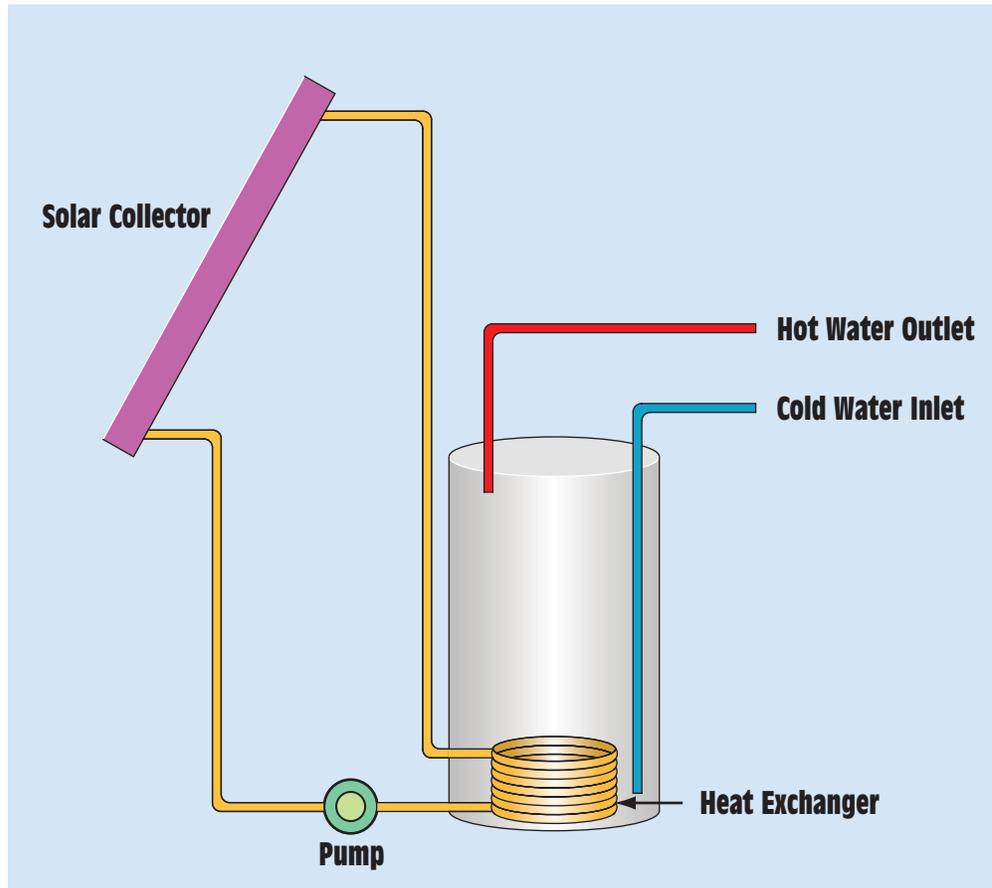


**FIGURE OCCUPATIONS 2** Solar water heaters mounted on a roof.

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.

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



Copyright © Cengage Learning®.

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



Courtesy of Solar Community

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



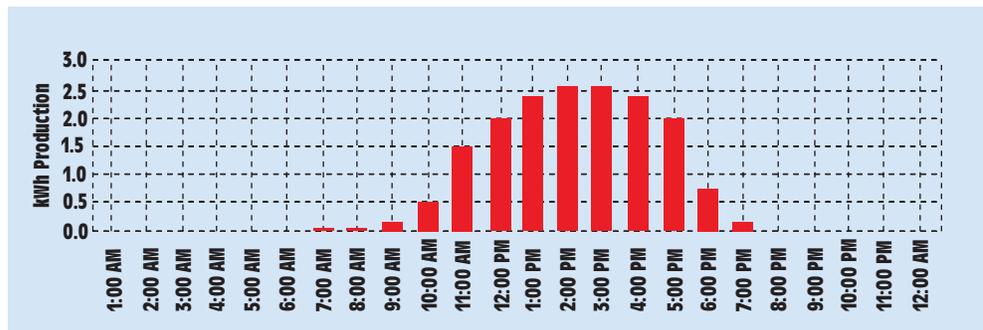
Courtesy of Solar Community

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



Courtesy of Solar Community

**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.



Courtesy of Solar Community

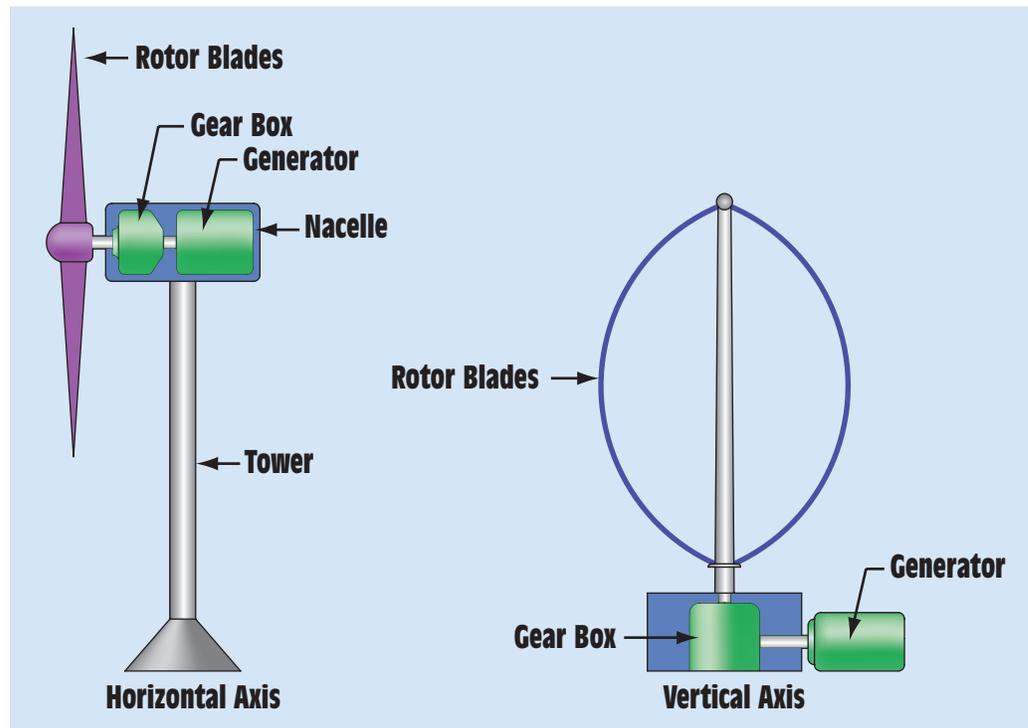
**FIGURE OCCUPATIONS 7** Generation of electric power over a 24-hour period.

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.

Regardless of the type of system, there are generally specific procedures that must be followed during the installation of solar systems. Special circuit breakers designed for direct current and high amperage interrupt capability are often required. Manufacturers' recommendations as well as national and local electrical codes should be followed.

## Wind Power

Another widely used form of "Green" energy is wind. Wind is actually a product of solar energy. The Sun heats different areas of the Earth's surface at different rates. Hot air rises at a faster rate than cool air. As the hot air rises, cool air rushes in to replace the void left by the rising hot air, and wind is created. Air has mass, and moving air can contain a lot of energy. Wind generators convert the kinetic energy of moving air into electricity. Wind



Copyright © Cengage Learning®.

**FIGURE OCCUPATIONS 8** Wind turbine types.

energy increases by the cube of the speed, which means that each time the wind speed doubles, the amount of energy increases eight times. This is the reason that the shape of many automobiles is designed to move through the air with less friction. The wind resistance of an automobile traveling at 60 miles per hour will be eight times greater than when traveling at 30 miles per hour.

Wind generators are often referred to as wind turbines. There are two basic designs of wind turbines, the horizontal axis and the vertical axis, *Figure Occupations 8*. Vertical axis turbines are often called “egg beaters.” The main advantage of vertical axis turbines is that they are omnidirectional, meaning that they will operate regardless of wind direction. Although horizontal axis turbines must turn to face the wind, they are mostly used for producing electricity. The size of wind turbines can vary greatly depending on the amount of electricity they are intended to produce. Utility scale turbines used in land-based wind farms, *Figure Occupations 9*, can have rotor diameters that range from 50 meters (164 feet)



Copyright © Cengage Learning®.

**FIGURE OCCUPATIONS 9** Wind farm.

to 90 meters (295 feet). The tower height is generally the same as the rotor diameter. Utility wind turbines generally feed the electricity they produce directly into the power grid to aid other electricity-generating plants that use fossil fuels.

Wind turbines intended for residential or small commercial use are much smaller. Most have rotor diameters of 8 meters (26 feet) or smaller and are mounted on towers of 40 meters (131 feet) or less. As with solar installations, wind-powered systems can be installed to connect directly to the power grid or to charge a bank of batteries. An inverter is used to convert the direct current of the batteries into alternating current to supply the home. Inverters used to couple the wind turbine to the power line must be able to maintain a steady power flow with varying wind speeds and varying voltages. They must also be able to shape the waveform to that of a sine wave. Similar to solar installations, some wind-powered systems cause the electric meter to run backward when it is producing more power than is required by the home. Some utility companies will give credit for the amount of power generated, and some will purchase the power from the customer. Other utilities require the use of two separate meters to determine the amount of wind power produced.

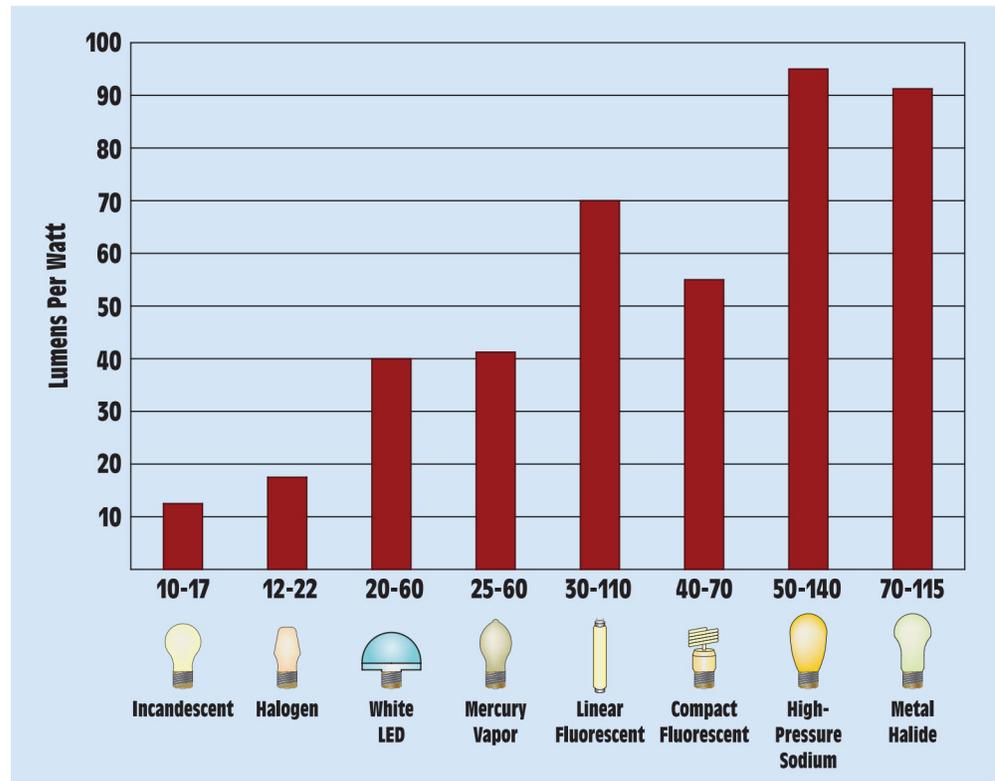
As with solar systems, when installing a wind-powered system, manufacturers' instructions and utility requirements should be followed. Before installing a wind-powered system, check to make certain that the area has a high enough average wind speed to justify the cost of the system.

## Lighting

Electric lighting began in 1879 when Thomas Edison invented the first incandescent lamp. He employed the use of a carbon filament that was heated to a temperature that produced a dim light by today's standards. In 1906, the incandescent lamp was improved by replacing the carbon filament with one made of tungsten. Tungsten could be heated to a much higher temperature and therefore could produce a much brighter light. Incandescent lamps today still use tungsten filaments. Incandescent lamps have the advantage of being inexpensive to purchase, but they also have a disadvantage in that they are very energy inefficient. These lamps are basically room heaters that produce light as a byproduct. At best, incandescent lamps are about 5% efficient, which means that a 100-watt lamp actually produces about 95 watts of heat and about 5 watts of light. They consume about 400% more energy to produce the same amount of light as a standard fluorescent lamp.

Light is measured in *lumens*. The lumen, a metric measure of light intensity as perceived by the human eye, is based on the English measurement of a candela. Basically, a light source that uniformly radiates 1 candela in all directions is equal to  $4\pi$  lumens. Lighting efficiency is measured by the lumens produced by 1 watt of electricity (lumens per watt). The chart in *Figure Occupations 10* lists the average lumens per watt for different types of lighting. The actual light output per watt can vary greatly for each type of lamp, depending on many conditions such as temperature, age, wattage, and so on. The range is listed for each type.

The chart indicates that some types are much more energy efficient than others, but all are not suited for use inside buildings. High-pressure sodium is the most efficient, but it has a very orange color, making it unsuitable for many applications. These lamps are generally used in outdoor applications such as parking lots and street lamps. Metal halide is also very efficient and has a near white color. These lamps are often used in large buildings like factories, warehouses, and commercial locations such as building supply stores. Florescent lighting is probably the type most used for homes, office buildings, and retail stores. Compact fluorescent lamps are replacing incandescent lamps in many homes. Although compact fluorescent lamps have an initial cost that is greater than incandescent



**FIGURE OCCUPATIONS 10** Efficiencies of different types of lighting.

lamps, they use about one-fourth the energy to produce a similar amount of light, and their average life expectancy is about 10 times longer. Because compact fluorescent lamps are more energy efficient, they produce less heat for the same amount of light, reducing the load on air-conditioning systems. Over the life expectancy of the lamp, the average cost of the compact fluorescent lamp will be less than a similar incandescent lamp.

## Summary

The electrical field offers many avenues that can lead to success. Most electricians work in the construction industry, but many are employed as maintenance technicians in industry and other related fields. The demand for qualified electricians is expected to increase at a rate of over 8000 new jobs per year over the next 10 years. The lay-off rate for electricians is one of the lowest in the country. Electricity is the power that operates homes, businesses, and industry. If industry runs, it will require electricians to keep it running.



SECTION

# 1

# Safety, Basic Electricity, and Ohm's Law



© K. Miri Photography/Shutterstock.com

# Safety Overview

## Why You Need to Know

**S**afety is the job of each individual. You should be concerned not only with your own safety but also with the safety of others around you. This is especially true for persons employed in the electrical field. Some general rules should be followed when working with electric equipment or circuits.

## Outline

- S-1 General Safety Rules
- S-2 Effects of Electric Current on the Body
- S-3 On the Job
- S-4 Protective Clothing
- S-5 Ladders and Scaffolds
- S-6 Fires
- S-7 Ground-Fault Circuit Interrupters
- S-8 Arc-Fault Circuit Interrupters (AFCIs)
- S-9 Grounding

## Key Terms

Artificial respiration  
Cardiopulmonary  
resuscitation (CPR)  
Confined spaces  
De-energized circuit  
Disconnect  
Energized circuit  
Fibrillation  
Fire-retardant clothing  
Horseplay  
Idiot proofing  
Lockout and tagout  
Material safety data sheets  
(MSDS)  
Meter  
Milliamperes (mA)  
Occupational Safety and  
Health Administration  
(OSHA)  
Scaffolds

## Objectives

After studying this unit, you should be able to

- state basic safety rules.
- describe the effects of electric current on the body.
- discuss the origin and responsibilities of OSHA.
- discuss material safety data sheets.
- discuss lockout and tagout procedures.
- discuss types of protective clothing.
- explain how to properly place a straight ladder against a structure.
- discuss different types of scaffolds.
- discuss classes of fires.
- discuss ground-fault circuit interrupters.
- discuss the importance of grounding.

## S-1 General Safety Rules

### Never Work on an Energized Circuit If the Power Can Be Disconnected

When possible, use the following three-step check to make certain that power is turned off:

1. Test the **meter** on a known live circuit to make sure the meter is operating.
2. Turn off the power and test the circuit that is to become the **de-energized circuit** with the meter.
3. Test the meter on the known live circuit again to make certain the meter is still operating.

Install a warning tag at the point of disconnection so people will not restore power to the circuit. If possible, use a lock to prevent anyone from turning the power back on.

### Think

Of all the rules concerning safety, this one is probably the most important. No amount of safeguarding or **idiot proofing** a piece of equipment can protect a person as well as taking time to think before acting. Many technicians have been killed by supposedly “dead” circuits. Do not depend on circuit breakers, fuses, or someone else to open a circuit. Test it yourself before you touch it. If you are working on high-voltage equipment, use insulated gloves and meter probes to measure the voltage being tested. *Think* before you touch something that could cost you your life.

### Avoid Horseplay

Jokes and **horseplay** have a time and place, but not when someone is working on an electric circuit or a piece of moving machinery. Do not be the cause of someone's being injured or killed, and do not let someone else be the cause of your being injured or killed.

## Do Not Work Alone

This is especially true when working in a hazardous location or on a live circuit. Have someone with you who can turn off the power or give **artificial respiration** and/or **cardio-pulmonary resuscitation (CPR)**. Several electric shocks can cause breathing difficulties and can cause the heart to go into fibrillation.

## Work with One Hand When Possible

The worst kind of electric shock occurs when the current path is from one hand to the other, which permits the current to pass directly through the heart. A person can survive a severe shock between the hand and foot that would cause death if the current path were from one hand to the other.

## Learn First Aid

Anyone working on electric equipment, especially those working with voltages greater than 50 volts, should make an effort to learn first aid. A knowledge of first aid, especially CPR, may save your own or someone else's life.

## Avoid Alcohol and Drugs

The use of alcohol and drugs has no place on a work site. Alcohol and drugs are not only dangerous to users and those who work around them; they also cost industry millions of dollars a year. Alcohol and drug abusers kill thousands of people on the highways each year and are just as dangerous on a work site as they are behind the wheel of a vehicle. Many industries have instituted testing policies to screen for alcohol and drugs. A person who tests positive may or may not receive a warning the first time, depending on the stringency of the company's drug and alcohol policy.

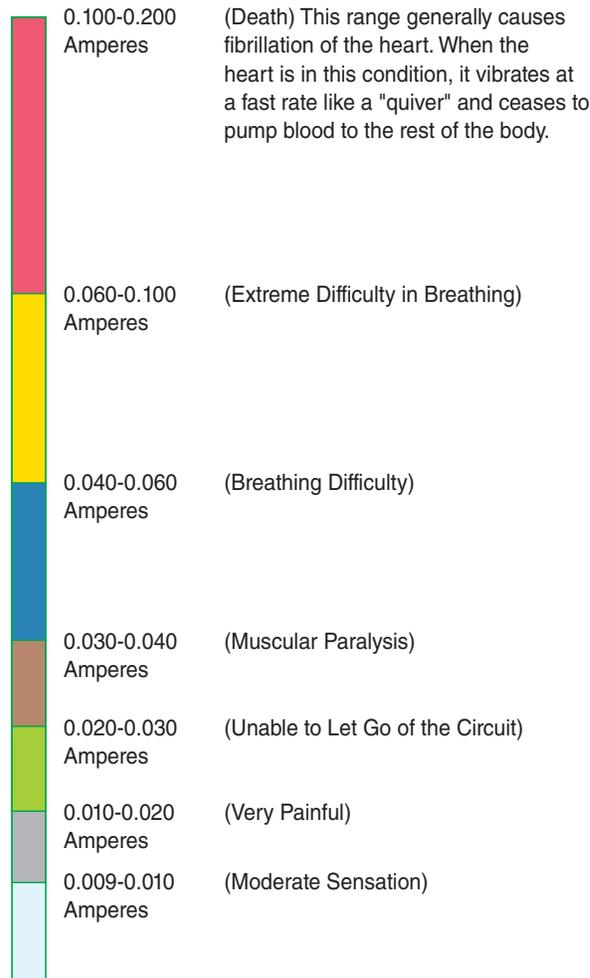
## S-2

## Effects of Electric Current on the Body

Most people have heard that it is not the voltage that kills but the current. This is true, but do not be misled into thinking that voltage cannot harm you. Voltage is the force that pushes the current through the circuit. It can be compared to the pressure that pushes water through a pipe. The more pressure available, the greater the volume of water flowing through the pipe. Students often ask how much current will flow through the body at a particular voltage. There is no easy answer to this question. The amount of current that can flow at a particular voltage is determined by the resistance of the current path. Different people have different resistances. A body has less resistance on a hot day when sweating, because salt water is a very good conductor. What one eats and drinks for lunch can have an effect on the body's resistance, as can the length of the current path. Is the current path between two hands or from one hand to one foot? All these factors affect body resistance.

*Figure S-1* illustrates the effects of different amounts of current on the body. This chart is general—some people may have less tolerance to electricity and others may have a greater tolerance.

A current of 2 to 3 **milliamperes (mA)** (0.002 to 0.003 amperes) usually causes a slight tingling sensation, which increases as current increases and becomes very noticeable at about 10 milliamperes (0.010 amperes). The tingling sensation is very painful at about 20 milliamperes. Currents between 20 and 30 milliamperes cause a person to seize the line and be unable to let go of the circuit. Currents between 30 and 40 milliamperes cause muscular paralysis, and those between 40 and 60 milliamperes cause breathing difficulty. When the current increases to about 100 milliamperes, breathing is extremely difficult.



**FIGURE S-1** The effects of electric current on the body.

Currents from 100 to 200 milliamperes generally cause death because the heart usually goes into **fibrillation**, a condition in which the heart begins to “quiver” and the pumping action stops. Currents above 200 milliamperes cause the heart to squeeze shut. When the current is removed, the heart usually returns to a normal pumping action. This is the operating principle of a defibrillator. The voltage considered to be the most dangerous to work with is 120 volts, because that generally causes a current flow of between 100 and 200 milliamperes through most people’s bodies. Large amounts of current can cause severe electric burns that are often very serious because they occur on the inside of the body. The exterior of the body may not look seriously burned, but the inside may be severely burned.

## S-3 On the Job

### OSHA

OSHA is an acronym for **Occupational Safety and Health Administration**, U.S. Department of Labor. Created by congress in 1971, its mission is to ensure safe and healthful workplaces in the United States. Since its creation, workplace fatalities have been cut in half, and occupational injury and illness rates have declined by 40%. Enforcement of OSHA regulations is the responsibility of the Secretary of Labor.

OSHA standards cover many areas, such as the handling of hazardous materials, fall protection, protective clothing, and hearing and eye protection. Part 1910, Subpart S, deals mainly with the regulations concerning electrical safety. These regulations are available in books and can be accessed at the OSHA website on the Internet at <http://www.osha.org>.

## Hazardous Materials

It may become necessary to deal with some type of hazardous material. A hazardous material or substance is any substance to which exposure may result in adverse effects on the health or safety of employees. Hazardous materials may be chemical, biological, or nuclear. OSHA sets standards for dealing with many types of hazardous materials. The required response is determined by the type of hazard associated with the material. Hazardous materials are required to be listed as such. Much information concerning hazardous materials is generally found on **material safety data sheets (MSDS)**. (A sample MSDS is included at the end of the unit.) If you are working in an area that contains hazardous substances, always read any information concerning the handling of the material and any safety precautions that should be observed. After a problem exists is not the time to start looking for information on what to do.

Some hazardous materials require a hazardous materials (HAZMAT) response team to handle any problems. A HAZMAT team is any group of employees designated by the employer who are expected to handle and control an actual or potential leak or spill of a hazardous material. They are expected to work in close proximity to the material. A HAZMAT team is not always a fire brigade, and a fire brigade may not necessarily have a HAZMAT team. On the other hand, a HAZMAT team may be part of a fire brigade or fire department.

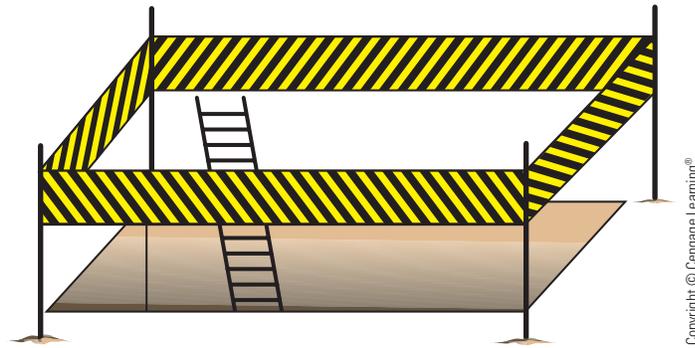
## Employer Responsibilities

Section 5(a)1 of the Occupational Safety and Health Act basically states that employers must furnish each of their employees a place of employment that is free of recognized hazards that are likely to cause death or serious injury. This places the responsibility for compliance on employers. Employers must identify hazards or potential hazards within the work site and eliminate them, control them, or provide employees with suitable protection from them. The employer is responsible for obtaining, maintaining, and posting (or making available) MSDS for all hazardous materials that may be used in the workplace. It is the employee's responsibility to read and understand the MSDS for all chemicals and materials that they may be exposed to in their working environment and to follow the safety procedures set up by the employer in the event of an accident. Employees should ask questions about any information or procedures they do not understand.

To help facilitate these safety standards and procedures, OSHA requires that an employer have a competent person oversee implementation and enforcement of these standards and procedures. This person must be able to recognize unsafe or dangerous conditions and have the authority to correct or eliminate them. This person also has the authority to stop work or shut down a work site until safety regulations are met.

## MSDS

MSDS stands for material safety data sheets, which are provided with many products. They generally warn users of any hazards associated with the product. They outline the physical and chemical properties of the product; list precautions that should be taken when using the product; and list any potential health hazards, storage consideration, flammability, reactivity, and, in some instances, radioactivity. They sometimes list the name, address, and telephone number of the manufacturer; the MSDS date and emergency telephone numbers; and, usually, information on first aid procedures to use if the product is



**FIGURE S-2** Place a barricade around a trench and use a ladder to enter and exit the trench.

swallowed or comes in contact with the skin. Safety data sheets can be found on many home products such as cleaning products, insecticides, and flammable liquids. A typical MSDS is shown in Table S-1 at the end of this unit.

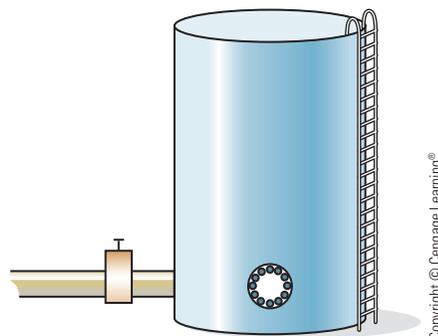
### Trenches

It is often necessary to dig trenches to bury conduit. Under some conditions, these trenches can be deep enough to bury a person if a cave-in should occur. Safety regulations for the shoring of trenches is found in OSHA Standard 1926, Subpart P, App C, titled “Timber Shoring for Trenches.” These procedures and regulations are federally mandated and must be followed. Some general safety rules also should be followed:

1. Do not walk close to trenches unless it is necessary. This can cause the dirt to loosen and increase the possibility of a cave-in.
2. Do not jump over trenches if it is possible to walk around them.
3. Place barricades around trenches (*Figure S-2*).
4. Use ladders to enter and exit trenches.

### Confined Spaces

**Confined spaces** have a limited means of entrance or exit (*Figure S-3*). They can be very hazardous workplaces, often containing atmospheres that are extremely harmful or deadly. Confined spaces are very difficult to ventilate because of their limited openings. It is often necessary for a worker to wear special clothing and use a separate air supply to work there. OSHA Section 12, “Confined Space Hazards,” lists rules and regulations for working in a confined space. In addition, many industries have written procedures that must be followed when working in confined spaces. Some general rules include the following:

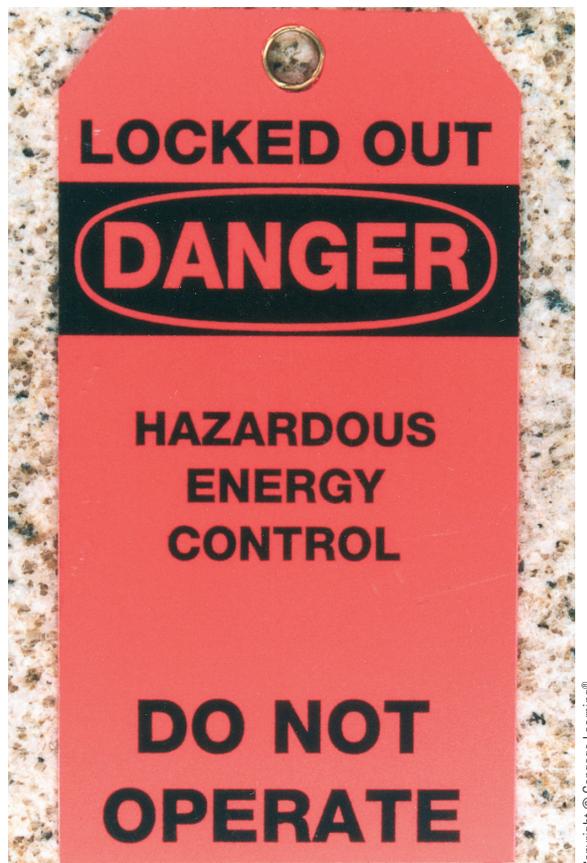


**FIGURE S-3** A confined space is any space having a limited means of entrance or exit.

1. Have a person stationed outside the confined space to watch the person or persons working inside. The outside person should stay in voice or visual contact with the inside workers at all times. He or she should check air sample readings and monitor oxygen and explosive gas levels.
2. The outside person should never enter the space, even in an emergency, but should contact the proper emergency personnel. If he or she should enter the space and become incapacitated, there would be no one available to call for help.
3. Use only electric equipment and tools that are approved for the atmosphere found inside the confined area. It may be necessary to obtain a burning permit to operate tools that have open brushes and that spark when they are operated.
4. As a general rule, a person working in a confined space should wear a harness with a lanyard that extends to the outside person, so the outside person could pull him or her to safety if necessary.

### Lockout and Tagout Procedures

**Lockout and tagout** procedures are generally employed to prevent someone from energizing a piece of equipment by mistake. This could apply to switches, circuit breakers, or valves. Most industries have their own internal policies and procedures. Some require that a tag similar to the one shown in *Figure S-4* be placed on the piece of equipment being



**FIGURE S-4** Safety tag used to tagout equipment.



**FIGURE S-5** The equipment can be locked out by several different people.

serviced; some also require that the equipment be locked out with a padlock. The person performing the work places the lock on the equipment and keeps the key in his or her possession. A device that permits the use of multiple padlocks and a safety tag is shown in *Figure S-5*. This is used when more than one person is working on the same piece of equipment. Violating lockout and tagout procedures is considered an extremely serious offense in most industries and often results in immediate termination of employment. As a general rule, there are no first-time warnings.

After locking out and tagging a piece of equipment, it should be tested to make certain that it is truly de-energized before working on it. A simple three-step procedure is generally recommended for making certain that a piece of electric equipment is de-energized. A voltage tester or voltmeter that has a high enough range to safely test the voltage is employed. The procedure is as follows:

1. Test the voltage tester or voltmeter on a known energized circuit to make certain the tester is working properly.
2. Test the circuit you intend to work on with the voltage tester or voltmeter to make sure that it is truly de-energized.
3. Test the voltage tester or voltmeter on a known energized circuit to make sure that the tester is still working properly.

This simple procedure helps to eliminate the possibility of a faulty piece of equipment indicating that a circuit is de-energized when it is not.

## S-4 Protective Clothing

Maintenance and construction workers alike are usually required to wear certain articles of protective clothing, dictated by the environment of the work area and the job being performed.

### Head Protection

Some type of head protection is required on almost any work site. A typical electrician's hard hat, made of nonconductive plastic, is shown in *Figure S-6*. It has a pair of safety goggles attached that can be used when desired or necessary.