

This International Student Edition is for use outside of the U.S.

FRANK D. PETRUZELLA

THIRD EDITION

# ELECTRICITY FOR THE TRADES



Mc  
Graw  
Hill  
Education



# Electricity for the Trades

Frank D. Petruzella



## ELECTRICITY FOR THE TRADES

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121. Copyright ©2020 by McGraw-Hill Education. All rights reserved. Printed in the United States of America. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw-Hill Education, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19

ISBN 978-1-260-54784-9

MHID 1-260-54784-1

Cover Image: ©Chockchai Paralart/123RF

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw-Hill Education, and McGraw-Hill Education does not guarantee the accuracy of the information presented at these sites.

<i>Preface</i>	<i>xi</i>
<i>Acknowledgments</i>	<i>xiv</i>
<i>Walkthrough</i>	<i>xv</i>

## Section One Fundamentals of Electricity

Chapter 1	Safety	2
Chapter 2	Atoms and Electricity	14
Chapter 3	Sources and Characteristics of Electricity	20
Chapter 4	Electrical Quantities and Ohm's Law	28
Chapter 5	Simple, Series, and Parallel Circuits	37
Chapter 6	Measuring Voltage, Current, and Resistance	46
Chapter 7	Ohm's Law	59
Chapter 8	Resistors	68
Chapter 9	Electricity and Magnetism	81
Chapter 10	Electric Power and Energy	96

## Section Two Direct Current (DC) Circuits

Chapter 11	Solving the DC Series Circuit	112
Chapter 12	Solving the DC Parallel Circuit	126
Chapter 13	Solving the DC Series-Parallel Circuit	139
Chapter 14	Network Theorems	159

## Section Three Alternating Current (AC) Circuits

Chapter 15	Alternating Current Fundamentals	176
Chapter 16	Inductance and Capacitance	193
Chapter 17	Resistive, Inductive, Capacitive (RLC) Series Circuits	213
Chapter 18	Resistive, Inductive, Capacitive (RLC) Parallel Circuits	243
Chapter 19	Transformers	270

## Section Four Electrical Installation and Maintenance

Chapter 20	Circuit Conductors and Wire Sizes	294
Chapter 21	Fuses and Circuit Breakers	306
Chapter 22	Relays	318
Chapter 23	Lighting Equipment	329
Chapter 24	Electric Motors and Controls	338
Chapter 25	Electronic Controls	360

<i>Appendix: Multisim Simulation Lab Manual</i>	<i>AP-1</i>
<i>Index</i>	<i>I-1</i>



# CONTENTS

Preface	xi
Acknowledgments	xiv
Walkthrough	xv



©Alberto Masnovo/Shutterstock

## Chapter 1 Safety 2

Part 1	Safety Overview	3
1.1	Electric Shock	3
1.2	Arc Flash Hazards	3
1.3	Confined Spaces	5
1.4	Personal Protective Equipment	5
1.5	Fall Protection	6
1.6	Lifting and Moving Loads	8
1.7	Fire Prevention	8
1.8	Hazardous Waste	8
Part 2	Grounding—Fault Protection— Lockout—Codes	9
1.9	Grounding and Bonding	9
1.10	Ground-Fault and Arc-Fault Protection	10
1.11	Lockout and Tagout	11
1.12	Electrical Codes and Standards	12

## Chapter 2 Atoms and Electricity 14

Part 1	Atoms and Ions	15
2.1	Electron Theory of Matter	15

2.2	Bohr Model of Atomic Structure	15
2.3	Ions	16
Part 2	Electron Flow	16
2.4	Electricity Defined	16
2.5	Electrical Conductors, Insulators, and Semiconductors	17
2.6	Basic Concepts of Voltage, Current, and Resistance	18
2.7	Testing for Electrical Continuity	19
2.8	Electrical and Electronic Devices	19

## Chapter 3 Sources and Characteristics of Electricity 20

Part 1	Static Electricity	21
3.1	Static Electricity	21
3.2	Charged Bodies	21
3.3	Charging by Conduction and Induction	22
3.4	Practical Uses for Static Charges	22
Part 2	Current Flow	23
3.5	Current Electricity	23
3.6	Sources of Electromotive Force	24

## Chapter 4 Electrical Quantities and Ohm's Law 28

Part 1	Current, Voltage, and Resistance	29
4.1	Current	29
4.2	Voltage	30
4.3	Resistance	31
Part 2	Power, Energy, and Ohm's Law	31
4.4	Power	32
4.5	Energy	32
4.6	Electric Circuit	33
4.7	Ohm's Law	34
4.8	Direction of Current Flow	35



## Chapter 5 Simple, Series, and Parallel Circuits 37

- Part 1** Circuit Symbols and Diagrams 38
  - 5.1 Circuit Symbols 38
  - 5.2 Circuit Diagrams 39
- Part 2** Simple, Series, and Parallel Circuits 41
  - 5.3 Simple Circuit 41
  - 5.4 Series Circuit 41
  - 5.5 Parallel Circuit 42
  - 5.6 Breadboarding and Computer Simulation of Circuits 43
  - 5.7 Short and Open Circuit Faults 44

## Chapter 6 Measuring Voltage, Current, and Resistance 46

- Part 1** Measurement of Voltage and Current 47
  - 6.1 Analog and Digital Meters 47
  - 6.2 Multimeter 47
  - 6.3 Measuring Voltage 49
  - 6.4 Measuring Current 51
- Part 2** Meter Resistance Measurement, Safety, and Specifications 53
  - 6.5 Measuring Resistance 53
  - 6.6 Multimeter Safety 54
  - 6.7 Multimeter Specifications 55
  - 6.8 Virtual Multimeter 57

## Chapter 7 Ohm's Law 59

- Part 1** Electrical Units and Prefixes 60
  - 7.1 Metric Prefixes 60
- Part 2** Mathematical Relationships between Current, Voltage, Resistance, and Power 61
  - 7.2 Ohm's Law 61
  - 7.3 Applying Ohm's Law to Calculate Current 62
  - 7.4 Applying Ohm's Law to Calculate Voltage 63
  - 7.5 Applying Ohm's Law to Calculate Resistance 63
  - 7.6 Power Formulas 64
  - 7.7 Ohm's Law in Graphical Form 66

## Chapter 8 Resistors 68

- Part 1** Resistor Types and Color Code 69
  - 8.1 Resistance Wire 69
  - 8.2 Resistors 69
  - 8.3 Types of Resistors 69
  - 8.4 Rheostats and Potentiometers 71
  - 8.5 Resistor Color Code 71
- Part 2** Resistor Connections 75
  - 8.6 Series Connection of Resistors 75
  - 8.7 Parallel Connection of Resistors 76
  - 8.8 Series-Parallel Connection of Resistors 78

## Chapter 9 Electricity and Magnetism 81

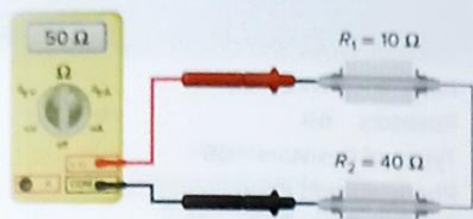
- Part 1** Magnetism 82
  - 9.1 Properties of Magnets 82
  - 9.2 Types of Magnets 82
  - 9.3 Laws of Magnetic Poles 83
  - 9.4 Polarity of Magnets 83
  - 9.5 Magnetic Field 84
  - 9.6 Theories of Magnetism 85
  - 9.7 Uses for Permanent Magnets 86
- Part 2** Electromagnetism 87
  - 9.8 Magnetic Field around a Current-Carrying Conductor 87
  - 9.9 Electromagnets 89
  - 9.10 The Magnetic Circuit 90
  - 9.11 Electromagnetic Induction Principles 91
  - 9.12 Uses for Electromagnets 91

## Chapter 10 Electric Power and Energy 96

- Part 1** Generation and Transmission of Electricity 97
  - 10.1 Electric Generating Stations 97
  - 10.2 Alternative Ways of Generating Electricity 99
  - 10.3 Transmitting Electricity 103
- Part 2** Power Metering and Costs 105
  - 10.4 Energy, Work, and Power 105
  - 10.5 Calculating Electric Power 105
  - 10.6 Measuring Electric Power 107
  - 10.7 Energy Costs 108



## Section Two



## Direct Current (DC) Circuits

### Chapter 11

## Solving the DC Series Circuit 112

- Part 1** Series Circuit Characteristics 113
  - 11.1 Series Circuit Connection 113
  - 11.2 Determining Current Flow 113
  - 11.3 Determining Voltage 114
  - 11.4 Determining Individual Resistance Values 114
  - 11.5 Determining Power 115
- Part 2** Solving the DC Series Circuit 116
  - 11.6 Solving for Current, Voltage, Resistance, and Power 116
  - 11.7 Series Circuit Polarity 119
  - 11.8 Series-Aiding and Series-Opposing Voltage Sources 120
  - 11.9 Voltage Source Resistance 120
  - 11.10 Series Conductor Resistance 121
  - 11.11 Troubleshooting a Series Circuit 122

### Chapter 12

## Solving the DC Parallel Circuit 126

- Part 1** Parallel Circuit Characteristics 127
  - 12.1 Parallel Circuit Connection 127
  - 12.2 Determining Current Flow 127
  - 12.3 Determining Voltage 128
  - 12.4 Determining Total Resistance 128
  - 12.5 Determining Power 129
- Part 2** Solving the DC Parallel Circuit 130
  - 12.6 Solving for Current, Voltage, Resistance, and Power 130
  - 12.7 Parallel Circuit Polarity 133
  - 12.8 Parallel Voltage Sources 134
  - 12.9 Troubleshooting a Parallel Circuit 134

### Chapter 13

## Solving the DC Series-Parallel Circuit 139

- Part 1** Series-Parallel Circuit Characteristics 140
  - 13.1 Series-Parallel Circuit Connection 140
  - 13.2 Determining Current Flow 140
  - 13.3 Determining Voltage 141
  - 13.4 Determining Resistance 142
  - 13.5 Determining Power 143
- Part 2** Solving the DC Series-Parallel Circuit 144
  - 13.6 Solving for Current, Voltage, Resistance, and Power 144
  - 13.7 Polarity in DC Series-Parallel Circuits 152
  - 13.8 Troubleshooting a Series-Parallel Circuit 152
  - 13.9 Three-Wire Circuits 153

### Chapter 14

## Network Theorems 159

- Part 1** Superposition Theorem 160
  - 14.1 Voltage and Current Sources 160
  - 14.2 Superposition Theorem 161
- Part 2** Thevenin and Norton Theorems 166
  - 14.3 Thevenin's Theorem 166
  - 14.4 Norton's Theorem 170

## Section Three



©emel82/123RF

## Alternating Current (AC) Circuits

### Chapter 15

## Alternating Current Fundamentals 176

- Part 1** Alternating Current Generation and Measurement 177
  - 15.1 Differences between DC and AC 177
  - 15.2 Alternating Current Generation 178



15.3	Alternating Current Measurements	181
Part 2	AC Systems and Resistive Circuits	185
15.4	Single- and Three-Phase Systems	185
15.5	Resistive Circuits	189

## Chapter 16 Inductance and Capacitance 193

Part 1	Inductance	194
16.1	Inductance	194
16.2	Inductive Reactance	197
16.3	Phase Shift in an Inductor	199
16.4	Inductive Reactive Power	199
Part 2	Capacitance	201
16.5	Capacitance	201
16.6	Capacitor Ratings, Connections, and Types	202
16.7	RC Time Constant	205
16.8	Capacitive Reactance	206
16.9	Phase Shift in a Capacitor	209
16.10	Capacitive Reactive Power	210
16.11	Troubleshooting Inductors and Capacitors	210

## Chapter 17 Resistive, Inductive, Capacitive (RLC) Series Circuits 213

Part 1	Vectors	214
17.1	Vector Diagrams	214
17.2	Combining Vectors	214
Part 2	Series RL Circuit	219
17.3	Series RL Circuits	219
Part 3	Series RC Circuit	225
17.4	Series RC Circuits	225
Part 4	Series RLC Circuit	230
17.5	Series LC Circuits	230
17.6	Series RLC Circuits	232
Part 5	Series Resonant Circuit	238
17.7	Series Resonant Circuits	238

## Chapter 18 Resistive, Inductive, Capacitive (RLC) Parallel Circuits 243

Part 1	Parallel RL Circuit	244
18.1	Parallel RL Circuits	244
Part 2	Parallel RC Circuit	249

18.2	Parallel RC Circuits	249
Part 3	Parallel RLC Circuit	254
18.3	Parallel LC Circuits	254
18.4	Parallel RLC Circuits	256
Part 4	Parallel Resonance and Power Factor Correction	263
18.5	Parallel Resonant Circuits	263
18.6	Power Factor Correction	265

## Chapter 19 Transformers 270

Part 1	Transformer Basics	271
19.1	Transformer Operation	271
19.2	Relationship of Voltage, Current, and Power	272
Part 2	Single-Phase Transformer	276
19.3	Transformer Losses	276
19.4	Transformer Ratings	277
19.5	Single-Phase Transformer Connections	279
Part 3	Three-Phase Transformer	282
19.6	Three-Phase Transformer Connections	282
Part 4	Transformer Installations	288
19.7	Instrument Transformers	288
19.8	Transformer Insulation Resistance	289
19.9	Cooling of Transformers	290
19.10	Transformer Overcurrent Protection	290
19.11	Harmonics	291

## Section Four



©Fluke Corporation

## Chapter 20 Circuit Conductors and Wire Sizes 294

Part 1	Electric Wire and Cable	295
20.1	Building Wire and Cable	295
20.2	Conductor Insulation	295



20.3	Cable Assemblies	296
20.4	Conduit Systems	297
20.5	Wire Sizes	298
Part 2	Conductor Ampacity and Line Losses	300
20.6	Conductor Ampacity	300
20.7	Conductor Resistance	301
20.8	Line Voltage Drop and Power Loss	301

## Chapter 21 Fuses and Circuit Breakers 306

Part 1	Circuit Protection	307
21.1	Overloads and Short Circuits	307
21.2	Ratings of Protection Devices	308
Part 2	Fuses and Circuit Breakers	309
21.3	Types of Fuses	309
21.4	Testing Fuses	311
21.5	Circuit Breakers	312
21.6	Selective Coordination of Protective Devices	314
21.7	Load Centers and Circuit Breakers	314

## Chapter 22 Relays 318

Part 1	Relay Fundamentals	319
22.1	Electromechanical Relay	319
22.2	Relay Applications	320
22.3	Relay Styles and Specifications	321
Part 2	Types of Relays	322
22.4	Solid-State Relays	322
22.5	Time-Delay Relays	323
22.6	Latching Relays	324
22.7	Protective Relays	325
22.8	Contactors and Motor Starters	325

## Chapter 23 Lighting Equipment 329

Part 1	Lamps and Luminaires	330
23.1	Lamps	330
23.2	Wiring Luminaires	332
Part 2	Lighting Control	333
23.3	Light Switches	333
23.4	Switch Wiring	335

## Chapter 24 Electric Motors and Controls 338

Part 1	Three-Phase Motors	339
24.1	Rotating Magnetic Field	339
24.2	Squirrel-Cage Induction Motor	340
Part 2	Single-Phase Motors	344
24.3	Single-Phase Induction Motor	344
24.4	Split-Phase Motor	344
24.5	Single-Phase Capacitor Motor	346
24.6	Shaded-Pole Motor	347
24.7	Universal Motor	347
Part 3	Motor Controls	348
24.8	Motor Protection	348
24.9	Motor Starting	351
24.10	Motor Stopping	352
Part 4	Direct Current Motors	354
24.11	Permanent-Magnet DC Motor	354
24.12	Series DC Motor	355
24.13	Shunt DC Motor	355
24.14	Compound DC Motor	356
24.15	Direction of Rotation	356
24.16	Motor Counter Electromotive Force (CEMF)	357
24.17	Armature Reaction	358
24.18	Motor Speed	358

## Chapter 25 Electronic Controls 360

Part 1	Electronic Components	361
25.1	Diodes	361
25.2	Transistors	362
25.3	Thyristors	363
25.4	Integrated Circuits (ICs)	364
Part 2	Electronic Control Devices	366
25.5	Diode Rectifiers and Inverters	366
25.6	Transistor Switching and Amplification	367
25.7	Thyristor Control Applications	368
25.8	Electronic Motor Drives	370
25.9	Programmable Logic Controllers (PLCs)	372
Part 3	Digital Logic Circuits	374
25.10	Analog versus Digital	374
25.11	Logic Gates	375
25.12	Combination Logic Circuits	377

Appendix: Multisim Simulation  
Lab Manual AP-1

Index I-1



The third edition of **Electricity for the Trades** focuses on the understanding of topics required for careers in the electrical industry and associated disciplines. The main objective of this text is to explain, **as simply as possible**, the electrical theory and its applications to related electrical circuits and products.

## New to This Edition

- New topics, including three-wire circuits, protection relays, CD motor control, and digital logic circuits
- Additional Test and Review Questions for each chapter
- More solved Example Problems
- Added Troubleshooting Problems for series circuits and parallel circuits
- Extended coverage of:

National Electrical Code  
Short and Open Circuit Faults  
Pumped Storage Hydroelectric Plant  
Open Delta Connection  
Teck Cable  
Protective Relays  
Direct Current Motors

Basic Concepts of Voltage, Current, and Resistance  
Electromagnetic Induction  
Eddy Currents and Skin Effect  
Operational Amplifiers  
Load Centers and Circuit Breakers  
Split Receptacle and Lighting Control Devices



# connect®

## Your grades. Your time. Make the most of it.

You want to achieve the best grades possible with the limited time you have to study. McGraw-Hill Connect helps you do just that. Connect is your personalized digital learning assistant that makes earning better grades and managing time easier, quicker, and more convenient than ever.



3175  
If you need a hand getting started with Connect, or at any step along the way, we're standing by—ready to help.

[mhhe.com/collegesmarter](http://mhhe.com/collegesmarter)  
800.331.5094

