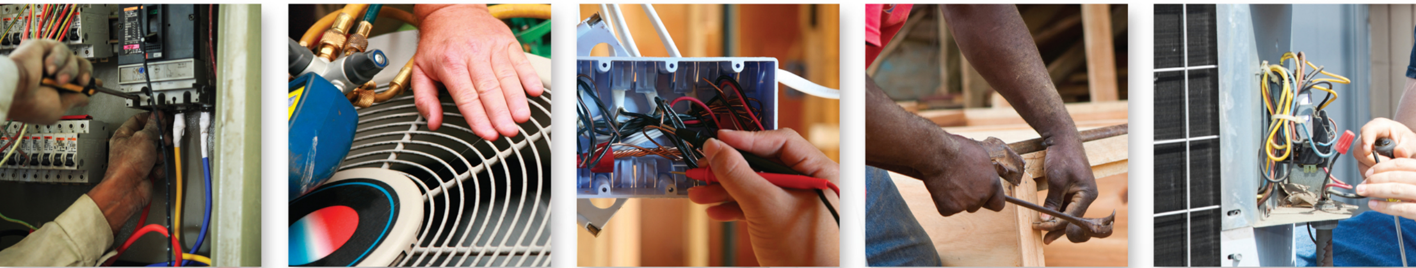
5th Edition

Electrical Studies for Trades



Stephen L. Herman

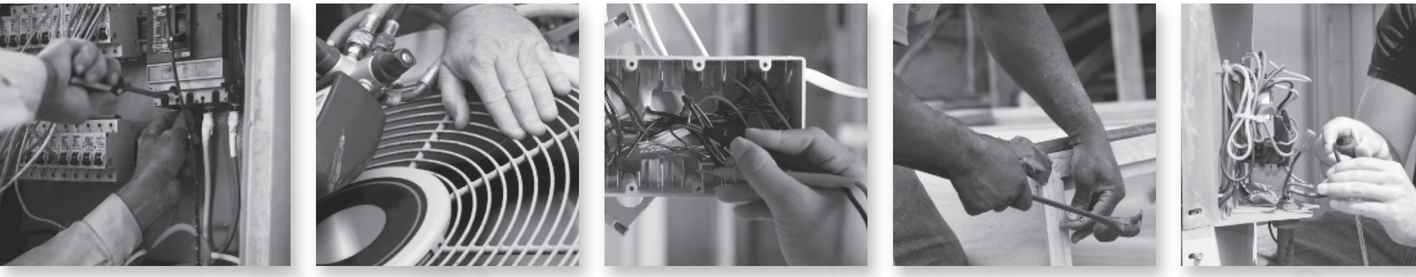
5th Edition

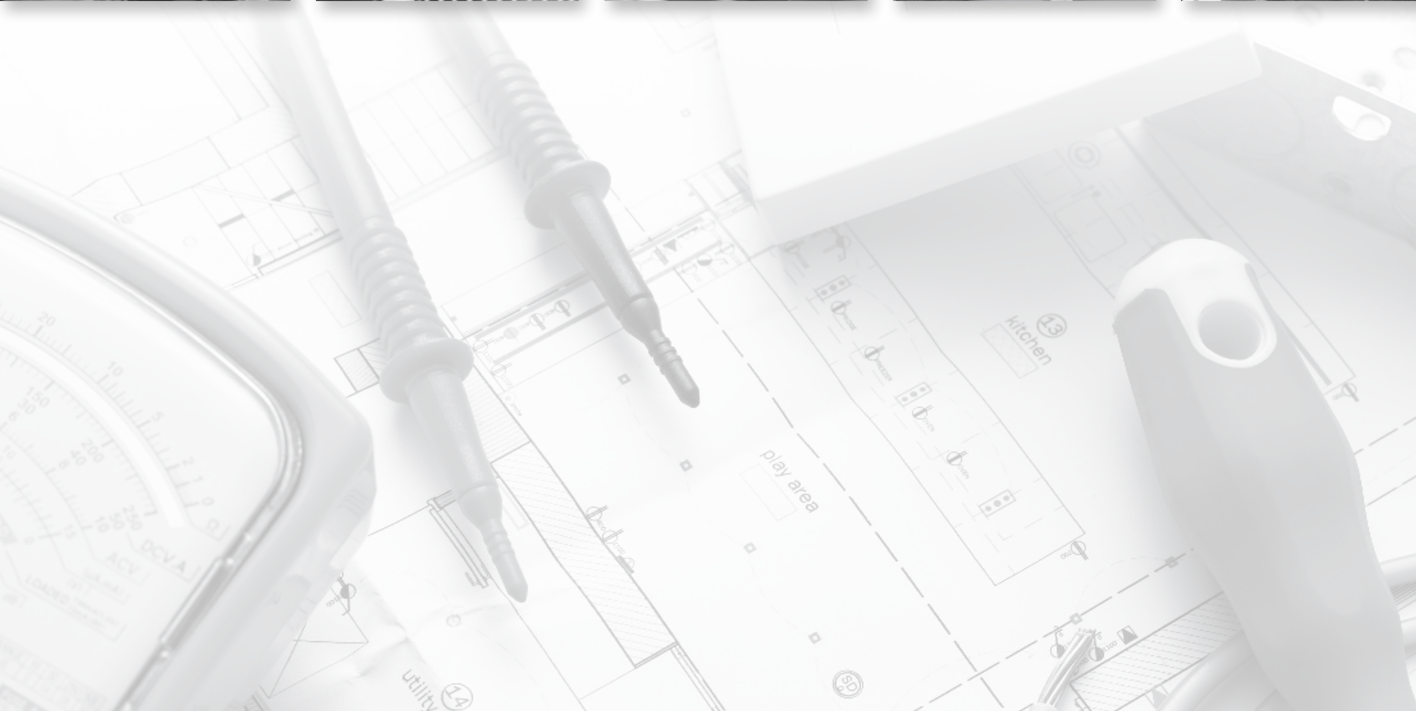
Electrical Studies for Trades

5th Edition

Electrical Studies for Trades

Stephen L. Herman





DELMAR
CENGAGE Learning®

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

DELMAR
CENGAGE Learning

Electrical Studies in Trades, 5E
Stephen L. Herman

Vice President, Careers & Computing: Dave Garza

Director of Learning Solutions: Sandy Clark

Acquisitions Editor: Stacy Masucci

Director, Development-Career and Computing: Marah Bellegarde

Managing Editor: Larry Main

Senior Product Manager: John Fisher

Editorial Assistant: Kaitlin Murphy

Brand Manager: Kristin McNary

Market Development Manager: Erin Brennan

Senior Production Director: Wendy Troeger

Production Manager: Mark Bernard

Senior Content Project Manager: Glenn Castle

Senior Art Director: David Arsenault

Technology Project Manager: Sheila Kosztowny

Cover image(s): Air Condition Service © iStockphoto/Janice Richard; Electric Works © iStockphoto/Danish Khan; Air Conditioning Repair © iStockphoto/Lisa F. Young; Electrical Switch Testing © iStockphoto/Yenwen Lu; Men Building Cabinet © iStockphoto/Steven Frame; Electrical Equipment On House Plans © iStockphoto/Catherine Yeulet

Library of Congress Control Number: 2012952120

ISBN-13: 978-1-133-27823-8

ISBN-10: 1-133-27823-X

Delmar
5 Maxwell Drive
Clifton Park, NY 12065-2919
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:
international.cengage.com/region

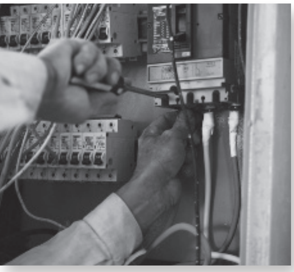
Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Delmar, visit **www.cengage.com/delmar**

Purchase any of our products at your local college store or at our preferred online store **www.cengagebrain.com**

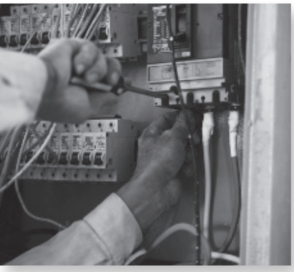
Printed in the United States of America
1 2 3 4 5 6 7 16 15 14 13

Contents





Preface





There are many technical fields that require a working knowledge of electricity, such as air conditioning and refrigeration, automotive repair, electrical apprenticing, carpentry, building maintenance, construction work, and appliance repair. *Electrical Studies for Trades, 5th Edition* is written for technicians who are not electricians but who must have a practical working knowledge of electricity in their chosen field. The 5th edition of *Electrical Studies for Trades* is the most comprehensive revision of the text since it was first published in 1997.

This text assumes the students have no knowledge of electricity. *Electrical Studies for Trades, 5th Edition* begins with atomic structure and basic electricity. The text progresses through Ohm's Law calculations and series, parallel, and combination circuits. These concepts are presented in an easy-to-follow, step-by-step procedure. The math level is kept to basic algebra and trigonometry. It is not the intent of this text to present electricity from a purely mathematical standpoint, but rather to explain it in an easy-to-read, straightforward manner using examples and illustration.

Electrical Studies for Trades, 5th Edition includes concepts of inductance and capacitance in alternating current circuits. Both single-phase and three-phase power systems are covered. Some of the electrical machines discussed in the text are transformers, three-phase motors, and single-phase motors. Common measuring instruments such as voltmeters, ammeters, and ohmmeters are covered. The text also includes information on oscilloscopes because there are many circuits that require the use of an oscilloscope in troubleshooting.

Electrical Studies for Trades, 5th Edition provides information on basic wiring practices such as connection of electrical outlets and switch connections. Detailed explanations for the connection of single-pole, three-way, and four-way switches are presented in an easy-to-follow step-by-step procedure. The text includes information on ground fault interrupters, arc-fault interrupters, light dimmers, and chime circuits. The final unit includes information on motor control schematics and wiring diagrams.

NEW FOR THE FIFTH EDITION

1. A completely new unit on three-phase transformers
2. Additional information on phase rotation
3. Updated graphics
4. The chapters concerning the installation of switches have been updated to the 2011 NEC

SUPPLEMENTS

An online Instructor Companion website contains an Instructor Guide with answers to end of chapter review questions, test banks, and chapter presentations done in PowerPoint.

ACCESSING AN INSTRUCTOR COMPANION WEBSITE SITE FROM SSO FRONT DOOR

1. Go to http://login.cengage.com and login using the Instructor email address and password.
2. Enter author, title, or ISBN in the “Add a Title to Your Bookshelf” search box, click on Search button.
3. Click Add to My Bookshelf to add Instructor Resources.
4. At the Product page, click on the Instructor Companion site link.

NEW USERS

If you’re new to Cengage.com and do not have a password, contact your sales representative.

ACKNOWLEDGMENTS

The author and Cengage Delmar Learning would like to acknowledge and thank the reviewers for the many suggestions and comments given during the development of this fifth edition. Thanks go to:

Daniel A. Blount
Holmes Community College
Ridgeland, MS

Ron Meyer
Central Community College
Hastings, NE

Marvin Moak
Hinds Community College
Raymond, MS

Larry Snyder
Red Rocks Community College
Lakewood, CO

Randy Ludington
Guilford Technical Community College
Jamestown, NC

Wes Evans
Truckee Meadows Community College
Reno, NV

Patrick Ottesen
Milwaukee Area Technical College
Oak Creek, WI

UNIT 1

Atomic Structure

OBJECTIVES: After studying this unit, you should be able to:

- List the three major parts of an atom.
- State the law of charges.
- Discuss the law of centrifugal force.
- Discuss the differences between conductors, insulators, and semiconductors.

Electricity is the driving force that provides most of the power for the industrialized world. It is used to light homes, cook meals, heat and cool buildings, drive motors, and supply the ignition for most automobiles. The technician who understands electricity can seek employment in almost any part of the world.

Electrical sources are divided into two basic types, **direct current** (DC) and **alternating current** (AC). Direct current is **unidirectional,** which means that it flows in only one direction. The first part of this text will be devoted mainly to the study of direct current. Alternating current is **bidirectional,** which means that it reverses its direction of flow at regular intervals. The latter part of this text is devoted mainly to the study of alternating current.

direct current
current that does not reverse its direction of flow.

alternating current
current that reverses its direction of flow periodically. Reversals generally occur at regular intervals.

unidirectional
current that flows in one direction only.

bidirectional
current that flows in more than one direction.

EARLY ELECTRICAL HISTORY

Although the practical use of electricity has become common within the last hundred years, it has been known as a force for much longer. The Greeks discovered electricity about 2,500 years ago. They noticed that when amber was rubbed with other materials, it became charged with an unknown force. This force had the power to attract other objects, such as dried leaves, feathers, bits of cloth, or other lightweight materials. The Greeks called amber *elektron.* The word *electric* was derived from this word because like amber, it had the ability to attract other objects. This mysterious force remained a curious phenomenon until other people began to conduct experiments about 2,000 years later. In the early 1600s, William Gilbert discovered that materials other than amber could be charged to attract other objects. He called materials that could be charged *electriks* and materials that could not be charged *nonelektriks.*

About 300 years ago, a few men began to study the behavior of various charged objects. In 1733, a Frenchman named Charles DuFay found that a piece of charged glass would repel some charged objects and attract others. These men soon learned that the force of **repulsion** was just as important as the force of **attraction.** From these experiments, two lists were developed, FIGURE 1-1. Any material in list A would attract any of the materials in list B. All materials in list A would repel each other, and all the materials in

repulsion
the force that repels one object from another.

attraction
the force that attracts one object to another.

LIST A	LIST B
Glass (rubbed on silk)	Hard rubber (rubbed on wool)
Glass (rubbed on wool or cotton)	Block of sulfur (rubbed on wool or fur)
Mica (rubbed on cloth)	Most kinds of rubber (rubbed on cloth)
Asbestos (rubbed on cloth or paper)	Sealing wax (rubbed on silk, wool, or fur)
Stick of sealing wax (rubbed on wool)	Glass or mica (rubbed on dry wool)
	Amber (rubbed on cloth)

FIGURE 1-1 List of charged materials.

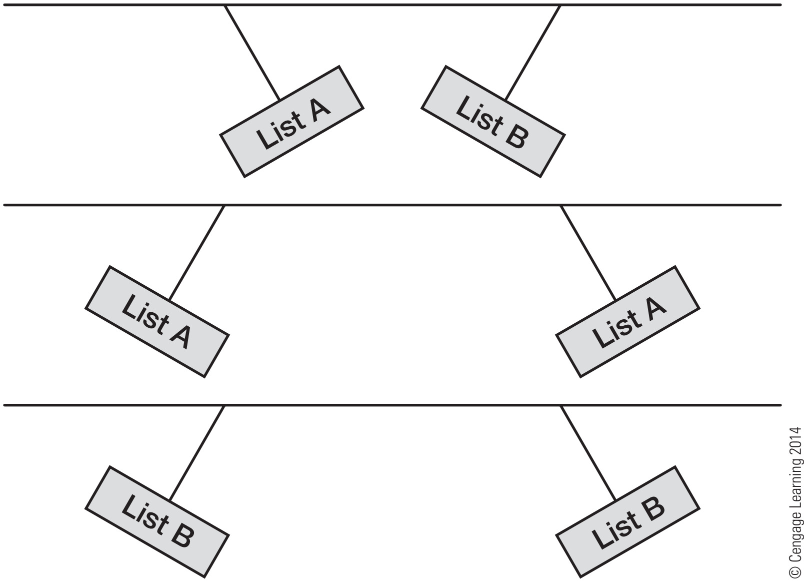


FIGURE 1-2 Unlike charges attract and like charges repel.

list B would repel each other, FIGURE 1-2. Various names were suggested for the materials in lists A and B. Any opposite-sounding names such as east and west, north and south, male and female could have been chosen. Benjamin Franklin named the materials in list A **positive** and the materials in list B **negative.** These names are still used today. The first item in each list was used as a standard for determining if a charged object was positive or negative. Any object repelled by a piece of glass rubbed on silk had a positive charge, and any item repelled by a hard rubber rod rubbed on wool had a negative charge.

ATOMS

To understand electricity, it is necessary to start with the study of atoms. The **atom** is the basic building block of the universe. All **matter** is made from a combination of atoms. Matter is any substance that has mass and occupies space. Matter can exist in any of three states: solid, liquid, or gas. Water, for example, can exist as a solid in the form of ice, as a liquid, or as a gas in the form of steam, FIGURE 1-3. An atom is the smallest part of an **element.** A chart listing both natural and artificial elements is shown in FIGURE 1-4. The three principal parts of an atom are the **electron, neutron,** and **proton.** The smallest atom is hydrogen which contains one proton and one electron. The smallest atom that contains both electrons and protons in the nucleus is helium which contains two protons and two neutrons.

positive/negative
one polarity of a voltage, current, or charge.

atom
smallest part of an element that contains all the properties of that element.

matter
a physical substance.

element
(1) One of the basic building blocks of nature. An atom is the smallest part of an element. (2) One part of a group of devices.

electron
one of the three major parts of an atom. The electron carries a negative charge.

neutron
one of the principal parts of an atom. The neutron has no charge and is part of the nucleus.

proton
one of the three major parts of an atom. The proton has a positive charge.

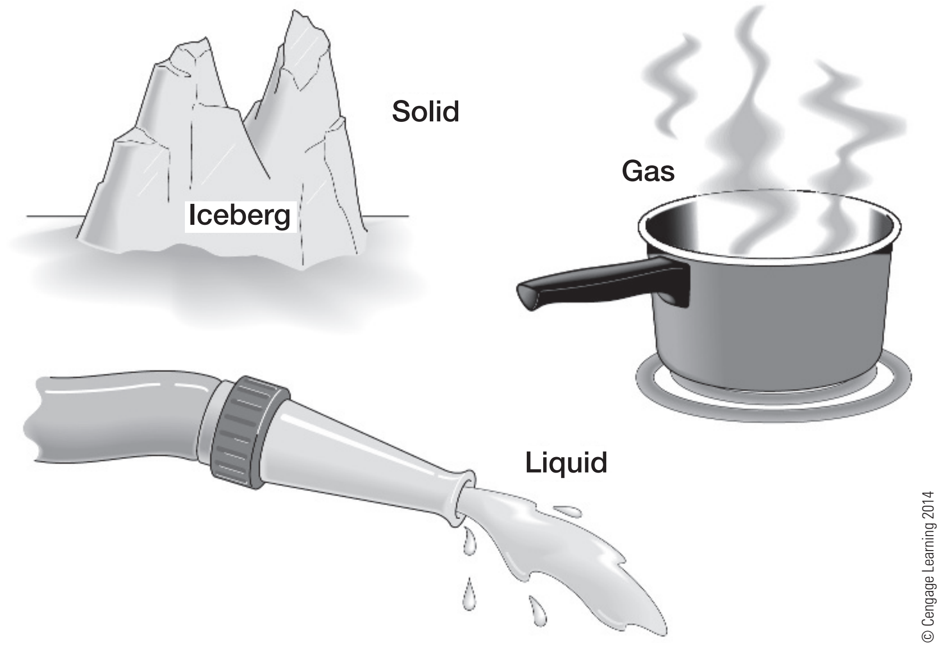


FIGURE 1-3 Water can exist in three states depending on temperature and pressure.

nucleus
the center of an atom composed of protons and neutrons.

atomic number
the number of protons contained in the nucleus of an atom.

Notice that the proton has a positive charge, the electron has a negative charge, and the neutron has no charge. The neutron and proton combine to form the **nucleus** of the atom. Because the neutron has no charge, the nucleus will have a net positive charge. The number of protons in the nucleus determines the element of an atom. Oxygen, for example, contains eight protons in its nucleus, and gold contains seventy-nine. The **atomic number** of an element is the same as the number of protons in the nucleus. The lines of force produced by the positive charge of the proton extend outward in all directions, FIGURE 1-6. The nucleus may or may not contain as many neutrons as protons. For example, an atom of helium contains two protons and two neutrons in its nucleus. An atom of copper contains twenty-nine protons and thirty-five neutrons, FIGURE 1-7.

The electron orbits around the outside of the nucleus. The latest scientific measurements suggest protons and neutrons weigh about 1838 times more than the electron, and that the electron is approximately 1/1000 the size of a proton, FIGURE 1-5. Many scientists believe that it is almost impossible to accurately measure the size of these particles and the actual size is of no real importance. It is the characteristics of the particles that is

ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL
1	Hydrogen	1	H
2	Helium	2	He
3	Lithium	1	Li
4	Beryllum	2	Be
5	Boron	3	B
6	Carbon	4	C
7	Nitrogen	5	N
8	Oxygen	6	O
9	Fluorine	7	F
10	Neon	8	Ne
11	Sodium	1	Na
12	Magnesium	2	Ma
13	Aluminum	3	Al
14	Silicon	4	Si
15	Phosphorus	5	P
16	Sulfur	6	S
17	Chlorine	7	Cl
18	Argon	8	A
19	Potassium	1	K
20	Calcium	2	Ca
21	Scandium	2	Sc
22	Titanium	2	Ti
23	Vanadium	2	V
24	Chromium	1	Cr
25	Manganese	2	Mn
26	Iron	2	Fe
27	Cobalt	2	Co
28	Nickel	2	Ni
29	Copper	1	Cu
30	Zinc	2	Zn
31	Gallium	3	Ga
32	Germanium	4	Ge
33	Arsenic	5	As
34	Selenium	6	Se
35	Bromine	7	Br
36	Krypton	8	Kr

ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL
37	Rubidium	1	Rb
38	Strontium	2	Sr
39	Yttrium	2	Y
40	Zirconium	2	Zr
41	Niobium	1	Nb
42	Molybdenum	1	Mo
43	Technetium	2	Tc
44	Ruthenium	1	Ru
45	Rhodium	1	Rh
46	Palladium	–	Pd
47	Silver	1	Ag
48	Cadmium	2	Cd
49	Indium	3	In
50	Tin	4	Sn
51	Antimony	5	Sb
52	Tellurium	6	Te
53	Iodine	7	I
54	Xenon	8	Xe
55	Cesium	1	Cs
56	Barium	2	Ba
57	Lanthanum	2	La
58	Cerium	2	Ce
59	Praseodymium	2	Pr
60	Neodymium	2	Nd
61	Promethium	2	Pm
62	Samarium	2	Sm
63	Europium	2	Eu
64	Gadolinium	2	Gd
65	Terbium	2	Tb
66	Dysprosium	2	Dy
67	Holmium	2	Ho
68	Erbium	2	Er
69	Thulium	2	Tm
70	Ytterbium	2	Yb
71	Lutetium	2	Lu
72	Hafnium	2	Hf

ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL
73	Tantalum	2	Ta
74	Tungsten	2	W
75	Rhenium	2	Re
76	Osmium	2	Os
77	Iridium	2	Ir
78	Platinum	1	Pt
79	Gold	1	Au
80	Mercury	2	Hg
81	Thallium	3	Tl
82	Lead	4	Pb
83	Bismuth	5	Bl
84	Polonium	6	Po
85	Astatine	7	At
86	Radon	8	Rd
87	Francium	1	Fr
88	Radium	2	Ra
89	Actinium	2	Ac
90	Thorium	2	Th
91	Protactinium	2	Pa
92	Uranium	2	U
	Artifical Elements		
93	Neptunium	2	Np
94	Plutonium	2	Pu
95	Americium	2	Am
96	Curium	2	Cm
97	Berkelium	2	Bk
98	Californium	2	Cf
99	Einsteinium	2	E
100	Fermium	2	Fm
101	Mendelevium	2	Mv
102	Nobelium	2	No
103	Lawrencium	2	Lw

FIGURE 1-4 Table of elements.

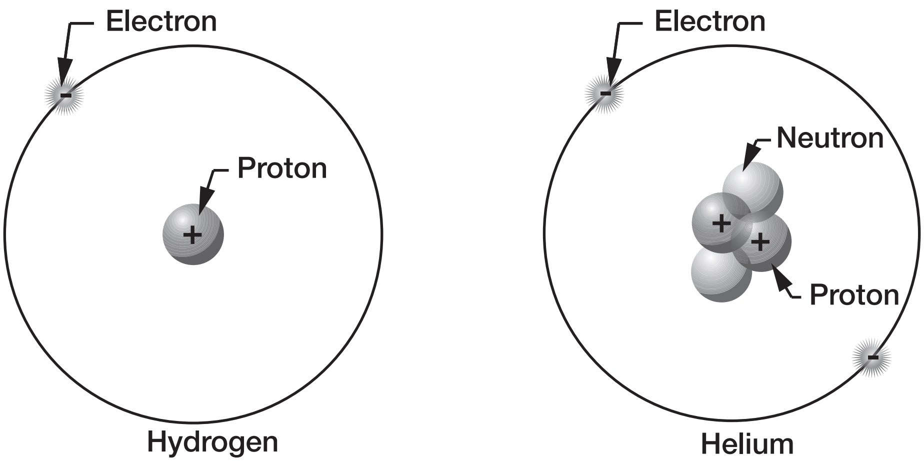


FIGURE 1-5 The smallest atom that contains both protons and neutrons in the nucleus is helium.

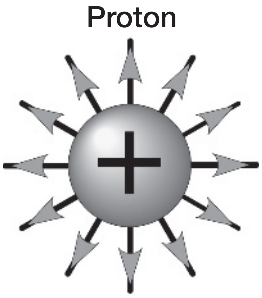


FIGURE 1-6 The lines of force extend outward.

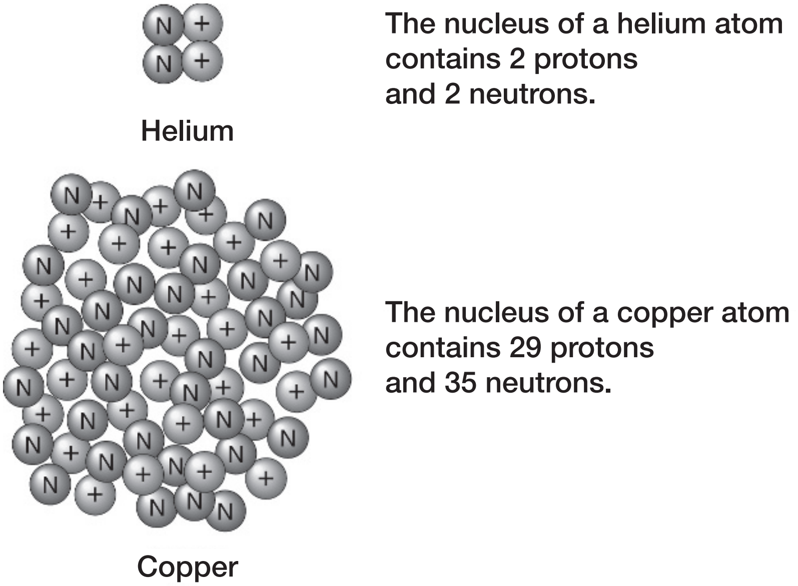


FIGURE 1-7 The nucleus may or may not contain the same number of protons and neutrons.

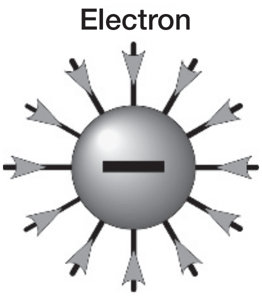


FIGURE 1-8 The lines of force move toward the electron.

of importance. Because the electron exhibits a negative charge, the lines of force come from all directions, FIGURE 1-8.

THE LAW OF CHARGES

One of the basic laws concerning atoms is the law of charges, which states that **opposite charges attract and like charges repel.** FIGURE 1-9 illustrates this principle. In Figure 1-9, charged balls are suspended from strings. Notice that the two balls that contain opposite charges are attracted to each other. The two positively charged balls and the two negatively charged balls are repelled from each other. The reason for this is that a basic law of physics states that lines of force can never cross each other. The outward-going lines of force of a positively charged object combine with the inward-going lines of force of a negatively charged object, FIGURE 1-10. This produces an attraction between the two objects. If two objects with like charges come in proximity with each other, the lines of force repel, FIGURE 1-11. Since the nucleus has a net positive charge and the electron has a negative charge, the electron is attracted to the nucleus.

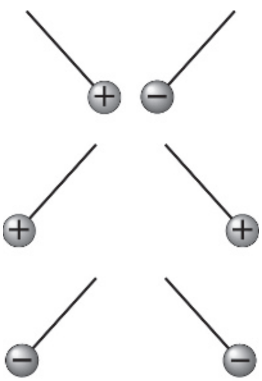


FIGURE 1-9 Unlike charges attract and like charges repel.

Because the nucleus of an atom is formed from the combination of protons and neutrons, one might ask why the protons of the nucleus do not repel each other since they all have the same charge. Two theories attempt to explain this. The first theory, which is no longer supported, asserted that

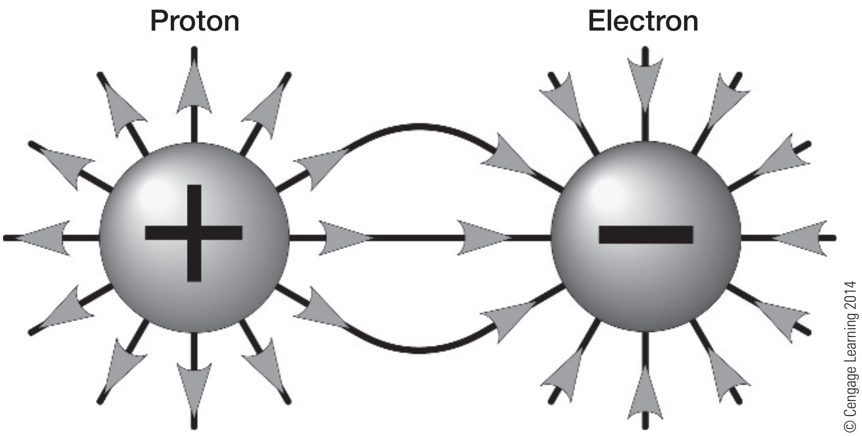


FIGURE 1-10 Unlike charges attract each other.

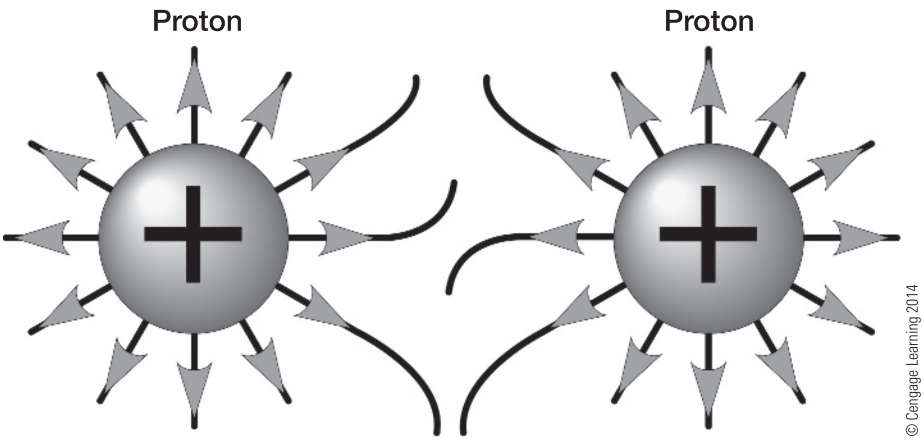


FIGURE 1-11 Like charges repel each other.

the force of gravity held the nucleus together. Neutrons, like protons, are extremely massive particles. It was first theorized that the gravitational attraction caused by their mass overcame the repelling force of the positive charges. By the mid-1930s, however, it was known that the force of gravity could not hold the nucleus together. According to Coulomb's Law, the electromagnetic force in helium is about 1.1×10^{36} times greater than Newton's Law of gravitational force. In 1947 the Japanese physicist, Hideki Yukawa, introduced the second theory by identifying a subatomic particle that acts as a mediator to hold the nucleus together. The particle is a quark known as a *gluon.* The force of the gluon is about 10^2 times stronger than the electromagnetic force.

KEY POINT

Opposite charges attract and like charges repel.

STRUCTURE OF THE ATOM

In 1808, a scientist named John Dalton proposed that all matter was composed of atoms. Although the assumptions that Dalton used to prove his theory were later found to be factually incorrect, the idea that all matter is composed of atoms was adopted by most of the scientific world. Then in 1897, J.J. Thompson discovered the electron. Thompson determined that electrons have a negative charge and that they have very little mass compared to the atom. He proposed that atoms have a large positively charged massive body with negatively charged electrons scattered throughout it. Thompson also proposed that the negative charge of the electrons exactly balanced the positive charge of the large mass, causing the atom to have a net charge of zero. Thompson's model of the atom proposed that electrons existed in a random manner within the atom, much like firing BBs from a BB gun into a slab of cheese. This was referred to as the plum pudding model of the atom.

In 1913, a Danish scientist named Niels Bohr presented the most accepted theory concerning the structure of an atom. In the Bohr model, electrons exist in specific or "allowed" orbits around the nucleus in much the same that planets orbit the sun, FIGURE 1-12. The orbit in which the electron exists is determined by the electron's mass, times its speed, times the radius of the orbit. These factors must equal the positive force of the nucleus. In theory there can be an infinite number of allowed orbits.

When an electron receives enough energy from some other source it "quantum jumps" into a higher allowed orbit. Electrons, however, tend to return to a lower allowed orbit. When this occurs, the electron emits the excess energy as a single photon of electromagnetic energy.

ELECTRON ORBITS

Atoms have a set number of electrons that can be contained in one orbit, or shell, called an **electron orbit,** FIGURE 1-13. The number of electrons that can be contained in any one shell is found by the formula ($2N^2$). The letter N represents the number of the orbit, or shell. For example, the first orbit can hold no more than two electrons.

$$2 \times (1)^2 \text{ or}$$

$$2 \times 1 = 2$$

The second orbit can hold no more than eight electrons.

$$2 \times (2)^2 \text{ or}$$

$$2 \times 4 = 8$$

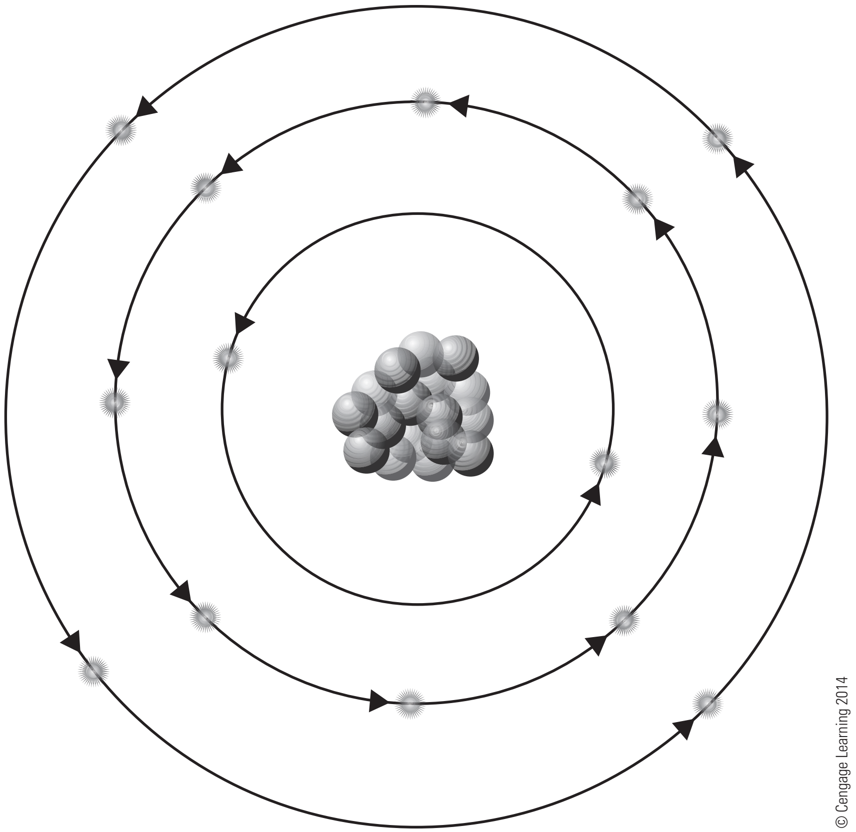


FIGURE 1-12 Electrons exist in allowed orbits around the nucleus.

The third orbit can contain no more than eighteen electrons.

$$2 \times (3)^2 \textbf{ or}$$

$$2 \times 9 = 18$$

The fourth and fifth orbits can hold no more than thirty-two electrons. Thirty-two is the maximum number of electrons that can be contained in any orbit.

$$2 \times (4)^2 \textbf{ or}$$

$$2 \times 16 = 32$$

Although atoms are often drawn flat, as illustrated in Figure 1-13, the electrons orbit around the nucleus in a circular fashion, as shown in FIGURE 1-14. The electrons travel at such a high rate of speed that they form