CHAPTER

11 Electrical Engineering

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OBJECTIVES

After studying this chapter, you should be able to:

- Define *electrical engineering*.
- List the secondary and college level education requirements for employment in the electrical engineering profession.
- Explain how electrons move on an atomic level.
- Calculate voltage, current, resistance, and power for series, parallel, and series-parallel combination circuits.
- Explain Ohm's law and use it to solve for values in a circuit.
- Identify the operation and application of common electronic components such as resistors, switches, capacitors, diodes, and transistors.

THINK LIKE AN
ENGINEER

How many products can you think of that were influenced by electrical engineering?

Key Terms

alternating current (ac)
American Wire Gauge (AWG) system
ammeter
atom
battery
capacitor
cell
circuit board
compact fluorescent lamp (CFL)
conductor
continuity tester
coulomb
current
diode
direct current (dc)
electrical engineering
electricity
electrode
electron
fluorescent lamp
gas discharge lamp
generator
hybrid car
incandescent lamp
Institute of Electrical and Electronics Engineers (IEEE)
insulator
integrated circuit (IC)
ion
law of conservation of energy
light-emitting diode (LED) lamp
motor
neutron
ohm (Ω)
ohmmeter
Ohm's law
oscilloscope
parallel circuit
polarity
power
primary cell
proton
resistance
resistor
schematic diagram
schematic symbol
secondary cell
semiconductor
sensor
series circuit
series-parallel combination circuit
solar cell
solderless breadboard
static electricity
switch
transistor
troubleshoot
valence shell
variable resistor
volt
voltage
voltmeter
volt-ohm-milliammeter (VOM)
watt
Watt's law
zener diode

Have you ever wondered who designs and builds things like power plants, space shuttle electronics, or your favorite electronic gadget? You can be sure that electrical engineers were involved in every step along the way. ***Electrical engineering*** is the design and construction of electrical and electronic components and devices. Electrical engineers design, test, develop, and build products like these every day. See **Figure 11-1**.

In telecommunications, electrical engineers are responsible for designing and overseeing the construction and maintenance of the systems and networks through which customers receive voice and data services. They deal with copper telephone equipment, fiber optics, electronic switching systems, radio and television systems, and satellite systems.

Professional Aspects

The requirement for an entry-level electrical engineering position is a bachelor's degree in electrical engineering. For higher-level positions, master's degrees or doctorate degrees are usually required. To earn a degree in electrical engineering, students must take courses in electricity, electronics, chemistry, biology, physics, and higher-level math and statistics. In order to be accepted into an undergraduate-level engineering program, students need outstanding grades in advanced high school math and science classes.

Did You Know?

Edith Clarke was the first woman to earn a degree in electrical engineering from MIT.

metamorworks/Shutterstock.com

Figure 11-1.
Electrical engineers are designing new and exciting products every day. ***If you become an electrical engineer, what kinds of products might you like to design?***

Electrical technicians are commonly responsible for installation and maintenance of electrical equipment and devices. Becoming an electrical technician usually requires a two-year associate's degree.

The broadest professional association for electrical engineers is the ***Institute of Electrical and Electronics Engineers (IEEE)***. The acronym is pronounced *I triple E*. IEEE comprises over 419,000 members in more than 160 countries. The IEEE is dedicated to advancing technological innovation and excellence through their publications, conferences, standards, and activities. See **Figure 11-2**.

It is critical for all engineers to conduct themselves in an ethical manner. For electrical engineers, this means ensuring safety above all else, no matter the cost or consequences. Electrical engineers need to be honest in their dealings with people, provide information that is accurate to the best of their knowledge, give credit to others for their work and contributions, treat everyone equally, make people aware of factors that could cause harm, and much more.

"Success comes from curiosity, concentration, perseverance and self-criticism."
—Albert Einstein

Electrical engineers often work with people from a wide variety of backgrounds and must have strong teamwork skills. An electrical engineer might serve on a design team with other engineers, technicians, electricians, financial experts, and others. The same skills that make you an effective team member may also help you get hired as an engineer. Employers are looking for engineers with strong teamwork skills.

Electrical Engineering Principles

There are a number of basic electrical concepts that are fundamental to the job of electrical engineer. Electrical engineers must know what electricity is, how it is created, how it is transmitted

Figure 11-2. FrameStock/Shutterstock.com
Electrical engineers belong to the professional association called the Institute of Electrical and Electronics Engineers.

and controlled, how it is changed into a form of energy that meets human needs and wants, and, most importantly, how to deal with electricity in a safe manner.

Electricity on the Atomic Level

To understand ***electricity***, or the movement of electrons, it is important to first understand the atom. All matter is made up of microscopic building blocks called ***atoms***, which are like microscopic models of our solar system. The planets in our solar system orbit around the sun. In much the same way, atoms are made up of electrons, protons, and neutrons. Negatively charged subatomic particles called ***electrons*** orbit around a nucleus, which is made up of positively charged ***protons*** and electrically neutral ***neutrons***. **Figure 11-3** shows a diagram of an atom.

Most atoms have an equal number of protons and electrons, which makes them electrically neutral. Under normal circumstances, these atoms are stable. When an outside force like energy is introduced to an atom, it becomes excited. If the atom becomes excited enough, it can lose electrons from its outer ring, which is called the ***valence shell***. ***Ions*** are electrically charged atoms. Atoms that gain an electron take on a negative charge and become negative ions. Atoms that lose an electron take on a positive charge and become positive ions. The fewer the electrons in the valence shell, the more easily an atom can share electrons. The concept of electrons moving from one atom to another is critical to understanding electricity.

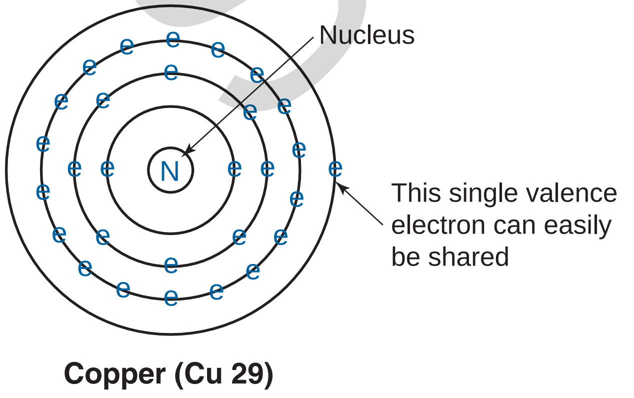

Figure 11-3. *Goodheart-Willcox Publisher*
This atom shows the electron shells around a nucleus.

Static Electricity

Static electricity is the excess of charge on the surface of an object. Have you ever dragged your feet on the carpet or gone down a plastic slide and then gotten a bit of a shock when you touched something metal, such as a doorknob? If so, you have seen static electricity in action. As you rub against the carpet or slide, you develop a charge. The charge is neutralized when you touch a material capable of conducting electricity.

Static electricity has many industrial applications. One of the most popular applications is the electrostatic precipitator, which can be used to remove particles from the air. See **Figure 11-4**.

Particles are charged on their way in, and the collection plates are given an opposite charge. The particles then stick to the plates.

Electricity through a Conductor

Electricity usually flows through a solid piece of material called a ***conductor***. Copper, in the form of copper wire, is the most commonly used conductor. There are two theories of electrical current flow: conventional current flow theory and electron flow theory. The conventional current flow theory states that electrical current flows from positive to negative. Electron flow

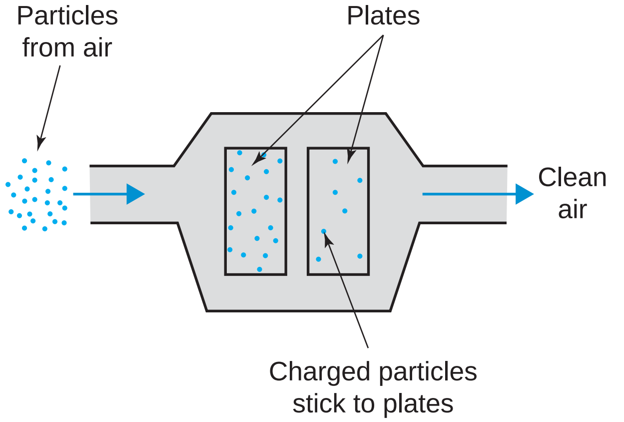

Figure 11-4. *Goodheart-Willcox Publisher*
This schematic of an electrostatic precipitator shows how particles are filtered from the air using static electricity. ***Can you think of applications for electrostatic precipitators around your school or in an industrial setting?***

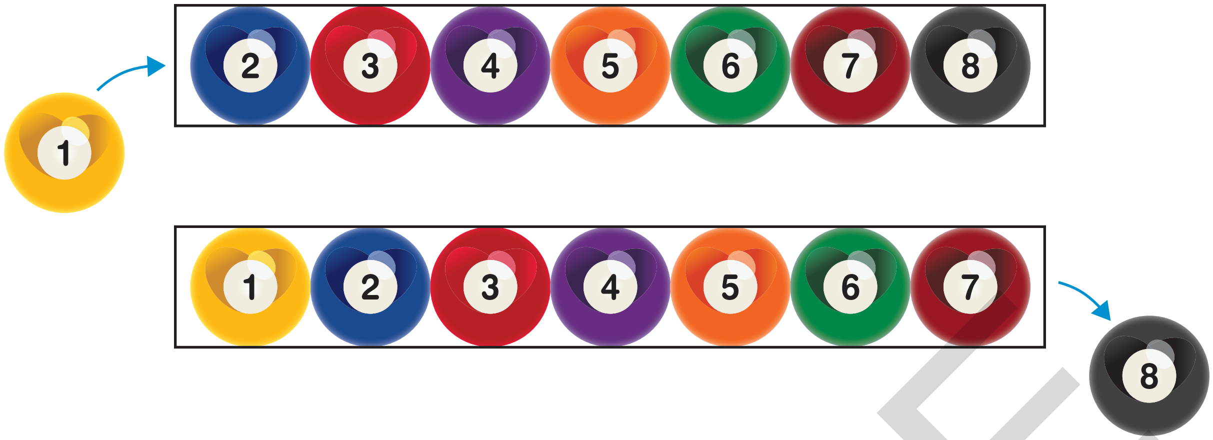

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Figure 11-5.
When a ball is pushed into one end, a ball comes out the other end immediately. Each ball in the tube moved a short distance, but the effect was that one ball moved very quickly.

theory states that electrons flow from negative to positive because the negatively charged electrons are attracted to the positively charged protons. Individual electrons in the conductor move almost as slowly as the minute hand on a clock. The effect of electricity (rather than actual electricity) moves at the speed of light, which is roughly 186,000 miles per second. It is the effect of electricity flowing because the copper wire is full of electrons. When one electron is added to one end, it pushes on all of the electrons in the wire until one pops out the other end. Each electron only moves a tiny bit inside the wire, but the effect is as if an electron flowed all the way through from one end to the other. Think of a long tube full of balls. If you push a ball in one end of the tube, a ball immediately comes out of the other end. Your ball does not travel the entire length of the tube. Each ball moves a little bit, which makes it seem like your ball instantly comes out the other end. See **Figure 11-5**.

Sources of Electricity

You may have wondered where the electricity comes from to power your lights at night or to operate the *International Space Station*. Sources of electricity include magnetism, chemical action, and solar cells. In each case, some form of energy is converted into electrical energy. The ***law of conservation of energy*** states that energy cannot be created or destroyed. It can only be converted from one form to another.

Magnetism

Most electricity is produced using electric generators. ***Generators*** produce electricity by changing mechanical energy to electrical energy. When a magnet passes by a wire, a small amount of voltage is induced in that wire. Voltage is the electrical force that causes electrons to move. The action of producing voltage in a wire this way is called *induction*. As a generator turns, a conductor is passed across invisible lines of magnetic force that surround magnets called magnetic lines of flux, and a current is induced in the conductor. See **Figure 11-6**.

In coal, nuclear, and natural gas power plants, tremendous amounts of steam are generated. This steam is used to turn massive turbines, creating rotary motion that spins a generator. In

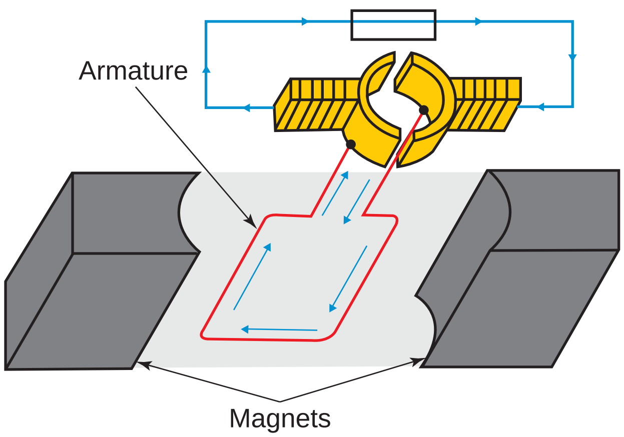

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Figure 11-6.
This simple generator produces electricity by changing mechanical energy to electrical energy.

Science

Magnetism

Magnets are important in electrical engineering because they are used to generate electricity. A magnet is usually made of iron, steel, or a mixture of metals. A magnet contains polarities. Polarity describes the direction of a magnetic field. The magnetic field is strongest at a magnet's poles, each in the direction opposite of the other. A magnet has two poles. Earth is considered a magnet with two poles: north and south.

Every magnet has two poles. If you cut a magnet in half, each piece would then have two poles. Like poles repel each other, while opposite poles attract. For example, the north pole of one magnet will attract the south pole of another magnet. However, the north poles of two magnets will push away from each other.

Every magnet has a magnetic field created by its poles. A stronger magnetic field is created between two magnets with opposite poles. The field surrounds the magnets and pulls them closer together. The magnetic fields of two magnets with similar poles are different. Because the magnets repel each other, their magnetic fields stay as they are.

hydroelectric dams, falling water is used to turn turbines. These turbines then turn generators. In wind farms, turbine blades are turned by the wind to create rotary motion for the generator.

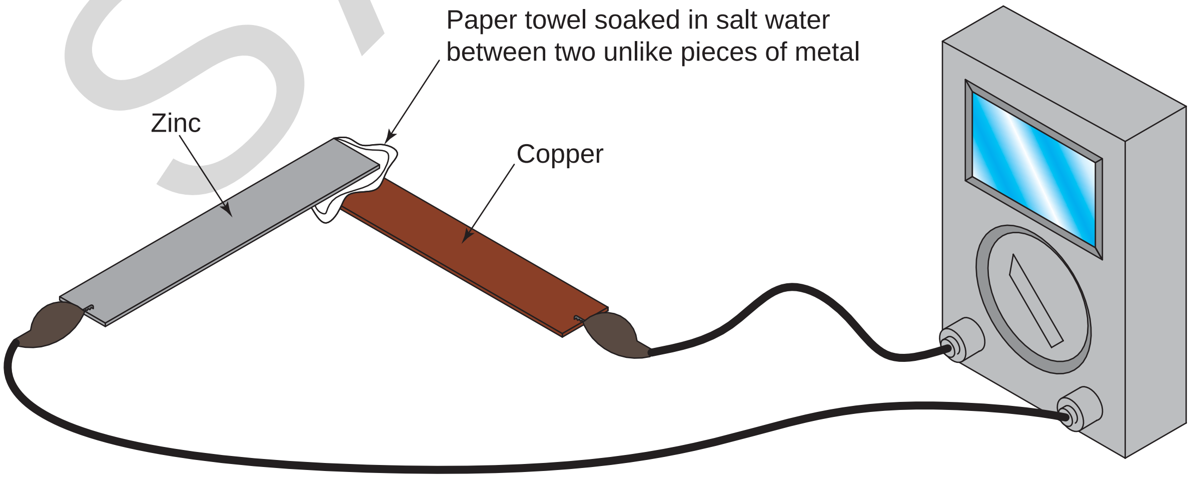
Chemical Action

Cells create electrical energy using a chemical action. A ***battery*** is an electrical connection of two or more cells. An ***electrode*** is a solid conductor through which electricity enters or leaves a medium. When two electrodes made of different materials are placed in an electrolyte, electrons gather on the negative terminal and a voltage builds up between the electrodes. The electrolyte acts chemically on the electrodes and conducts electrons between the electrodes. Disposable batteries are called ***primary cells,*** and batteries that can be recharged are called ***secondary cells***.

Making a cell can be as simple as soaking a paper towel in salt water and placing it between two unlike pieces of metal. A very small voltage can be read between the metals. **Figure 11-7** shows a very simple cell that you can make.

Solar Cells

Solar cells use light to create electricity. Inside a solar cell, a layer of positive semiconductor material is sandwiched together with a layer of negative semiconductor material. Semiconductors, such as silicon, have conductive properties between those of conductors and insulators. When light shines on the cell, some of the light energy is absorbed. This energy knocks electrons loose, and they begin to flow in the form of electrical current. Many small cells can be connected to power devices like calculators, satellites, and even entire houses. See **Figure 11-8**.



Goodheart-Willcox Publisher

Figure 11-7.
This is a basic cell. Unlike metals are separated by a paper towel soaked in salt water.

Figure 11-8. Ivonne Wierink/Shutterstock.com
Solar cells can be used to power several different types of devices, such as a navigational buoy. ***What are the benefits and limitations of generating electricity from solar cells?***

Characteristics and Measurements

Once electricity is generated, it has certain characteristics that electrical engineers use in a number of different ways. It is important for electrical engineers to understand these characteristics and how to measure them.

Voltage

Voltage is the amount of pressure causing the flow of electrons, which is expressed as electromotive force (EMF). Voltage is also known as potential difference because it describes the difference in charge from one place to the other. A higher voltage will cause more electrons to flow. The letter *E* is often used as an abbreviation for voltage and stands for electromotive force. Voltage is measured in ***volts***. The abbreviation for volts is the letter *V*. Typical wall outlets in a house provide 120 V, while a battery used to power a flashlight might provide 1.5 V.

Current

Current is a measure of the flow of electrons per unit time. To understand current, you must first understand ***coulombs***, which is a measure of the amount of electricity. One coulomb is equal to 6.24×10^{18} electrons. The term *amperage* is also used to describe current.

When discussing the flow of electrons, it is important to include time. As an example, let's say 100 students walked down the hall in front of your classroom. That does not mean much to you unless you know the time frame. Did it take all day for 100 students to pass by? Would it mean more if it were 100 students in two minutes?

One ampere, or amp, is the measurement of one coulomb of charge passing a point in one second. The letter *I* is used as an abbreviation for current because it stands for intensity. Current is measured in amps. The letter *A* is used as an abbreviation for amps. For example, a common 100-watt lightbulb draws about 0.83 amps.

Polarity refers to the positive or negative condition at the power supply terminal. Sometimes polarity is constant and current flows in only one direction. This is called ***direct current (dc)***. Sometimes the polarity changes back and forth from positive to negative, causing current to go back and forth. This is called ***alternating current (ac)***. Batteries supply direct current. A battery-operated

Did You Know?

In the 1880s, Thomas Edison and Nikola Tesla argued over whether alternating current or direct current electricity would be better to power the country.

Math

Scientific Notation

It is very common to encounter extremely large and small numbers when working with or studying electricity and electronics. Sometimes numbers are too large or small to be conveniently written. They can be represented using scientific notation. The base number in scientific notation is a number from 1 to 9 and is multiplied by a power of 10.

For example, 7×10^3 (seven times ten to the third power) is $7 \times 10 \times 10 \times 10 = 7{,}000$. The *3* is an exponent. Exponents show how many times to use the number in multiplication. Positive exponents are used for numbers larger than the base number, and negative exponents are used for numbers that are smaller than the base number.

For example, imagine you want to represent five megawatts using scientific notation. The metric prefix *mega-* refers to million. Therefore, you are trying to show 5,000,000 watts. That can be shown as $5 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$. Using scientific notation, it is 5×10^6 watts.

The metric prefix *milli-* is used to show thousandths of a base number. For example, seven milliamperes is seven thousandths of one ampere, or 0.007 amperes. Using scientific notation, this is shown as 7×10^{-3}. The exponent is *–3* because the decimal place moves to the right three places, from 7 to 0.007.

Figure A shows common metric prefixes and their symbols, decimal values, and values in scientific notation.

Write the following numbers using scientific notation, converting units where necessary.

1. 8,730,000,000 watts
2. 6,270 nanovolts
3. 0.00047 amperes
4. 4,383,000 ohms
5. 2,000 volts
6. 3.2 kilohms

Prefix	Symbol	Value	Decimal
giga-	G	10^9	1,000,000,000
mega-	M	10^6	1,000,000
kilo-	k	10^3	1,000
milli-	m	10^{-3}	0.01
micro-	µ	10^{-6}	0.000001
nano-	n	10^{-9}	0.000000001
pico-	p	10^{-12}	0.000000000001

Figure A. *Goodheart-Willcox Publisher*

flashlight uses dc. The wall outlets in your school provide ac. **Figure 11-9** shows the difference between ac and dc.

Resistance

Resistance is the opposition to current flow. ***Resistors*** are used to limit current flow and divide voltage. All conductors, components, and circuits have some level of resistance. Resistance is measured in ***ohms*** **(Ω)**. The Greek symbol for omega (Ω) is used to represent ohms.

Materials with very little resistance (allow current to flow freely) are conductors. Copper, aluminum, gold, and silver are examples of good conductors. Materials with a very high resistance that do not allow current to flow are called ***insulators***. Plastic, glass, rubber, and paper are examples of good insulators.

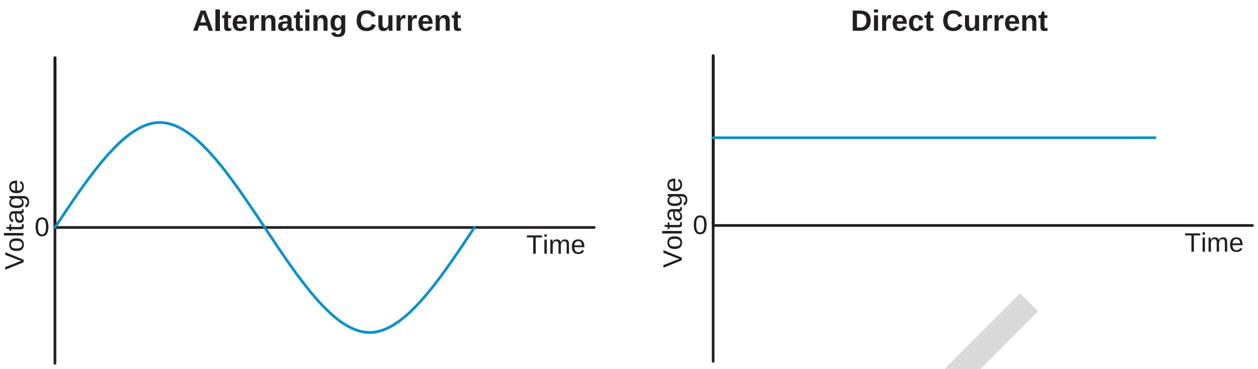


Figure 11-9. *Goodheart-Willcox Publisher*
The ac wave crosses the zero line and changes polarity. The dc wave does not cross the zero line. ***If voltage fluctuates, but does not cross the zero line and change polarity, is it still dc?***

A standard kitchen faucet can help you understand the relationship between current, voltage, and resistance. Think of the water pressure as voltage, the amount of water flowing as current, and the faucet handle as providing resistance. In this example, the water pressure (voltage) remains constant as it is supplied from the water system. If the water is turned on as far as possible, there is very little resistance from the faucet and, therefore, very high flow (current). By slowly turning the faucet handle, resistance is increased and flow (current) is decreased. This example shows that if voltage is held constant, current and resistance are inversely proportional. If resistance increases, current decreases. If resistance decreases, current increases.

Power

Power can be defined as the rate at which work is done or the amount of work done based on a period of time. Electrical power can be defined as the product of voltage and current. The ***watt*** is the unit of electrical power. It is named for the inventor of the steam engine, James Watt. One watt is the measure of one volt moving one coulomb of electricity in one second.

Laws

Ohm's law is the relationship between resistance, current, and voltage in electrical circuits. This law is one of the most important concepts to master in the field of electrical engineering because it will be used more than any other. Ohm's law was named for a nineteenth century German physicist named Georg Ohm. He discovered that if he kept resistance constant and varied voltage, dividing the voltage by the current always equaled the resistance. This formula can be used to solve for any of the three variables:

$$R = E/I$$
$$I = E/R$$
$$E = I \times R$$

For example, let's say you want to calculate the resistance of a flashlight bulb. You know that your batteries are providing 3 V and you are drawing 0.1 A (or 100 milliamps) of current flow.

Use the following formula:

$$\begin{aligned} R &= E/I \\ &= 3\text{ V}/0.1\text{ A} \\ &= 30\ \Omega \text{ of resistance} \end{aligned}$$

The handy reminder in **Figure 11-10** can be used to find all three formulas. If you place your finger over the quantity you are looking for, you will see the necessary formula. For instance, cover the *R* with your finger and you will see *E*/*I*.

Watt's law states that power equals effort multiplied by rate. This can be expressed using the following formula:

$$P = I \times E$$

Using this formula, you can find any one of the three values when two are known. Let's say you wanted to know how much current was flowing through a 100-watt incandescent lightbulb in your

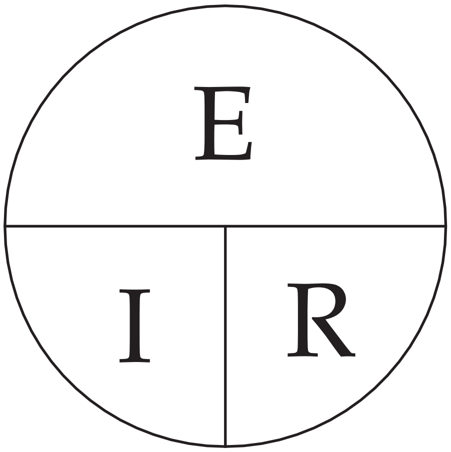


Figure 11-10. Goodheart-Willcox Publisher
This diagram can help you remember the three formulas related to Ohm's law.

home. You know that the supply voltage is 120 V and the bulb is rated for 100 W.

You would use the following formula:

I = P/E
= 100 W/120 V
= 0.84 A of current flowing through the lightbulb

An electric bill is calculated in kilowatt-hours, or thousands of watt-hours. If you take the wattage used times the number of hours it was used, you can find the watt-hours. Let's say you turn on a 100-watt lightbulb for ten hours.

100 watts × 10 hours = 1,000 watt-hours = 1 kilowatt-hour

As an example, if you are being charged 15 cents per kilowatt-hour by your local power company, it costs 15 cents to operate that 100-watt lightbulb for 10 hours.

Applications

Electrical engineers use their knowledge of the characteristics and laws of electricity to design applications for its use. The applications utilize circuits and electrical components.

Basic Circuits

The most basic circuit consists of a power source, a load (device that uses the electricity), and conductors to connect them. Electrical circuits can be designed in three ways: series, parallel, or series-parallel. Electrical engineers must understand these circuits in order to understand, design, build, and troubleshoot electrical devices. Each circuit has unique benefits and drawbacks for given situations.

Series Circuits

Series circuits have only one path for current to flow from the power source through the circuit and back to the power source. Current leaves the power source, flows through all loads in the circuit, and goes back to the power source.

Holiday light strings are a good example of series circuits. The current in these lights runs through each individual light and back to the power source. If one light burns out, every light in the string turns off due to that one open in the circuit. **Figure 11-11** shows a schematic drawing of lights wired in series.

Voltage in a series circuit is equal to the sum of the voltage drop across each load in the circuit. The voltage drop across each load varies in proportion to its resistance, but the sum of all drops equals the applied voltage. Use a string of 60 holiday lights wired in series as an example. They would be plugged into a common 120 V household electric outlet. To find the voltage drop across each light, divide 120 V by 60 lights. There is a voltage drop of 2 V across each light.

This can be expressed as:

$$E_t = E_1 + E_2 + E_3 + \ldots + E_N$$

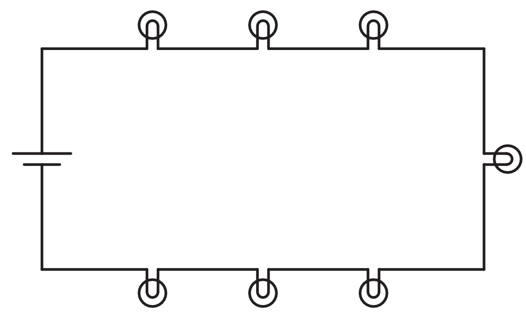


Figure 11-11. Goodheart-Willcox Publisher
This is a typical series lighting circuit. Current must pass through all seven incandescent lamps in this example.

Total resistance in a series circuit is equal to the sum of the resistance of each individual load. For example, picture three resistors wired in series. Their values are 10 Ω, 20 Ω, and 30 Ω. The total resistance in the circuit is the sum of all resistances, or 60 Ω. This can be expressed as:

$$R_t = R_1 + R_2 + R_3 + \ldots + R_N$$

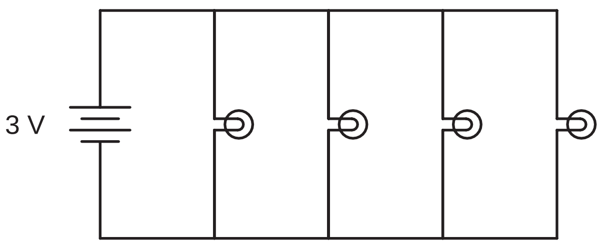
Current is constant throughout a series circuit. Think of water flowing through a garden hose. Whatever flow goes into one end of the hose will flow through and come out the other end. This is the same in electricity. In the previous example, the three resistors have a total resistance of 60 Ω. If they are connected to a 120 V power source, there will be 2 A (120 V/60 Ω = 2 A) of current flowing at every single point in the circuit. No matter where the current is tested, it would read 2 A. This can be expressed as:

$$I_t = I_1 = I_2 = I_3 = \ldots = I_N$$

Parallel Circuits

Parallel circuits have more than one load and have multiple paths for current flow. Each path is a branch and contains one load. Current is divided between the branches in proportion to the resistance of the load in each branch. In other words, the branch with the lowest resistance will have the highest current flow. The voltage across the load in each branch is equal to the source voltage.

Many modern holiday lights are wired in parallel. Each light is wired into its own branch in the circuit. If one light burns out, only that light turns off and the rest stay lit. **Figure 11-12** shows a typical parallel lighting circuit.



Goodheart-Willcox Publisher

Figure 11-12.
This is an example of a typical parallel lighting circuit.

Voltage in a parallel circuit is the same across each load as it is at the source. All loads get the total source voltage. Think of your home as an example. Numerous receptacles and lights might be on the same circuit, but they all get 120 V. Voltage in a parallel circuit can be expressed as:

$$E_t = E_{R_1} = E_{R_2} = E_{R_3} = \ldots = E_{R_N}$$

In a parallel circuit, the sum of all branch currents equals the total current in the circuit. In other words, to find the total current in a circuit, add all of the branch currents together. Current in a parallel circuit can be expressed as:

$$I_t = I_{R_1} + I_{R_2} + I_{R_3} + \ldots + I_{R_N}$$

Resistance in a parallel circuit is a bit more complicated. The total resistance in a parallel circuit is always lower than the lowest branch resistance. Adding more branches to a parallel circuit causes the total resistance to decrease. Resistance in a parallel circuit can be expressed as:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N}}$$

Series-Parallel Combination Circuits

Series-parallel combination circuits are not simply series or parallel. They are a combination of both types of circuits. Therefore, the rules and formulas for solving a series or parallel circuit cannot be used. In order to study a series-parallel circuit, the parallel parts must be broken down and studied as if they were series elements. **Figure 11-13** shows a series-parallel circuit with three lights where the first light is in series and the other two lights are in parallel. The light in series would be much brighter because it receives roughly twice the current of each of the other two.

"Scientists study the world as it is; engineers create the world that has never been."

—Theodore von Karman

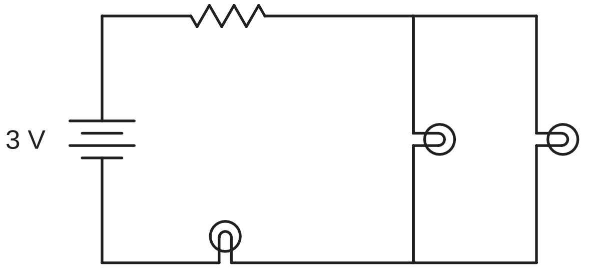


Figure 11-13. Goodheart-Willcox Publisher
This schematic shows a series-parallel lighting circuit. ***Will all three bulbs in this circuit have the same brightness?***

Circuit Components

Electrical engineers must fully understand each component that can be used in a circuit. Electrical engineers often design, build, and troubleshoot electrical circuits. They must know how each component of the circuit works so they can select the best parts to solve a given design problem or troubleshoot a circuit that is not working properly.

Conductors

Conductors provide a path for current to flow to the parts that will control and use it. Materials with very low resistance are conductors. They easily share electrons from one atom to the next when a charge is applied. Copper is the most common conductor. Aluminum is not quite as good as copper, but is lighter and less expensive. Aluminum is often used in thick service entrance cables that bring electricity into houses. Silver and gold are better conductors than copper and aluminum, but are only used in very specific applications due to their cost.

Conductors come in a wide variety of configurations. They can be solid wire, stranded wire, ribbon, and bar shapes based on their intended use. For example, solid copper wire is commonly used in residential wiring because it does not need to move once it is installed. If a solid conductor is bent back and forth too many times, it will break like a paper clip that is bent repeatedly. Stranded copper wire is used in extension cords because it bends easily and will not break when bent repeatedly.

Conductors are sized based on their cross-sectional area. The size of round conductors is determined using the ***American Wire Gauge (AWG) system***. In the AWG system, smaller numbers represent larger wire. For instance, 12-gauge wire is larger than 30-gauge wire. 14-gauge wire is commonly used in houses for general lighting and receptacle circuits. **Figure 11-14** shows common wire types.

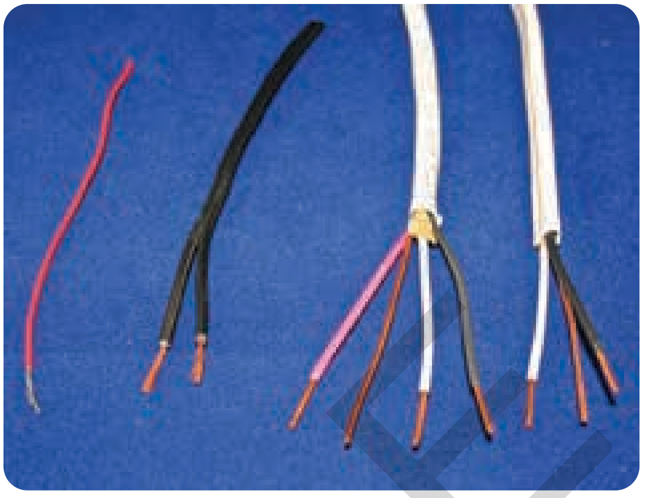


Figure 11-14. Goodheart-Willcox Publisher
Common solid, stranded, one-conductor, two-conductor, and three-conductor wire types are shown.

Control Components

Control devices direct and/or limit current flow so a circuit meets its desired function. For example, insulators keep current in the conductor and protect against shorts, and resistors limit current flow to protect sensitive components.

Insulators

Materials with extremely high resistance that do not conduct electricity under normal circumstances are insulators. The most commonly used insulators are plastic, glass, paper, rubber, and mica. Insulators are used to keep electricity confined to the desired circuit path and away from people and other parts of the circuit. A short circuit can be defined as an undesired path to ground. In a short circuit, electricity is able to neutralize its charge without having to flow through the load. Without the resistance provided by the load, current increases dramatically, which can cause a fire or other damage.

Resistors

The resistor is one of the most common and reliable electrical components. Resistors are used to limit current flow and divide voltage in a circuit.

Resistors come in a variety of sizes, shapes, and configurations. Most are made from carbon. Resistors are available in values ranging from less than one ohm to many millions of ohms.

A system of color-coding resistors with their values was developed because it is not always possible to print values on very small resistors. Resistors typically have three or four (sometimes five) color bands. The first two colors represent digits. The third band is the multiplier and tells what power of ten the digits should be multiplied by. The fourth band is the tolerance, which indicates the accuracy of the resistor value. If there is no fourth band, a 20% tolerance is assumed. On a five-band resistor, the first three are digits, the fourth is the multiplier, and the fifth is the tolerance.

Refer to the resistor color code chart in **Figure 11-15**. Think of a resistor whose color bands from left to right are green, blue, brown, and silver.

The first two colors represent digits. The digit for green is 5 and the digit for blue is 6. Place these two numbers next to each other and you have 56. The third band is the multiplier and in this case it is brown, which has a value of 10.

So, now we have $56 \times 10 = 560$. This is referred to as a 560 Ω resistor.

The fourth band is the tolerance and in this case it is silver, which has a value of 10%. This means that the measured value of this resistor could be 10% above or below 560 Ω.

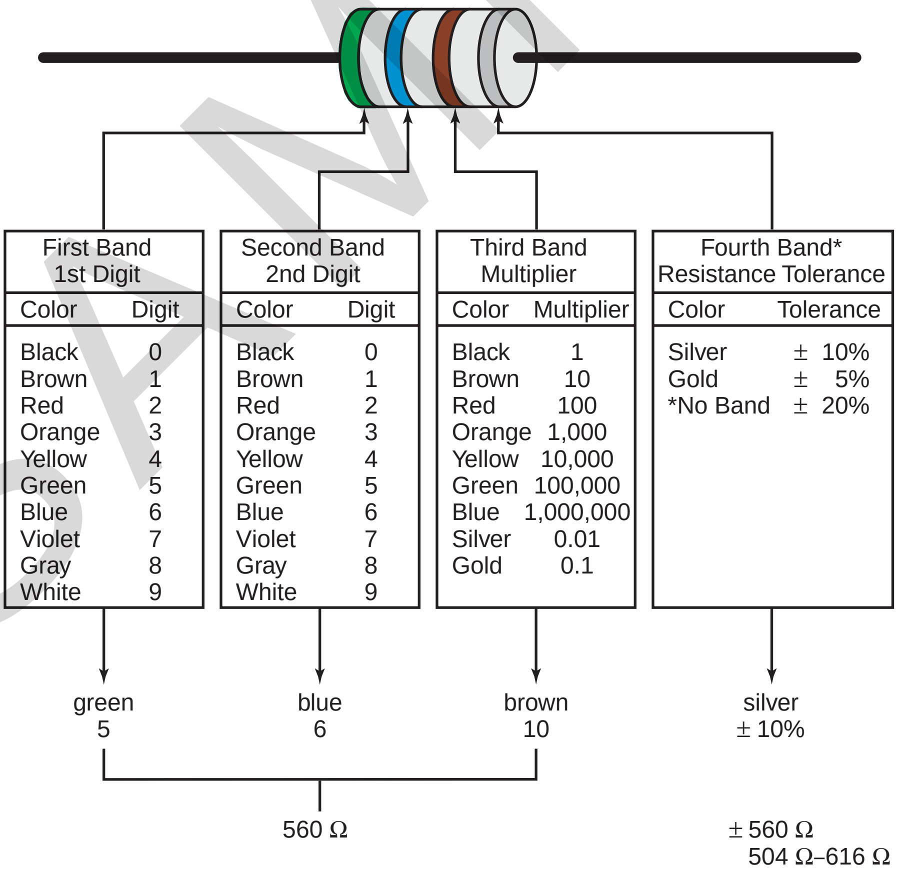
In order to find 10% of 560, do the following:

$$560 \times 0.1 = 56$$
$$560 - 56 = 504$$
$$560 + 56 = 616$$

The measured value of this 560 Ω resistor with a 10% tolerance could be anywhere between 504 Ω and 616 Ω.

Variable Resistors

At times, such as in dimmer switches and fan speed switches, it is important to vary the amount



Goodheart-Willcox Publisher

Figure 11-15.
This resistor color code chart shows the numerical values and tolerances for resistor color stripes.

of resistance. In these situations, resistors whose resistance can be changed, known as ***variable resistors***, are used. Variable resistors have two terminals and a wiper, which is a knob or a sliding switch. As the wiper moves along a piece of resistive material, usually carbon, the amount of resistive material between the terminals changes, and so does the resistance. An arrow on the schematic for a variable resistor indicates that its value is variable. **Figure 11-16** shows common variable resistors.

Switches

Switches are used to control the flow of electricity in a circuit. They open and close (turn off and on) the circuit **or** direct the flow of electricity into a different circuit. Switches come in a wide variety of configurations to meet the specific needs of each application. Switches are characterized by the type of switch, the number of poles, and the number of throws. The number of poles indicates the number of paths for current flow into the switch. The number of throws indicates the number of paths leaving the switch. A single-pole single-throw (SPST) switch has one path for current flowing in and one path flowing out. This switch can only turn the current on or off to one circuit. For example, a switch on a lamp is usually a SPST switch. A single-pole double-throw (SPDT) switch can direct the current in one direction or the other. A common use for the SPDT switch is a lighting circuit where a light can be turned on or off from two different locations. In **Figure 11-17**, a light can be turned on or off from each of two SPDT switches.

Goodheart-Willcox Publisher

Figure 11-16.
These are common variable resistors. ***What are a few variable resistors you commonly encounter in buildings, in vehicles, or on devices?***

Diodes

Standard ***diodes*** are designed to allow current flow in only one direction. They can be used as rectifiers to change alternating current to direct current. Diodes have two electrodes called the *anode* and the *cathode*. The anode is made of a positive (P-type) semiconductor material and the cathode is made of a negative (N-type) semiconductor material. For the diode to allow current to flow, the correct polarity must be applied. Polarity is the condition of being positive or negative with respect to ground. The negative power supply terminal must be connected to the cathode (–)

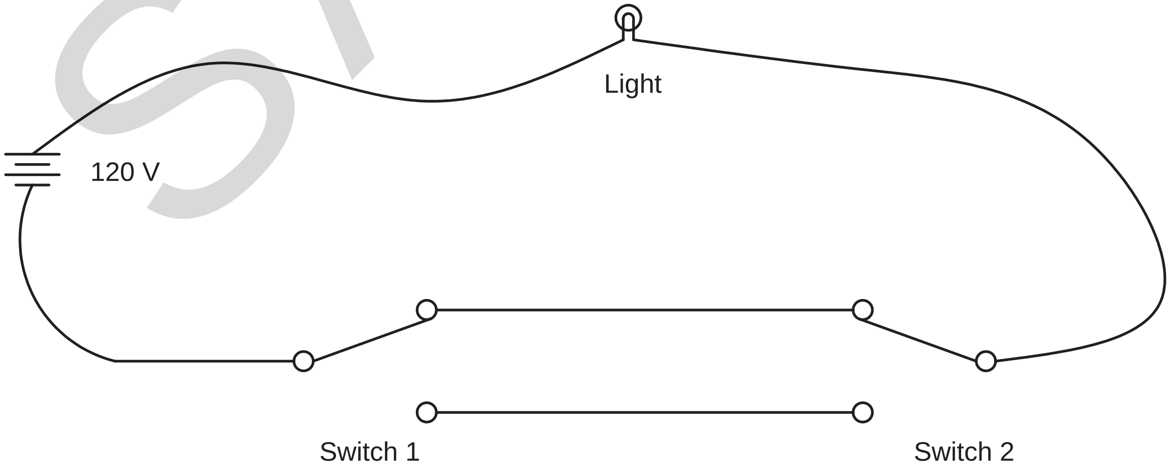


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Figure 11-17.
In this example, a light can be controlled from either of the two single-pole double-throw switches. ***Can you think of a lighting circuit in your home or school that is switched from more than one location?***

Design

Schematics

When drawing electrical circuitry, it is much easier to use simple symbols for parts than it is to draw pictures. These basic symbols are called ***schematic symbols***. A ***schematic diagram*** is a basic sketch of circuitry showing schematic symbols for parts and lines to represent conductors. Using a schematic diagram, electrical engineers can build or troubleshoot complex circuitry. Electrical engineers also use schematic diagrams in the circuit design phase. **Figure A** shows schematic symbols for common electronic components.

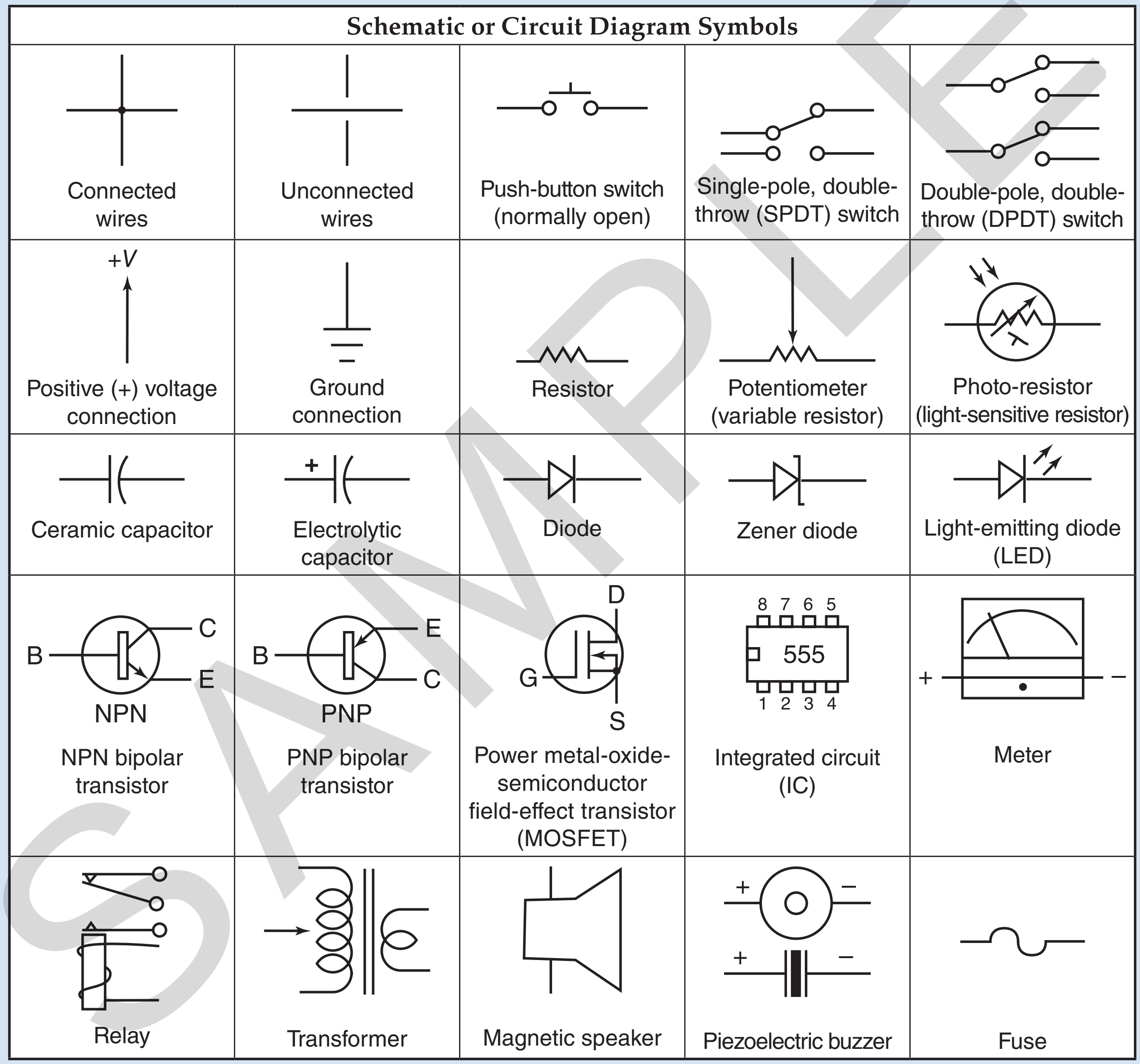


Figure A.

Goodheart-Willcox Publisher

and the positive terminal must be connected to the anode (+). This is called *forward bias*. Current will flow in forward bias. If the negative power supply terminal is connected to the anode and the positive to the cathode, a reverse bias condition would exist. Current cannot flow in reverse bias. See diodes being used in a bridge rectifier in **Figure 11-18**. Bridge rectifiers change ac to dc.

Zener Diodes

Zener diodes conduct electricity in reverse bias. They block current until the voltage reaches

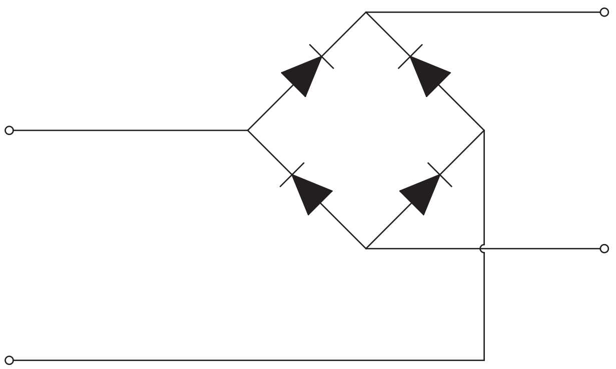


Figure 11-18. Goodheart-Willcox Publisher
Schematic of a bridge rectifier, which converts ac to dc.

a certain level. Once this level is reached, zener diodes conduct and help to keep the voltage at a constant level. Because of this characteristic, they are often used as voltage regulators, which help smooth out variations in voltage.

Transistors

Transistors can be used as solid-state switches and as amplifiers. They are called *solid-state switches* because they perform a switching function with no moving parts. Bipolar transistors have three junction points: emitter, base, and collector. Current flowing between the emitter and collector can be controlled by a current delivered to the base. Transistors can also be used as amplifiers. Amplifiers increase the power of a signal, most commonly an audio signal. A small amount of current applied to the base can create a gain in collector/emitter current. **Figure 11-19** shows a PNP and an NPN transistor.

Capacitors

Capacitors have the ability to store and discharge electricity very quickly. They store much less electricity by volume than a battery, but they can discharge and recharge much more quickly. Capacitors can smooth out (filter) variations in voltage and can block continuous dc flow while allowing pulses to pass. Capacitors smooth out variations in voltage by absorbing the spikes and filling in the valleys. For example, the internal

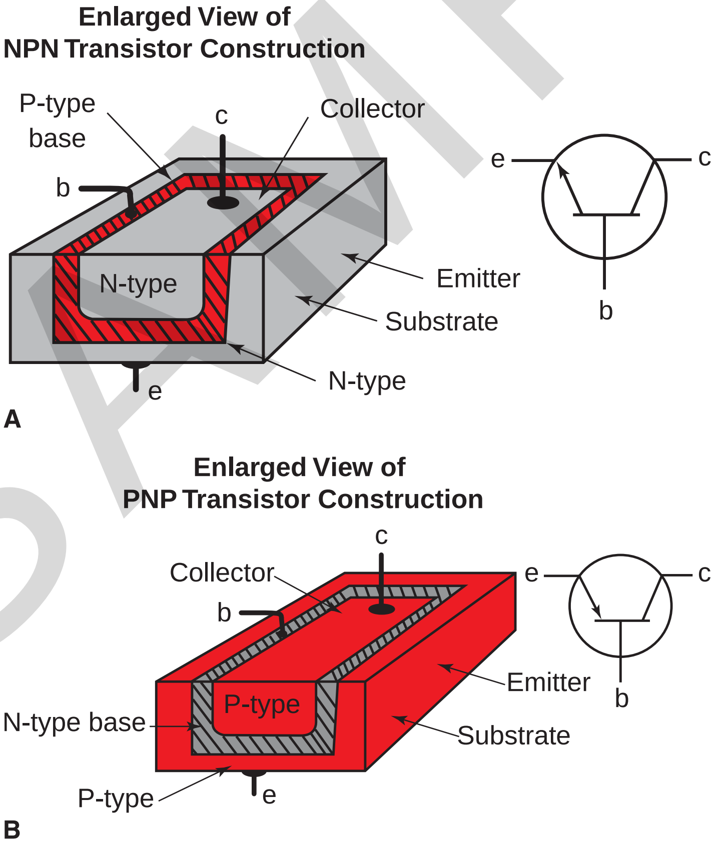


Figure 11-19. Goodheart-Willcox Publisher
Bipolar transistor construction and schematic symbols are shown. The three junction points are the emitter (e), the base (b), and the collector (c). A—An NPN transistor. B—A PNP transistor.

History

Electrical Engineering in History

Many people have contributed to the development of batteries throughout history, but one man's contribution stands above the rest. An Italian physicist named Alessandro Volta is credited with inventing the battery. A colleague of Volta, Luigi Galvani, discovered that a dead frog's leg would twitch when the nerves were touched with unlike metals. He believed that the animal tissue contained a cell potential, which he called animal electricity.

Alessandro Volta expanded on Galvani's discovery by demonstrating in 1791 that electrical current can be produced by layering unlike metals (copper and zinc) with cardboard or cloth soaked in salt water. He later piled up numerous layers of unlike metals (like cells wired in series) to create more current. This is called the *voltaic pile*, and it was the first battery capable of providing sustained electrical current.

Volta discovered that he could measure the difference in charge, or electromotive force, from the top of the stack to the bottom. The measurement unit *volt* is named for him.

workings of computers require dc, but wall outlets supply ac. Inside of computers, ac is rectified, or changed, to dc. This dc voltage can vary a great deal. Capacitors are used to smooth out or filter the voltage.

There is a wide variety of capacitors, but ceramic disc and electrolytic are the most common. See **Figure 11-20**. Both work the same way, but electrolytic capacitors can hold much more charge.

A capacitor is made up of two conductive plates separated by a thin layer of insulation called a *dielectric*. When a capacitor is connected to a power source, current will flow for a short period of time until the negative plate has gained enough electrons to reach saturation. This negative charge repels electrons from the opposite plate, causing it to take on a positive charge. See **Figure 11-21**.

Capacitors can maintain a charge long after the power source is removed. When working with capacitors, it is important to treat them as if they are charged and capable of delivering a shock.

Integrated Circuits (ICs)

An ***integrated circuit (IC)*** consists of multiple electronic circuits etched into a thin layer of silicon and enclosed in a protective material like

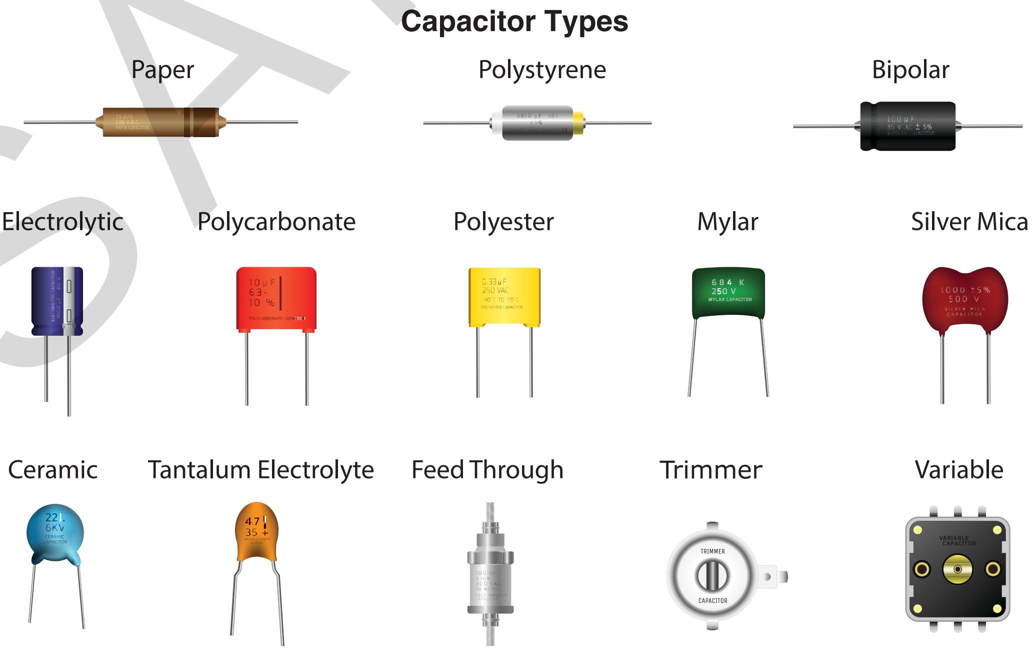


Figure 11-20.
Capacitors are available in many different styles.

BLKstudio/Shutterstock

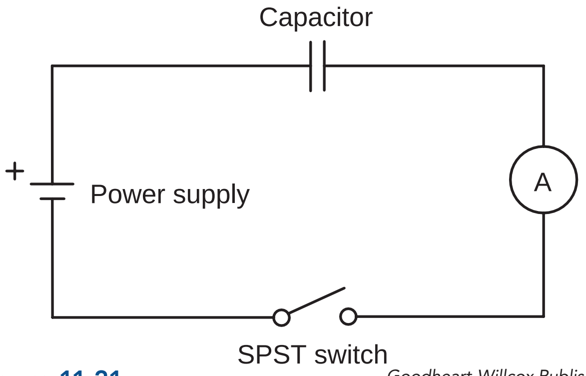


Figure 11-21. Goodheart-Willcox Publisher
When the switch is closed, the ammeter will read some current flow until the capacitor reaches saturation.

Figure 11-22. MNI/Shutterstock.com
It is important to take antistatic precautions when working with ICs because they are very sensitive to charge buildup. One type of precaution is this antistatic wrist strap.

plastic. A dot or notch on the outside of the chip is used for orientation. ICs contain resistors, capacitors, diodes, transistors, and the conductors to connect the circuits. Some ICs are very sensitive to static electricity, or charge buildup. It is important to take antistatic precautions when working with these ICs. See **Figure 11-22**.

One of the most common ICs is the 555 timer. It includes 23 transistors, 2 diodes, and 16 resistors. The 555 timer has literally thousands of applications. The 555 can be connected in a circuit in one of two ways: monostable or astable. When used in monostable mode, it creates an output for a given period of time. Think of a seat belt indicator on a car's dashboard that turns on to tell the driver to use the seat belt, but turns off after a given period of time. The 555 timer can also be used in astable mode, where a repetitive pulse is created. An example of this could be the repetitive buzzing of an alarm clock. **Figure 11-23** shows the 555 timer and its pin diagram.

Semiconductors

Semiconductors are materials with conductive capabilities between that of conductors and insulators. Silicon is the most common semiconductor. Semiconductors are used in items such as transistors, diodes, solar panels, and integrated circuits (ICs).

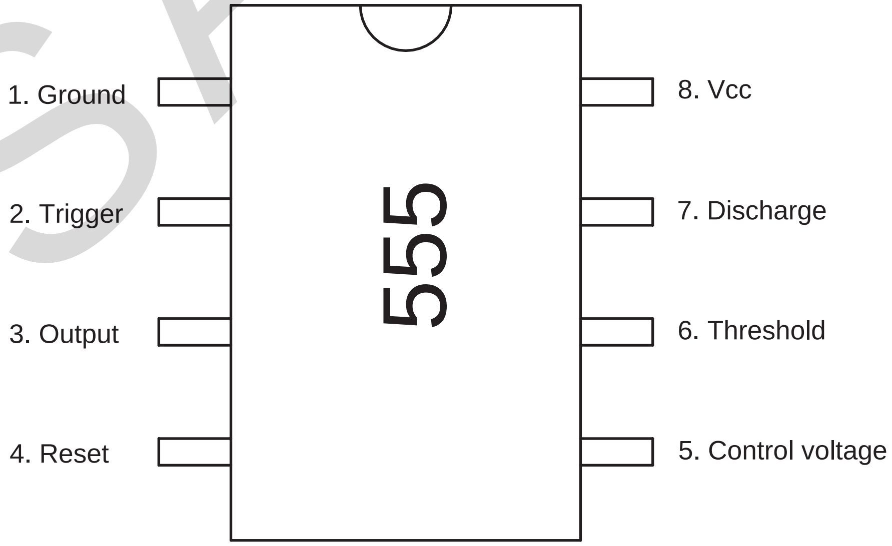


Figure 11-23. Goodheart-Willcox Publisher
This diagram shows a 555 timer and pin configuration.

Sensors

Electronic ***sensors*** create an electrical signal based on environmental conditions. The signal changes as the environmental conditions change. For example, electronic thermostats are used in many homes to tell the heating system when the house has cooled down and it is time to make more heat. Inside the thermostat is an electronic sensor. This sensor can tell what the temperature is in the home and sends that information through an electrical signal to the heating unit.

Control Systems

There are two types of control, or feedback, systems. They are open systems and closed systems. Closed systems include some sort of built-in feedback. Think of the heating system mentioned above. The heating system blows heat into the house and increases the temperature. The sensor provides feedback to the heating unit and tells the unit when the house has reached the desired temperature and it is time to turn off. A dimmer switch on a lighting circuit is an example of an open system. It does not have a mechanism for feedback built-in and relies on a person to manually adjust the light to the desired level. The lights will stay at that level until a person adjusts it.

Output Components

Output components are the parts that use electricity to perform a desired task. For example, a lamp uses electricity to create light and a motor uses electricity to create rotary motion.

Incandescent Lamps

As electrons flow through a conductor, they create friction and, therefore, heat. Some conductors can get very hot. This heat can be used to generate light. An ***incandescent lamp*** creates light when the current flow causes the tungsten filament to get so hot that it glows. The tungsten filament is suspended inside a glass globe. All of the air inside the globe is removed because the oxygen would allow the filament to burn. Sometimes the air is replaced with an inert gas, such as argon. See **Figure 11-24**. Federal energy efficiency legislation has mandated traditional incandescent bulbs be phased out in favor of more efficient devices, such as high-efficiency incandescent, CFLs, and LEDs, which are described below.

Gas Discharge Lamps

In ***gas discharge lamps***, the glass inside the globe is ionized. Electrons are released from their bonds and are free to flow. This causes the gas to glow and create light. Neon lamps are an example of gas discharge lamps, but other gases are also used. A resistor must be placed in series with the light to limit current flow because the resistance of the ionized glass is so low. Gas discharge lamps can create the same amount of light as incandescent lamps, using a fraction of the electricity.

Fluorescent Lamps

Fluorescent lamps consist of a long glass tube coated on the inside with phosphorous and filled with an inert gas. There is also a small amount of mercury. At each end of the tube, there is a filament, which creates a small amount of heat to vaporize the mercury. Passing electrical current through the vaporized mercury produces ultraviolet light, which is invisible to humans. The ultraviolet light causes the phosphorous to glow, creating the light we see. It is important to note that fluorescent lamps use much less electricity than incandescent lamps because incandescent lamps waste so much energy in the form of heat.

Yegor Korzh/Shutterstock.com

Figure 11-24.
This incandescent lamp uses a tungsten filament to create heat, which generates light.

Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) work on the same principle as the fluorescent lamps discussed previously, but are designed to fit into normal light sockets. CFLs use about 75% less energy than incandescent lamps and last up to ten times longer. **Figure 11-25** shows a compact fluorescent bulb. CFLs contain a very small amount of mercury. For this reason, it is best to recycle CFLs rather than throwing them away in the trash. Many waste haulers, power companies, and stores offer CFL recycling. There are also programs that allow you to mail them to a recycler for a fee. Because of the mercury, special precautions must be taken if a CFL breaks.

Light-Emitting Diode (LED) Lamps

Light-emitting diode (LED) lamps are extremely efficient lamps that create light by wiring semiconductor material in a forward biased position. Forward bias is achieved by wiring the negative side of the power supply to the negative (cathode) side of the diode and the positive side of the power supply to the positive (anode) side of the diode. A forward biased direct current is passed through a semiconductor material inside the LED casing, and light is emitted. Since the 1960s, LEDs have been used as indicator lights and in seven-segment displays on devices like digital clocks. As the technology has advanced, they have been used in traffic lights, automobile lights, and flashlights, as well as in a wide variety of household and commercial lighting applications. LED lamps are inexpensive, extremely efficient, and long lasting. Their efficiency and reliability result from the fact that they do not create heat like incandescent bulbs. See **Figure 11-26**.

Figure 11-25. Jonathan Vasata/Shutterstock.com
CFLs can be used to replace incandescent bulbs, using less energy.

Motors

You learned previously how generators convert mechanical energy into electrical energy. ***Motors*** work in the opposite way, changing

Going Green

Energy-Efficient Lighting

US federal lighting standards require lightbulbs to use about 25% less energy than traditional incandescent bulbs. This effectively means traditional incandescent bulbs will no longer be made or sold, except for specialty applications. High-efficiency halogen incandescent bulbs meet the new requirements. CFLs and LED bulbs are the most common replacement for traditional incandescent bulbs. LED bulbs have been gaining in popularity because they last longer and are more efficient than CFLs and they do not contain mercury. Linear fluorescent tubes, like those commonly found in schools, are also required to become more energy efficient. The standards also require that bulbs be advertised by lumens of light emitted rather than wattage, or power consumed. Lumens are the measure of the visible light emitted by a bulb.

High-efficiency lighting is good for our environment because it reduces energy consumption. If less electricity is used, less electricity needs to be generated. Electrical generation stations that burn fossil fuels emit greenhouse gases. Using less electricity means burning less fossil fuels and emitting less greenhouse gases.

The United States Environmental Protection Agency (EPA) recommends that every household replace their five most commonly used lights with ENERGY STAR®-qualified bulbs. This simple step will decrease greenhouse gases equal to that created by about 10 million cars.

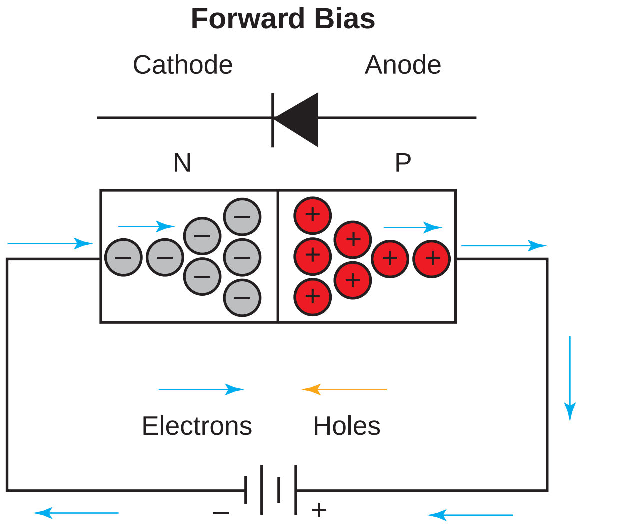


Figure 11-26. Goodheart-Willcox Publisher
A forward biased direct current can pass through a semiconductor material inside an LED casing to produce light.

electrical energy into mechanical energy. Picture an electromagnet between two permanent magnets. The electromagnet spins until its north pole is lined up with the south pole of the permanent magnet and its south pole is lined up with the north pole of the permanent magnet. By this time, the polarity of the electromagnet has reversed, causing it to be repelled from the permanent magnet and attracted to the other side. In this way, the magnet keeps rotating.

Component Platforms

To use the components previously described, they must be linked together on a platform. The most common type of platform used to create circuits is a circuit board. To experiment before soldering the components together, solderless breadboards can be used.

Circuit Boards

Circuit boards are commonly known as printed circuit boards (PCBs). A rigid piece of insulation (typically fiberglass) is used as a platform for circuitry. Thin copper tracks are laid on the insulation, and electronic components are soldered to the track. See **Figure 11-27**.

Solderless Breadboards

Solderless breadboards are ideal for experimentation and testing circuits before they are constructed.

Figure 11-27. Rawpixel.com/Shutterstock.com
Circuit boards contain copper tracks to which electronic components are soldered.

Components and leads can easily be moved from one place to another because no soldering is required to make connections. See **Figure 11-28**.

Electronic Circuit Simulation

Engineers and technicians can now simulate the performance of circuitry using computer software without ever having to build an actual circuit. Engineers lay out the components they would use on the screen, and the software shows them how it would work. See **Figure 11-29.** Simulation software saves time and money by speeding up the design and development process and identifying problems early on.

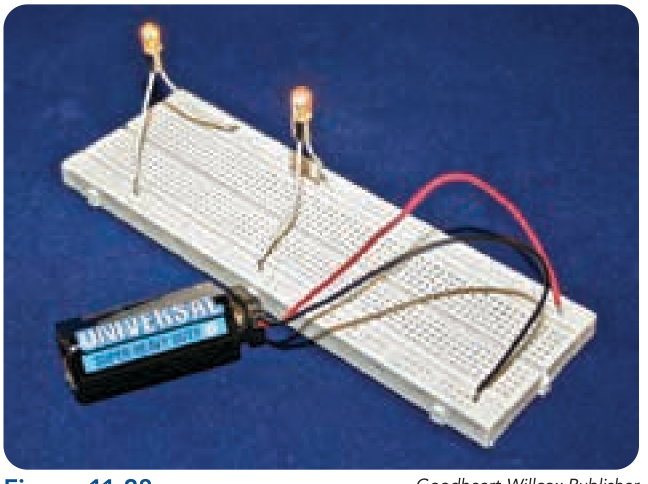


Figure 11-28. Goodheart-Willcox Publisher
Solderless breadboards can be used to experiment with circuits before soldering to make connections.

Figure 11-29. *Gorodenkoff/Shutterstock.com*
These engineers are using 3D CAD software to simulate the performance of an electric concept car. ***How might you be able to use simulation software to test an idea before you physically try it?***

Tools

Meters in Electrical Engineering

Electrical engineers must be competent in the safe and proper use of a wide variety of tools and meters in order to design, build, and troubleshoot electrical circuits and equipment.

Ammeter

Ammeters measure current flow in a circuit in amperes. The circuit must be disconnected so the ammeter can be wired in series and become part of the circuit. Ammeters must be wired in series with the proper polarity. Turn the power off, hook up the meter, and then turn the power back on. Never connect the meter into the circuit with the power on. Never connect an ammeter in parallel with a circuit. Doing so can provide an uncontrolled amount of current to the meter, causing damage to the meter and the circuit or bodily harm to the person holding the meter. When measuring an unknown current, always start on the highest range and work your way down until you get an accurate reading. Measuring values that are too high for the range you are on can damage the meter.

Voltmeter

Voltmeters measure potential differences from one point to another. Voltmeters are always wired in parallel with a device in the circuit. This could be a load or the power source. Always turn the power off, connect the voltmeter, and then turn the power back on before taking a reading. When measuring an unknown voltage, always start on the highest range and work your way down until you get an accurate reading. Measuring values that are too high for the range you are on can damage the meter.

Ohmmeter

Ohmmeters are used to measure resistance in ohms. Always turn off the power and isolate the part to be tested. Connect the ohmmeter in series with whatever you plan to test. The ohmmeter has its own power supply and tests resistance by applying a voltage to the item to be tested. When measuring an unknown resistance, always start on the highest range and work your way down until you get an accurate reading. Measuring values that are too high for the range you are on can damage the meter.

(*continued*)

Components in Use

Look at the circuit diagram of a ***continuity tester*** in **Figure 11-30**. When there is continuity between the two probes, the circuit is closed and a sound is heard from the speaker.

The input components in this circuit are the battery, the probes, and the conductors. The battery causes electron flow through a chemical process. The conductors and probes create a path for current to flow.

The switch, capacitor, transistor, 555 timer IC, and resistors are all control components. When there is a closed circuit between the probes and the switch is closed, the 555 timer IC generates an audio signal, which is amplified by the transistor and played through the speaker. The resistors limit current flow in the circuit.

Troubleshooting

Figure 11-31 shows a schematic drawing of a penlight circuit. The two cells, wired in series, provide about 3 V. The diode drops about 0.7 V, delivering about 2.3 V to the LED in forward bias.

To ***troubleshoot*** this circuit, an electrical engineer might start by testing the voltage at the batteries (cells) to see that it is close to 3 V. Then the engineer might go around the circuit with a continuity tester or ohmmeter to make sure there is continuity where there should be. Ohmmeters are

Tools

Volt-Ohm-Milliammeter (VOM)

Volt-ohm-milliammeters (VOMs) are common multimeters used in electronics. Most are handheld and digital, making them easier to use than stationary or analog meters. VOMs can test voltage, current, and resistance. Many VOMs can also test capacitors, transistors, and continuity.

Continuity Tester

Continuity is a term used to describe a complete path for current flow. If a circuit is complete, it has continuity. A continuity test can be made with an ohmmeter. Low or no resistance indicates continuity. Infinite resistance indicates an open circuit or a break in the circuit and no continuity. Continuity testers typically beep or use an indicator light if there is continuity. A continuity tester could be used to see if an incandescent lightbulb has burned out. If there is continuity, the light is still good. **Figure A** shows a modern digital multimeter capable of measuring voltage, current, resistance, continuity, and more.

Oscilloscope

The *oscilloscope* is one of the most widely used electrical test devices because it is so versatile. Oscilloscopes can show the exact shape of a wave on their screens, which will show any possible distortion. They can measure voltage, frequency, pulses, and the timing of multiple signals. See **Figure B**.

Figure A. *urbanbuzz/Shutterstock.com*

Figure B. *Oleksiy Mark/Shutterstock.com*

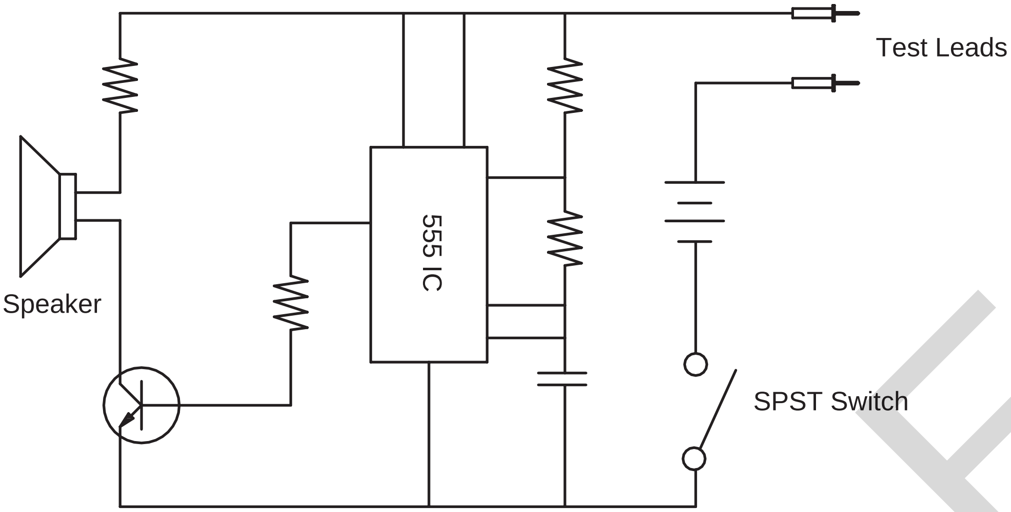


Figure 11-30. *Goodheart-Willcox Publisher*
This diagram shows a continuity tester, which helps test for properly working circuits. ***How might you use a continuity tester to determine if a switch is working properly?***

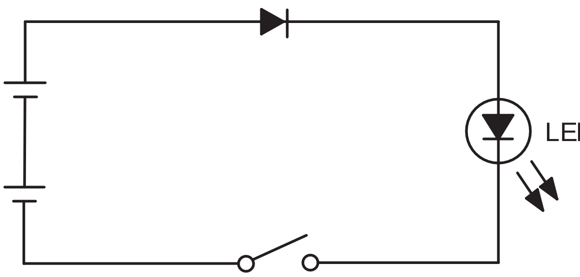


Figure 11-31. *Goodheart-Willcox Publisher*
This schematic shows a penlight circuit. Electrical engineers begin troubleshooting by testing battery voltage, then test the continuity throughout the circuit. ***What might cause a loss of continuity?***

used to measure resistance. The engineer might then test the diode to see that it conducts in forward bias but not in reverse. Then he or she might test the switch to see that there is continuity when the switch is closed. The LED can be tested by applying voltage directly to the LED to see if it lights. Keep in mind that a resistor must be used in series with the power source to protect the LED from excessive current.

Reverse Engineering

Reverse engineering can help electrical engineers solve many problems, but there are ethical factors to consider. In electrical engineering, reverse engineering involves taking apart and studying a component, integrated circuit (IC), or system to examine how it works so that commercially unavailable parts can be made, problems can be fixed, or products can be improved. For example, an IC manufacturer might need to recreate a chip that is no longer available or fix a problem with an existing chip design. They might delaminate the layers in an IC so they can study and understand how it works. They can use what they learn to design a better chip or to recreate it exactly like the original. Engineers need to be very careful during reverse engineering to ensure they do not violate patents or steal someone else's work.

Electrical Engineering in Action

Electrical engineers might use their knowledge of electrical characteristics, applications, and components to take on a project like increasing automobile efficiency. Gasoline vehicles are expensive to operate and create tremendous amounts of air pollution. People can choose to limit their use of

Did You Know?

Electric cars were invented in the 1800s and by the year 1900, they accounted for almost one third of all cars sold in the United States.

gasoline by driving hybrid electric cars or stop using gasoline entirely by driving electric vehicles or vehicles that use hydrogen fuel cells.

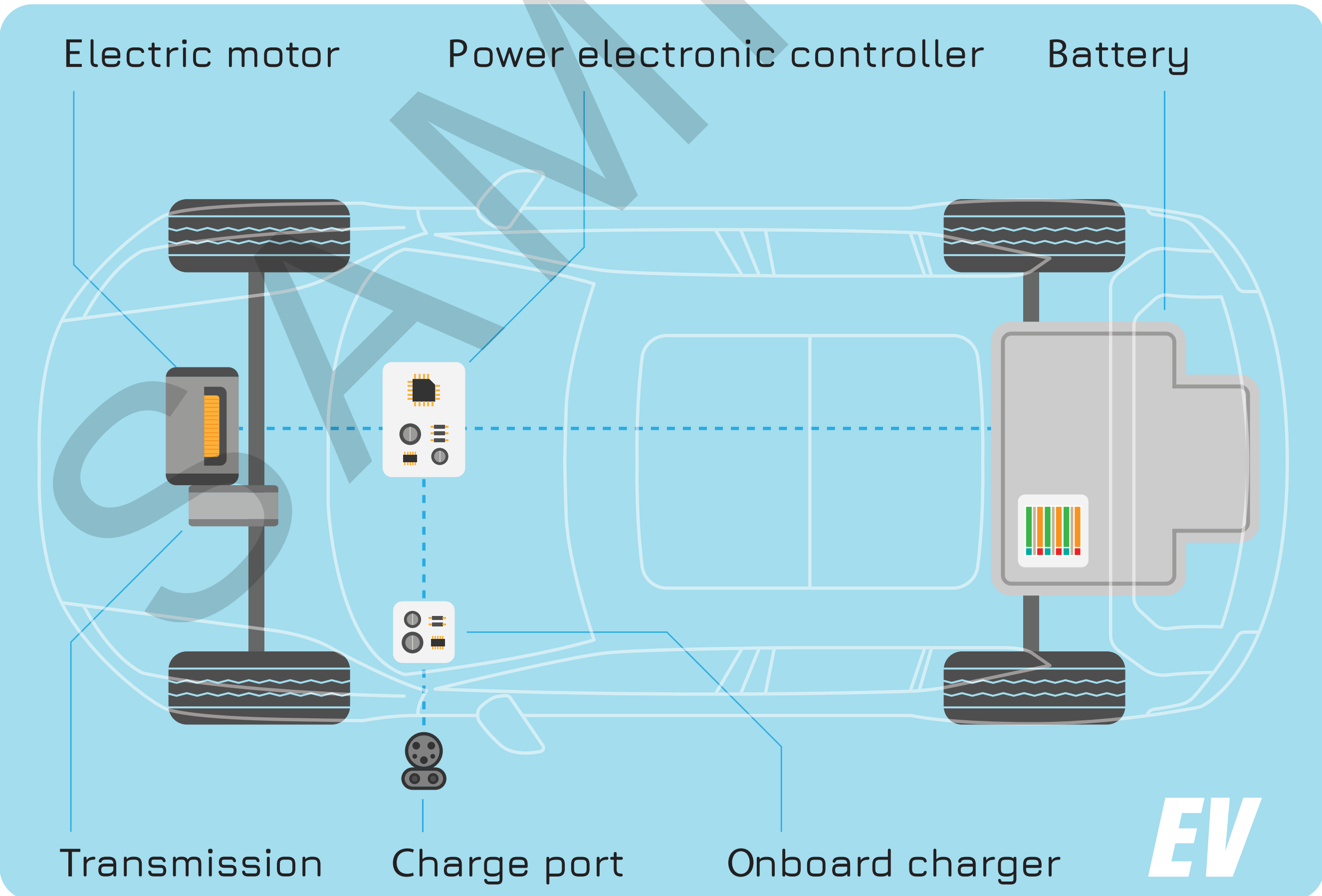
Hybrid cars use an internal combustion engine like a conventional car but also use an electric motor. Hybrid cars are quick to fuel, have a range similar to that of gasoline vehicles, and have less of an environmental impact than conventional gasoline vehicles.

One of the great gains of the hybrid car is that it has regenerative braking. When you apply the brakes in a conventional car, the kinetic energy from the car's movement is dissipated in the form of heat caused by the friction of the brakes. With regenerative braking, this kinetic energy is used to turn the electric motor in reverse, which generates electricity to charge the batteries. This is one of the reasons hybrids get much better mileage than conventional cars.

Hybrids are able to operate with a much smaller gas engine than conventional cars because the gas engine and electric motor can operate at the same time when necessary.

When sitting still in rush hour traffic or at a red light, most conventional vehicles idle, wasting gas. However, hybrids use no energy at all until the driver presses the accelerator. If battery charge falls below a certain level, the gas engine will automatically charge the batteries.

Fully electric cars do not pollute the air (except what may be created when the electricity is generated). See **Figure 11-32**. The biggest drawback with electric cars is their range because the batteries hold a limited charge. As technology improves, electric vehicles are able to go farther on a charge than they used to. Charging technology is also improving. Rapid chargers are being built along highways and in shopping areas to accommodate drivers who wish to travel long distances and charge along the way. Most electric vehicle owners install chargers at home and charge their cars overnight.



CW craftsman

Figure 11-32.
This schematic drawing shows the common parts of an electric vehicle.

Tools

Hand Tools in Electrical Engineering

Always choose the right tool of the correct size for the job. Use tools for their intended purpose only. Never use hand tools on electrical circuits and equipment unless you are sure the power is off and you have tested it. Keep your work area clean and your tools properly stored and maintained. Always wear safety glasses when using hand tools due to the possibility of flying objects and debris.

Wire cutters come in a variety of styles and sizes and are used to cut wire to the desired length. See **Figure A**.

Figure A. *Ilya Andriyanov/Shutterstock.com*

Pliers are used to hold small or hot objects and keep items from moving. The pliers shown in **Figure B** are called needle-nose pliers because the jaws are very thin. This pair also includes a wire cutter.

Figure B. *nahariyani/Shutterstock.com*

Wire strippers are used to remove insulation from wire so that the exposed ends can be used to make connections. A wire is placed in a slot according to gauge and the handles are squeezed, **Figure C**. This cuts the insulation, but not the wire. The strippers are then pulled toward the end of the wire and the insulation slides off, exposing the desired length of bare wire.

Figure C. *jeep5d/Shutterstock.com*

A wire gauge tool can be used to find the gauge of a wire; **Figure D**. Bare wires are inserted into the openings. When the wire fits snugly in the opening, the gauge has been found.

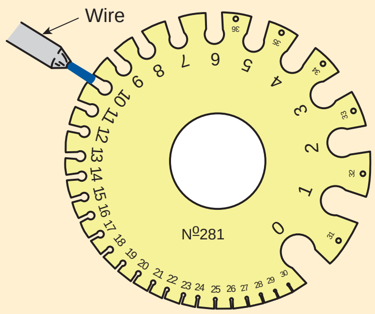


Figure D. *Goodheart-Willcox Publisher*

Crimpers come in many shapes and sizes. They are used to squeeze and compress connectors onto the ends of wires. The connectors are then held on with friction. See **Figure E**.

(*continued*)

Fuel cell cars produce electricity using hydrogen and oxygen. This electricity is then used to power the car. When a battery runs dead, it must be replaced or recharged depending on the type of battery. A fuel cell works much the same way, but a steady flow of hydrogen keeps it charged. Fuel cells create zero pollution and the only by-products are water and small amounts of heat.

Tools

Figure E. Skoda/Shutterstock.com

Utility knives are used for cutting, **Figure F**. Be careful when using utility knives. They are known to cause many injuries. Always cut away from yourself and make sure you and others are clear of the path of the moving knife. Always make sure the blade is fully retracted before putting it in your pocket or tool belt.

Figure F. PRILL/Shutterstock.com

Desoldering pumps are used to remove solder when a part needs to be removed from a circuit board or if solder has created a short. See **Figure G**. Use your thumb to pull the spring-loaded trigger on the end until it clicks and stays in place. Melt the solder using a soldering pencil. Place the end of the desoldering pump against the molten solder and press the button on the side. A spring-loaded plunger inside the pump moves, causing the molten solder to be sucked into the pump.

Figure G. Shahril KHMD/Shutterstock.com

Soldering pencils are used to heat solder so it will flow around electrical parts to make connections and to heat solder for removal. See **Figure H**. Always be careful when handling soldering pencils because they get very hot. Never touch a soldering pencil anywhere other than the handle. Always wear safety goggles when soldering. Make sure the soldering pencil is placed securely in its holder when not in use. Always unplug the soldering pencil and allow it to cool before leaving the room. Always be certain that the power is off and disconnected before working on any electrical circuit.

Figure H. Luís Brás/Shutterstock.com

Most people agree that we need to stop burning fossil fuels in transportation or at least increase the efficiency of the vehicles we are using. Hybrid vehicles, plug-in electric vehicles, fuel cell vehicles, or another new technology could be the solution to this problem. No matter what the solution, it will require the best and brightest scientists, designers, and electrical engineers to change our world for the better.

Summary

- Electrical engineers design, test, develop, and build things like power plants, space shuttle electronics, and electronic gadgets.
- The broadest professional society for electrical engineers is the Institute of Electrical and Electronics Engineers (IEEE).
- Electrical engineers must conduct themselves in an ethical manner and have strong teamwork skills.
- All matter is made up of microscopic building blocks called *atoms*.
- Electricity flows through solid pieces of materials known as *conductors*.
- Sources of electricity include magnetism, chemical action, solar cells, and other numerous sources.
- The law of conservation of energy states that energy cannot be created or destroyed. It can only be converted from one form to another.
- Four important characteristics of generated electricity are voltage, current, resistance, and power.
- Ohm's law and Watt's law provide formulas to help find values of voltage, current, resistance, and power within a circuit.
- Three types of circuits are series, parallel, and series-parallel circuits.
- Conductors are a common type of input component in an electrical circuit. Copper and aluminum are the most common materials used in conductors.
- Control components within circuits include insulators, resistors, switches, diodes, transistors, and capacitors.
- Closed control systems include some sort of built-in feedback.
- Open control systems do not have a built-in mechanism for feedback and rely on manual adjustment when necessary.
- Output components of electrical circuits include various types of lamps and motors.
- Circuit boards and solderless breadboards are two of the most common types of component platforms.
- A continuity tester can be used to help in troubleshooting circuits or to ensure circuits are functioning properly.
- The electric motors and other electronic components used in hybrid cars are designed by electrical engineers.

Know and Understand

Answer the following questions using the information provided in this chapter.

1. Electricity is the flow of _____.
   A. protons
   B. atoms
   C. electrons
   D. neutrons
2. Most electricity is produced using electric _____.
   A. motors
   B. electrolytes
   C. cells
   D. generators
3. A battery is an example of which source of electricity?
   A. Chemical action
   B. Magnetism
   C. Wind farms
   D. Solar cells
4. Which of the following is *not* an example of a good conductor?
   A. Copper
   B. Aluminum
   C. Rubber
   D. Gold

5. The unit for power is the _____.
   A. ohm
   B. amp
   C. watt
   D. coulomb
6. *True or False?* A parallel circuit has only one path for current flow.
7. *True or False?* A bachelor's degree in electrical engineering is required to become an electrical engineer.
8. Which of the following is *not* an example of a good insulator?
   A. Plastic
   B. Paper
   C. Steel
   D. Rubber
9. Incandescent bulbs use a _____ filament inside a globe where the oxygen has been removed.
   A. silicon
   B. carbon
   C. tungsten
   D. fluorescent
10. A(n) _____ can test for resistance and continuity.
    A. voltmeter
    B. ohmmeter
    C. ammeter
    D. oscilloscope
11. _____ is also known as electromotive force (EMF).
    A. Amperage
    B. Resistance
    C. Voltage
    D. Wattage
12. _____ is the amount of opposition to current flow.
    A. Amperage
    B. Resistance
    C. Voltage
    D. Wattage
13. In a(n) _____ circuit, voltage is equal across all loads.
    A. series
    B. parallel
    C. series-parallel
    D. energized
14. *True or False?* In electron flow theory, electricity flows from negative to positive.

Matching: Match each of the following electrical components with their descriptions.

A. Sensors
B. LEDs
C. Diodes
D. Semiconductors
E. Capacitors
F. Integrated circuits
G. Transistors

15. Create electrical signals based on conditions.
16. Entire circuits enclosed in a plastic case.
17. Serve as switches and amplifiers.
18. Conductivity between that of insulators and conductors.
19. Allow flow in only on direction.
20. Can store and discharge electricity.
21. Low-power, low-cost, reliable lighting once used only for indicators.

Apply and Analyze

1. Define *electrical engineering*.
2. What are PCBs and what are they used for?
3. Find the voltage for a series circuit where you know the current is 0.5 A and the resistance is 25 Ω.
4. A resistor with a color code of green-yellow-red-gold has a value of _______ Ω with a tolerance of _______%.

Critical Thinking

1. Explain some of the ways in which electrical engineers can help in the fight against climate change.
2. Describe why ethics must be considered when reverse engineering products and devices.

Communicating about Engineering

1. **Listening.** In small groups, discuss with your classmates—in basic, everyday language—your knowledge and awareness of electricity. Conduct this discussion as though you had never read this chapter. Take notes on the observations expressed. Then review the points discussed, factoring in your new knowledge of electricity. Develop a summary of what you have learned about electricity and present it to the class using the terms that you have learned in this chapter.
2. **Speaking.** Working in groups of three students, create flash cards for 10–15 Key Terms in this chapter. Each student chooses three to five terms and makes flash cards for those terms. On the front of the card, write the term. On the back of the card, write the pronunciation and a brief definition. Use your textbook and a dictionary for guidance. Then take turns quizzing one another on the pronunciations and definitions of the Key Terms.

ACTIVITY

11-1

Electricity from Magnets

Electrical engineers are heavily involved in the power generation field and must fully understand how electricity is produced from magnetism. In this activity, you will learn how magnets and motion can be used to generate electricity by passing a magnet through a coil of wire and testing the results on a meter.

Objective

After completing this activity, you will be able to:

- Demonstrate and explain how electricity is produced using magnets.

Materials

- Bar magnet
- Approximately 3′ of thin-gauge insulated wire
- Electrical meter

Procedure

1. Make a coil of wire just large enough for the magnet to pass through with as many turns of wire as possible.
2. Set the meter to read current and connect both ends of the wire to the meter. Insert the magnet into the coil and then pull it back out.
3. You should see a small amount of current as you push the magnet into the coil and the same amount of current in the opposite polarity when you pull it back out.
4. You can see that current flows in a circuit when magnetic lines of flux are cut by a coil. This is the fundamental concept behind the operation of electrical generators.

Reflective Questions

1. Would current be generated if the magnet was held still and the coil was passed over it? Why or why not?
2. Explain how this concept can be applied on a larger scale to generate large amounts of electricity.

ACTIVITY

11-2

Electricity from Solar Cells

Renewable energy will become one of the fastest growing sectors of the economy for many years to come. Electrical engineers are on the forefront of design and implementation of these systems and must understand how they work. In this activity, you will use solar cells to generate enough electricity to light a lightbulb and will measure the voltage and current in the circuit.

Objectives

After completing this activity, you will be able to:

- Use solar cells to power a small device.
- Show how multiple solar cells can be wired in series to increase output.
- Test for voltage and current.
- Wire a circuit with a power source and a load.

Safety

Always keep your hands away from electrical circuits when the power is turned on.

Materials

- Solar cell
- Lightbulb
- Wire or alligator test leads
- Electrical meter
- Pencil
- Blank sheet of paper

Procedure

1. Use the wire or test leads to connect the solar cell to the light. The light should turn on.
2. Measure and record the voltage across the lamp and the current flow in the circuit.
3. Wire two cells in series and observe the brightness of the lamp.
4. Measure and record the voltage across the lamp and the current flow in the circuit.
5. Cover the cell with a solid object and observe the brightness of the lamp.

Reflective Questions

1. What happened to the brightness of the lamp when a second cell was wired in series?
2. How did your voltage and current readings change when the second cell was added?
3. What happened to the lamp when you covered the cell? Why?
4. How could solar cells be used to power electrical devices at night?

ACTIVITY

11-3

Measuring Current, Voltage, and Resistance

To better understand how to read meters, it is essential that you learn to take measurements on real circuits. In this activity, you will build simple circuits and measure various values.

Objectives

After completing this activity, you will be able to:

- Build a simple circuit.
- Take measurements for voltage, current, and resistance.

Safety

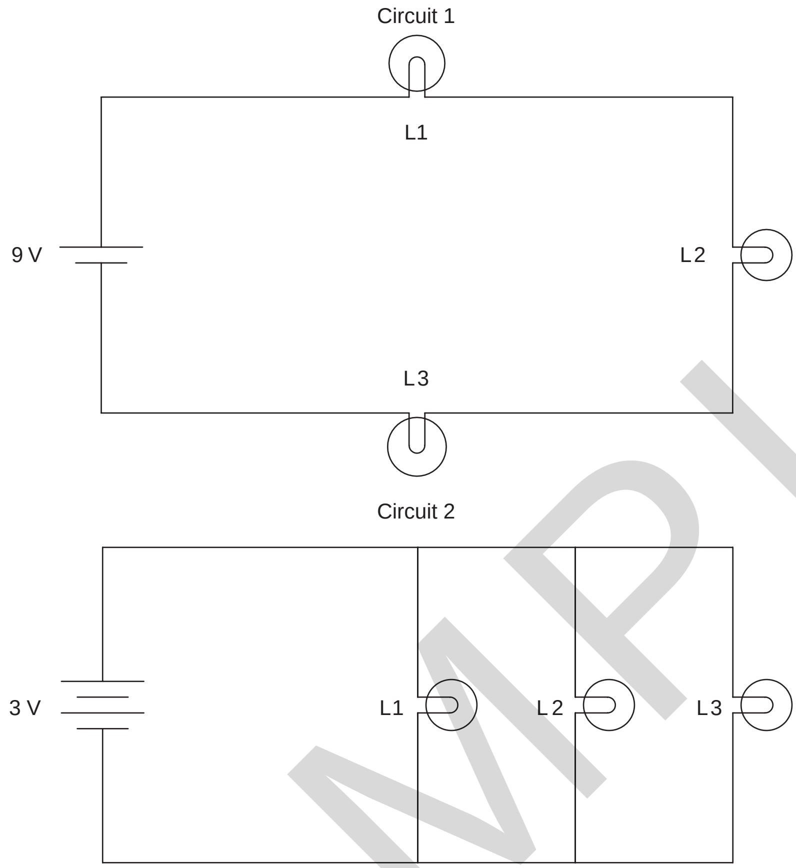
Some measurements must be taken with the circuit energized, so it is extremely important to follow the lab safety rules outlined by your instructor to avoid injury to yourself and others.

Materials

- Circuit-building materials will vary depending on the teacher's discretion
- Pencil
- Blank sheet of paper

Procedure

1. Build the circuits shown below (or similar circuits based on the directions of your instructor).



Goodheart-Willcox Publisher

2. Before taking any measurement, always turn off the power and wire the meter into the circuit. Then, turn the power back on and take a measurement.
3. Take voltage measurements and document your reading. Remember that voltage measurements are always taken in parallel across a power supply or a load with the circuit energized.
4. Take current measurements and document your reading. Remember that current measurements are always taken in series with the circuit energized.
5. Take resistance measurements with the power off and the part(s) to be measured isolated from the rest of the circuit.

Reflective Questions

1. Why do you think the measurements are taken as they are, in series with, in parallel with, or isolated from the circuit?
2. Do you believe the measurements you took were accurate? Why or why not?

ACTIVITY

11-4

Circuit Calculations

Electrical engineers must understand the specifics of series and parallel circuits in order to design and troubleshoot these circuits. Using some basic rules for series and parallel circuits in conjunction with Ohm's law, you can calculate information about these circuits. In this activity, you will solve a variety of problems in both series and parallel circuits.

Objectives

After completing this activity, you will be able to:

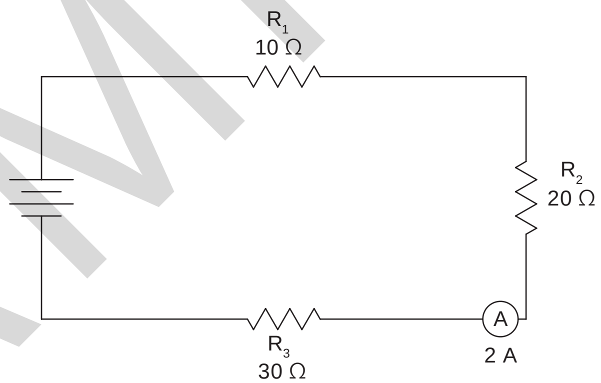
- Solve for current, voltage, and resistance in series and parallel circuits.
- Explain the rules for series and parallel circuits.

Materials

- Pencil
- Blank sheet of paper.

Procedure

1. Look at the following series circuit.



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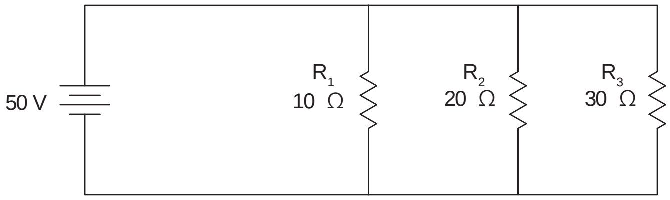
In a series circuit, the following rules apply:

- Current is the same everywhere in the circuit.
- The sum of the voltage drops across each part equals the source voltage.
- The sum of the resistances of each load equals the total.

Using the circuit shown above, calculate the following:

A. I_{R_1}
B. I_{R_3}
C. V_{R_2}
D. V_t
E. R_t
F. P_t

2. Look at the parallel circuit.



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For parallel circuits, the following rules apply:

- The sum of the current in each parallel branch is equal to the total current.
- The voltage drop across each branch is equal to the source voltage.

Total resistance is found using the following formulas:

- With only two loads:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

- With two or more loads:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N}}$$

Using the parallel circuit shown above, calculate the following:

A. I_t
B. R_t
C. V_{R_1}
D. V_{R_2}

Reflective Question

1. Why do you think the rules of a series circuit are different from the rules of a parallel circuit?

ACTIVITY

11-5

Ohm's Law and Watt's Law

Electrical engineers use Ohm's law and Watt's law in the design and troubleshooting of electrical circuits. Ohm's law describes the relationship between current, voltage, and resistance. Watt's law describes the relationship between current, voltage, and power. In this activity, you will use Ohm's law and Watt's law to solve common circuit problems.

Objectives

After completing this activity, you will be able to:

- Solve for current, voltage, or resistance when two of those values are known.
- Solve for power, voltage, or current when two of those values are known.
- Calculate the cost to operate a household device when its power usage and local billing rates are known.

Materials

- Figure 11-10 from the textbook
- Pencil
- Blank sheet of paper

Procedure

Solve the following problems using Ohm's law:

1. Calculate the voltage in a circuit with 50 Ω and 2 A.
2. Calculate the current in a circuit with 50 V and 25 Ω.
3. Calculate the resistance in a circuit with 120 V and 5 A.
4. Calculate the resistance in a circuit with 10 V and 20 mA. To complete this problem, first convert 20 mA to amps.

Use "PIE" formula (P = I x E) to solve the following problems:

5. Calculate the power for a circuit with 100 V and 5 A.
6. Calculate the current for a circuit with 1,000 W and 120 V.
7. Calculate the voltage for a circuit with 500 W and 2 A.

Use the following information to solve the following problems:

Electrical billing is done in kilowatt-hours. The prefix *kilo-* stands for thousands, so billing is done in thousands of watt-hours. If you turn on a 100-watt lightbulb for one hour, you use 100 watt-hours. If you leave it on for 10 hours, you use 1000 watt-hours, or 1 kilowatt-hour, of electricity.

8. Imagine you have a small fan in your home that you have on at night. You want to figure out how much it costs to operate that fan. The label says it draws 0.4 A at 120 V. Calculate the power used.
9. Assuming you operate your fan for 8 hours per night, 365 days per year, how many watt-hours are you using each year?
10. Assuming you are being billed at a rate of 15 cents per kilowatt-hour, what is the total cost to operate your fan every night for one year?

Reflective Questions

1. When do you think it might be more appropriate to calculate voltage, current, and resistance values rather than to test for them?
2. If voltage is held constant and resistance is increased, what will happen to current flow? Can you think of an example of where this is done in your home?
3. If people had a clear understanding of how much it costs per hour to operate each of their electrical devices, how do you think that would affect their behavior?