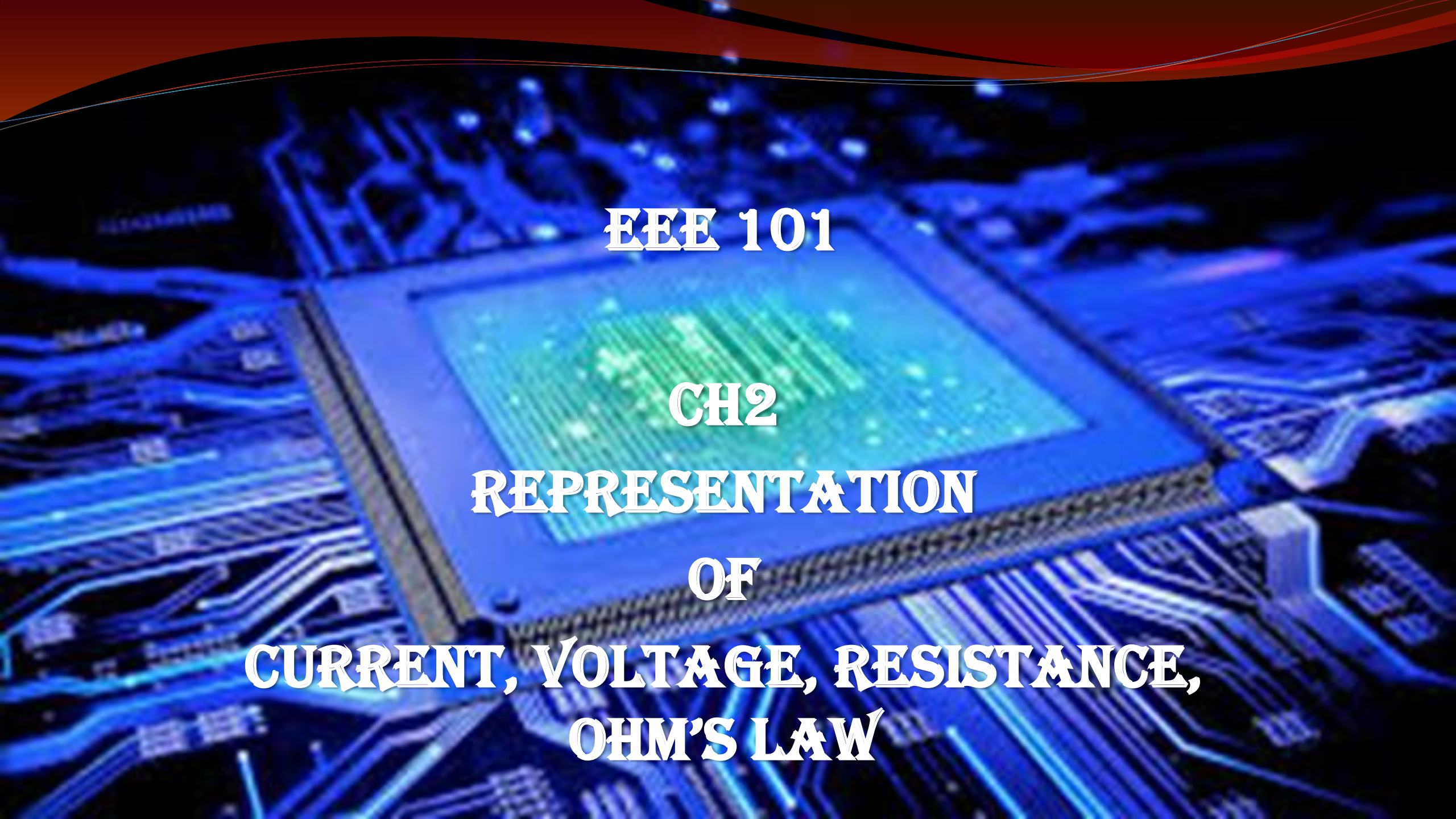




EEE 101

CH2

REPRESENTATION

OF

CURRENT, VOLTAGE, RESISTANCE,
OHM'S LAW

Current

► Objectives

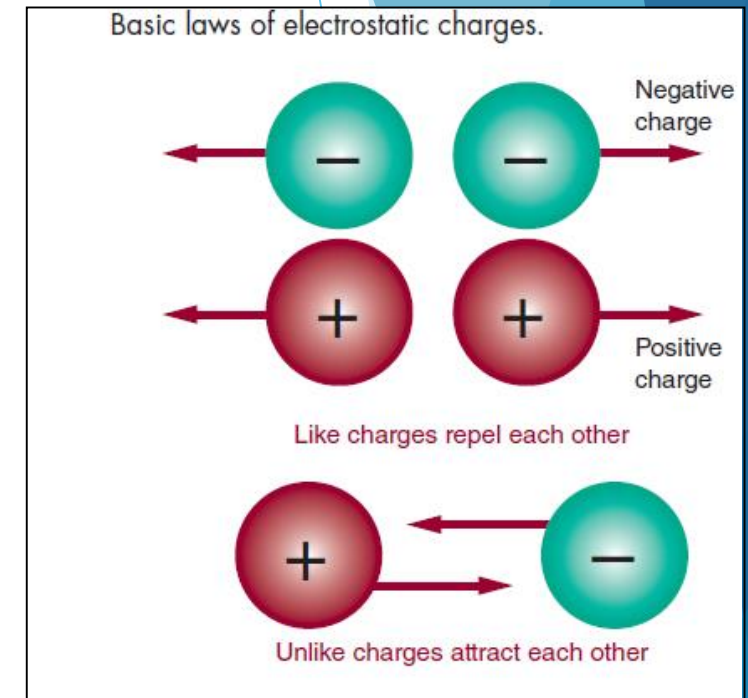
After completing this section, the student will be able to:

- State the two laws of electrostatic charges.
- Define coulomb.
- Identify the unit used to measure current flow.
- Define the relationship of amperes, coulombs, and time through a formula.
- Describe how current flows in a circuit.
- Describe how electrons travel in a conductor.
- Define and use scientific notation.
- Identify commonly used prefixes for powers of 10.

Current

ELECTRICAL CHARGE

- ▶ The atom has been defined as the smallest particle of an element. It is composed of electrons, protons, and neutrons.
- ▶ Electrons breaking away from atoms and flowing through a conductor produce an electric current.
- ▶ Two electrons together or two protons together represent “like” charges. Like charges resist being brought together and instead move away from each other. This movement is called **repelling**. This is the first law of electrostatic charges: Like charges repel each other (Figure). According to the second law of electrostatic charges: Unlike charges attract each other.
- ▶ Electrical charges are created by the displacement of electrons. When there is an excess of electrons at one point and a deficiency of electrons at another point, a difference of potential exists between the two points. When a difference of potential exists between two charged bodies connected by a conductor, electrons will flow along the conductor. This flow of electrons is called current



Current Flow

- ▶ An electric **current (I)** consists of the drift of electrons from an area of negative charge to an area of positive charge.
- ▶ The unit of measurement for current flow is the ampere (A). An ampere represents the amount of current in a conductor when 1 coulomb of charge moves past a point in 1 second.
- ▶ The relationship between amperes and coulombs per second can be expressed as follows:

$$I = \frac{Q}{t}$$

- ▶ Where:
 - ▶ I=current measured in amperes
 - ▶ Q=quantity of electrical charge in coulombs
 - ▶ t=time in seconds

Current Flow

- **Example:** What is the current in amperes if 9 coulombs of charge flow past a point in an electric circuit in 3 seconds?

Given

$$I = ?$$

$$Q = 9 \text{ coulombs}$$

$$t = 3 \text{ seconds}$$

Solution

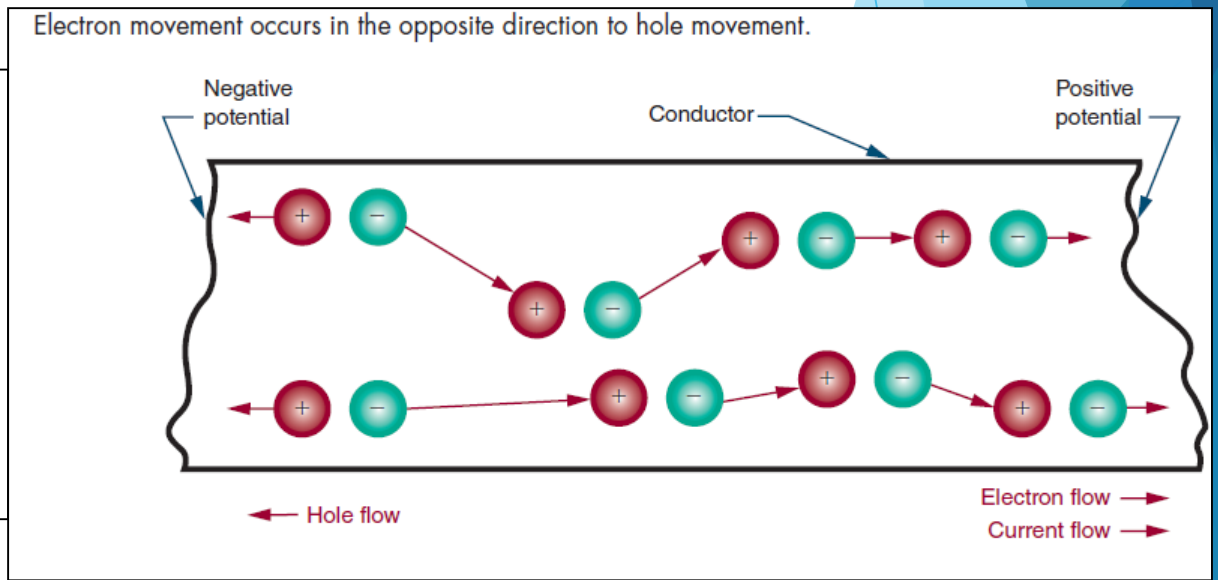
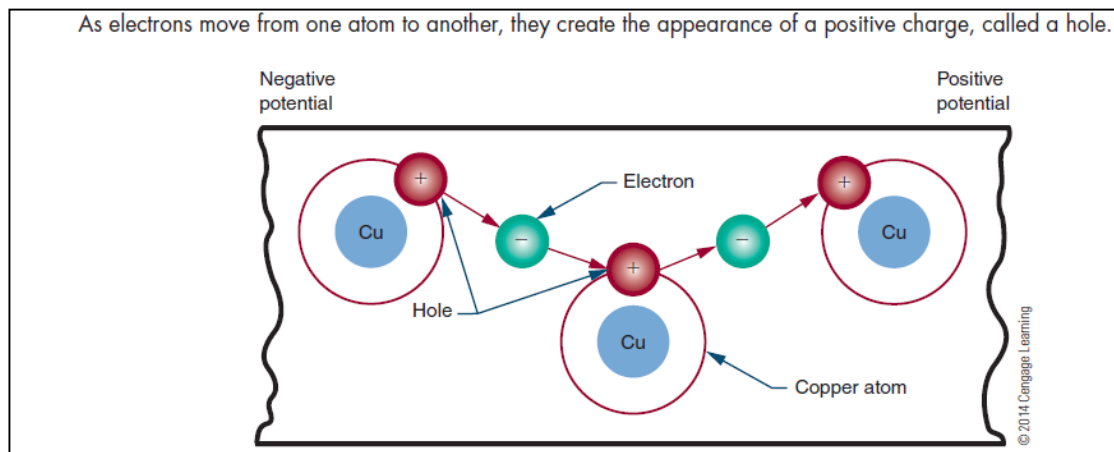
$$I = \frac{Q}{t}$$

$$I = \frac{9}{3}$$

$$I = 3 \text{ amperes}$$

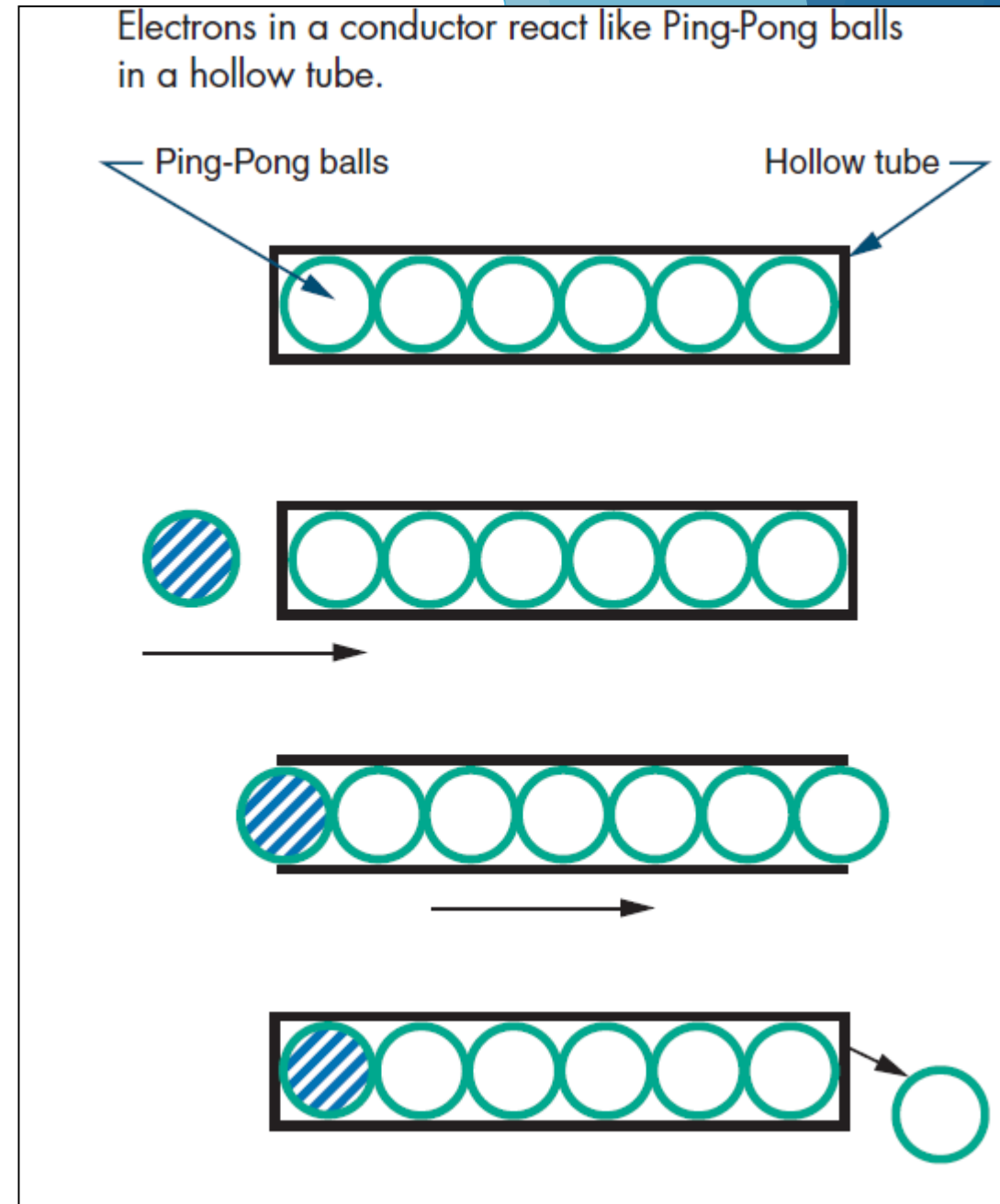
Current Flow

- ▶ Electrons, with their negative charge, represent the charge carrier in an electric circuit. Therefore, electric current is the flow of negative charges.
- ▶ Scientists and engineers once thought that current flowed in a direction opposite to electron flow. Later work revealed that the movement of an electron from one atom to the next created the appearance of a positive charge, called a **hole**, moving in the opposite direction (Figure 1 and Figure 2).
- ▶ Electron movement and current were found to be the same. If electrons are added to one end of a conductor and provision is made to take electrons from the other end, an electric current flows through the conductor. As free electrons move slowly through the conductor, they collide with atoms, knocking other electrons free. These new free electrons travel toward the positive end of the conductor and collide with other atoms.
- ▶ The electrons drift from the negative to the positive end of the conductor because like charges repel. In addition, the positive end of the conductor, which represents a deficiency in electrons, attracts the free electrons because unlike charges attract.



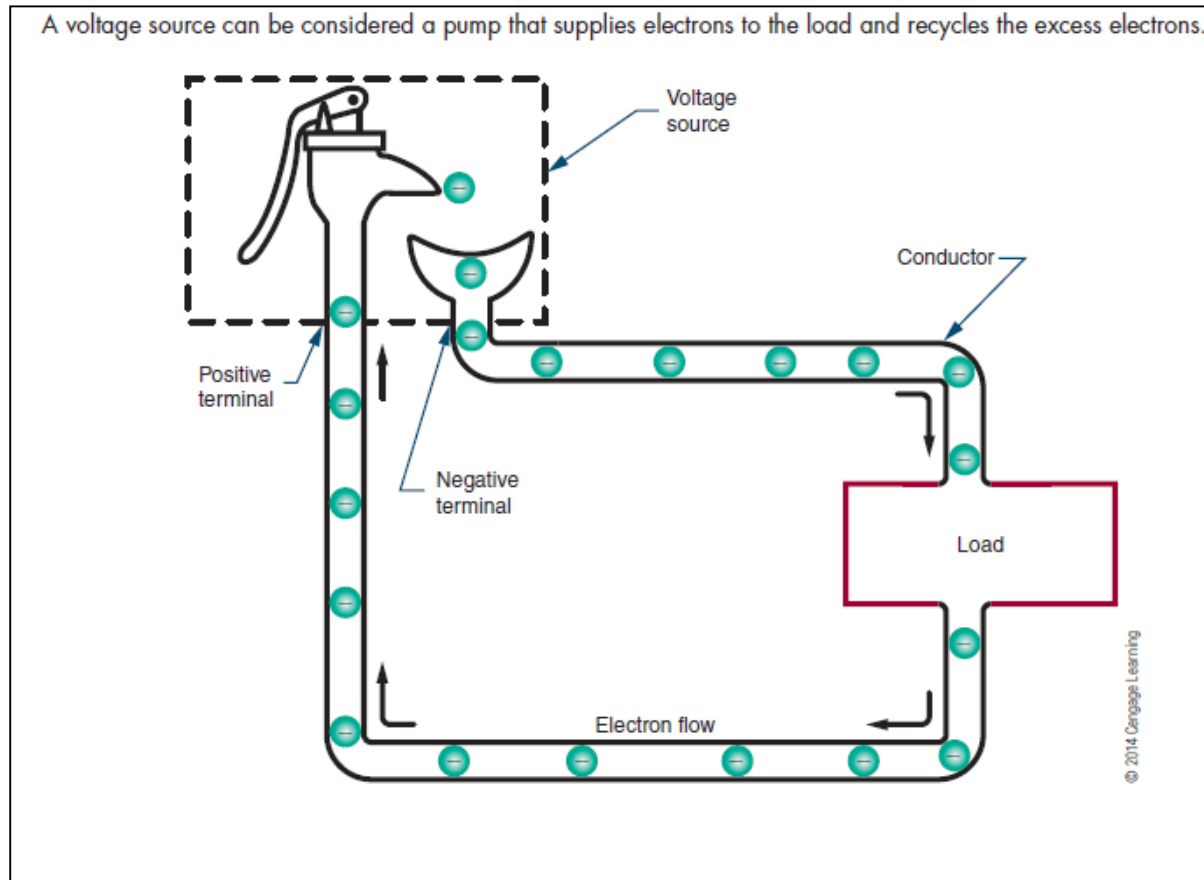
Current Flow

- ▶ The drift of electrons is slow (approximately an eighth of an inch per second), but individual electrons ricochet off atoms, knocking other electrons loose, at the speed of light (186,000 miles per second).
- ▶ For example, visualize a long, hollow tube filled with Ping-Pong balls (Figure). As a ball is added to one end of the tube, a ball is forced out the other end of the tube.
- ▶ Although an individual ball takes time to travel down the tube, the speed of its impact can be far greater.



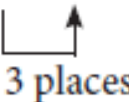
Current Flow

- ▶ The device that supplies electrons from one end of a conductor (the negative terminal) and removes them from the other end of the conductor (the positive terminal) is called the **voltage source**. It can be thought of as a kind of pump (Figure).



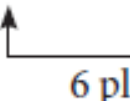
Scientific Notation

- ▶ In electronics, it is common to encounter very small and very large numbers. **scientific notation** is a means of using single-digit numbers plus powers of 10 to express large and small numbers. For example, 300 in scientific notation is 3×10^2 .
- ▶ The exponent indicates the number of decimal places to the right or left of the decimal point in the number.
- ▶ If the power is positive, the decimal point is moved to the right. For example:

$$3 \times 10^3 = 3.0 \times 10^3 = 3.000 = 3000$$


3 places

If the power is negative, the decimal point is moved to the left. For example:

$$3 \times 10^{-6} = 3.0 \times 10^{-6} = 0.000003 = 0.000003$$


6 places

Scientific Notation

- ▶ Figure lists some commonly used powers of 10, both positive and negative, and the prefixes and symbols associated with them.

Prefixes commonly used in electronics.

Prefix	Symbol	Value	Decimal Value
Tetra-	T	10^{12}	1,000,000,000,000
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}	0.001
Micro-	μ	10^{-6}	0.000001
Nano-	n	10^{-9}	0.000000001
Pico-	p	10^{-12}	0.000000000001

EXAMPLE: How many milliamperes are there in 2 amperes?

Solution:

$$\frac{1000 \text{ mA}}{1 \text{ A}} = \frac{X \text{ mA}}{2 \text{ A}} \quad (1000 \text{ mA} = 1 \text{ A})$$

$$\frac{1000}{1} = \frac{X}{2}$$

$$(1)(X) = (1000)(2)$$

$$X = 2000 \text{ mA}$$

EXAMPLE: How many amperes are there in 50 microamperes?

Solution:

$$\frac{1,000,000 \mu\text{A}}{1 \text{ A}} = \frac{50 \mu\text{A}}{X \text{ A}}$$

$$\frac{1,000,000}{1} = \frac{50}{X}$$

$$(1)(50) = (1,000,000)(X)$$

$$\frac{50}{1,000,000} = X$$

$$0.00005 = X$$

$$0.00005 \text{ A} = X$$

Voltage

OBJECTIVES

After completing this section, The student will be able to: Identify the six most common voltage sources.

- ▶ Describe six different methods of producing electricity.
- ▶ Define a cell and a battery.
- ▶ Describe the difference between primary and secondary cells.
- ▶ Describe how cells and batteries are rated.
- ▶ Identify ways to connect cells or batteries to increase current or voltage output or both.
- ▶ Define voltage rise and voltage drop.
- ▶ Identify the two types of grounds associated with electrical circuits.

Voltage

- ▶ In a piece of copper wire, the electrons are in random motion with no direction. To produce a current flow, the electrons must all move in the same direction.
- ▶ To produce motion in a given direction, energy must be imparted to the electrons in the copper wire. This energy comes from a source connected to the wire.
- ▶ The force that causes the electrons to move in a common direction is referred to as *difference of potential*, or *voltage*.

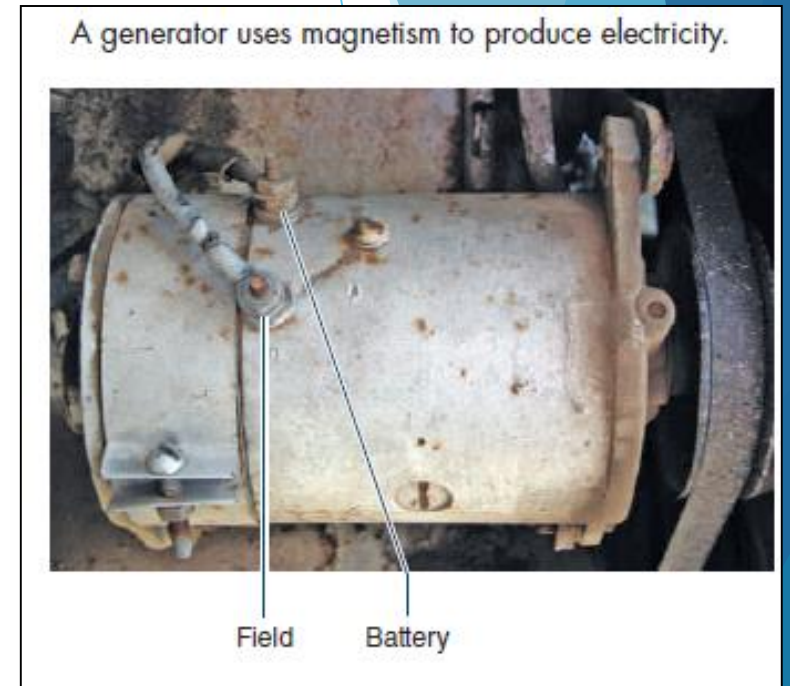
Voltage Sources

- ▶ A current is produced when an electron is forced from its orbit around an atom. Any form of energy that dislodges electrons from atoms can be used to produce current. It is important to note that energy is not created; rather, there is simply a transfer of energy from one form to another. The source supplying the voltage is not simply a source of electrical energy. Instead, it is the means of converting some other form of energy into electrical energy. The six most common voltage sources are friction, magnetism, chemicals, light, heat, and pressure.
- ▶ Friction is the oldest known method of producing electricity. A glass rod can become charged when rubbed with a piece of fur or silk. This is similar to the charge you can generate by scuffing your feet across a carpet in a dry room.
- ▶ A **Van de Graaf Generator** is a device that operates using the same principles as the glass rod and is capable of producing millions of volts (Figure).



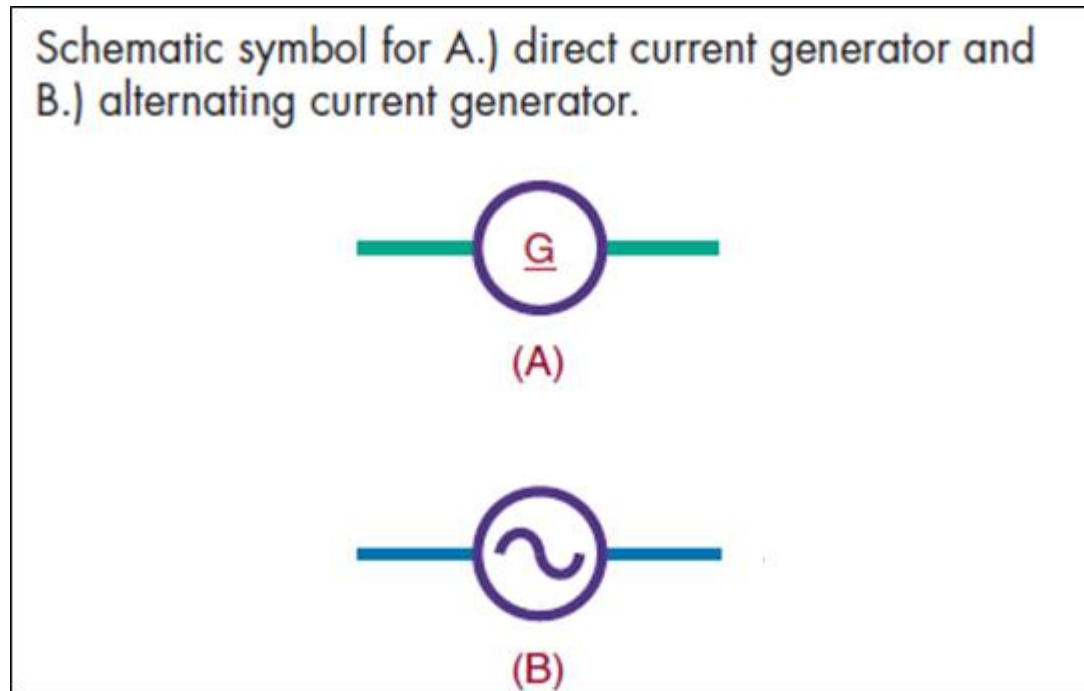
Voltage Sources

- ▶ Magnetism is the most common method of producing electrical energy today.
- ▶ If a wire is passed through a magnetic field, voltage is produced as long as there is motion between the magnetic field and the conductor.
- ▶ A device based on this principle is called a **generator** (Figure). A generator can produce either direct current or alternating current, depending on how it is wired.
- ▶ When electrons flow in only one direction, the current is called **direct current (DC)**. When electrons flow in one direction and then in the opposite direction, the current is called **alternating current (AC)**.
- ▶ A generator may be powered by steam from nuclear power or coal, water, wind, or gasoline or diesel engines.



Voltage Sources

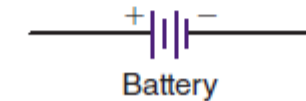
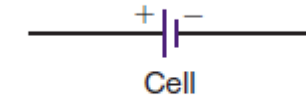
- ▶ The schematic symbol for a DC generator and an AC generator is shown in Figure .



Voltage Sources

- ▶ The second most common method of producing electrical energy today is by the use of a chemical **cell**.
- ▶ The cell establish contact with the electrolyte (the salt, acid, or alkaline solution) and the circuit.
- ▶ The electrolyte pulls the free electrons from the copper electrode, leaving it with a positive charge. The zinc electrode attracts free electrons in the electrolyte and thus acquires a negative charge.
- ▶ Several of these cells can be connected together to form a battery.
- ▶ Figure 1 shows the schematic symbol for a cell and battery. Many types of cells and batteries are in use today (Figure 2).

Schematic symbol for a cell and a battery. The combination of two or more cells forms a battery.



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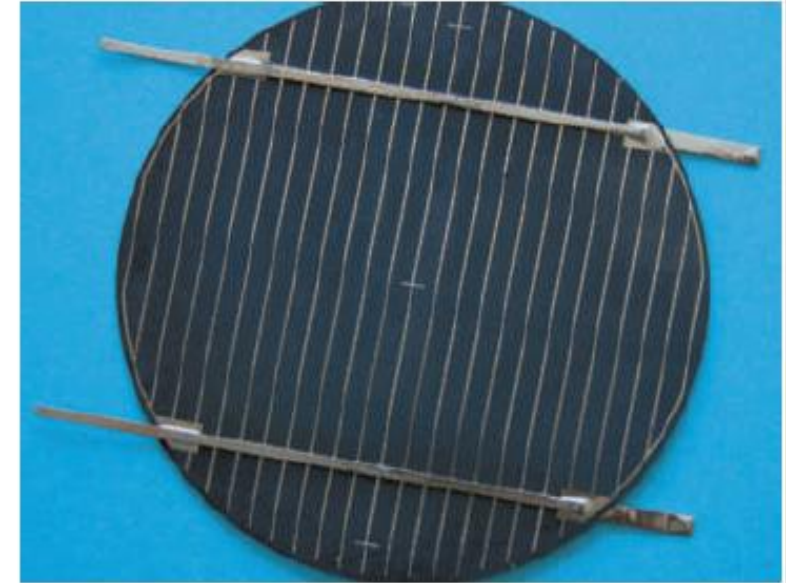
Some of the more common chemical batteries and cells in use today.



Voltage Sources

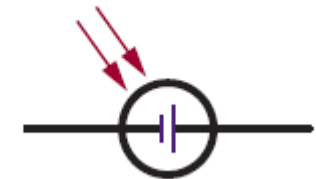
- ▶ Light energy can be converted directly to electrical energy by light striking a photosensitive (light- sensitive) substance in a **photovoltaic cell (solar cell)** (Figure 1).
- ▶ A solar cell consists of photosensitive materials mounted between metal contacts. When the surface of the photosensitive material is exposed to light, it dislodges electrons from their orbits around the surface atoms of the material.
- ▶ This occurs because light has energy. A single cell can produce a small voltage. Figure 2 shows the schematic symbol for a solar cell. Many cells must be linked together to produce a usable voltage and current.
- ▶ Solar cells are used primarily in satellites and cameras. The high cost of construction has limited their general application. However, the price of solar cells is coming down.

A photovoltaic cell can convert sunlight directly into electricity.



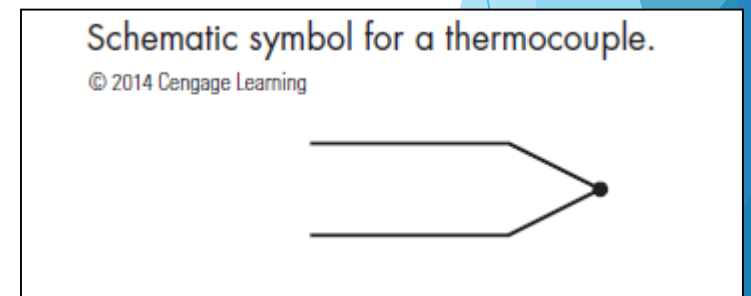
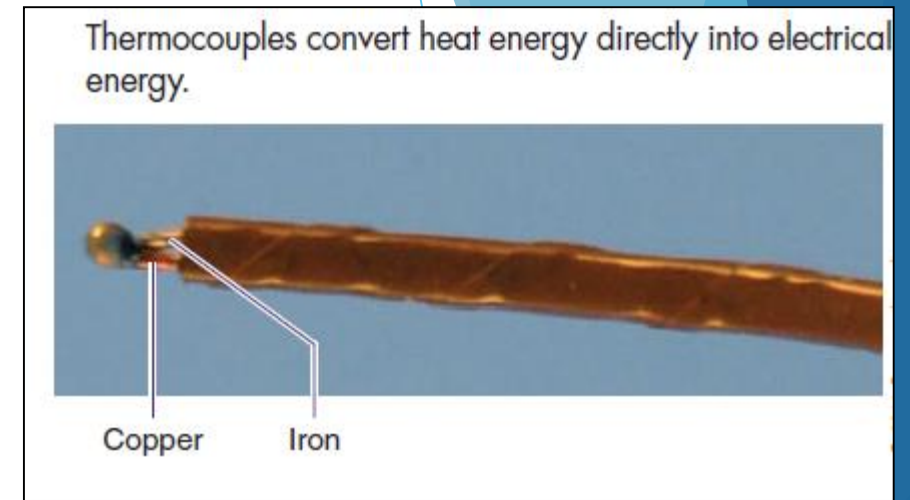
Schematic symbol of a photovoltaic cell (solar cell).

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Voltage Sources

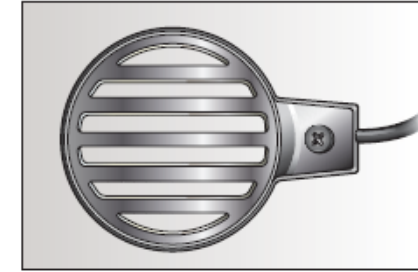
- ▶ Heat can be converted directly to electricity with a device called a **thermocouple** (Figure 1). The schematic symbol for a thermocouple is shown in Figure 2.
- ▶ A thermocouple consists of two dissimilar metal wires twisted together. One wire is copper and the other wire is zinc or iron. When heat is applied to the twisted connection, the copper wire readily gives up free electrons, which are transferred to the other wire.
- ▶ Thus the copper wire develops a positive charge and the other wire develops a negative charge, and a small voltage occurs. The voltage is directly proportional to the amount of heat applied.
- ▶ One application of the thermocouple is as a thermometer. Also called a pyrometer, these devices are often used in high-temperatures kilns and foundries.



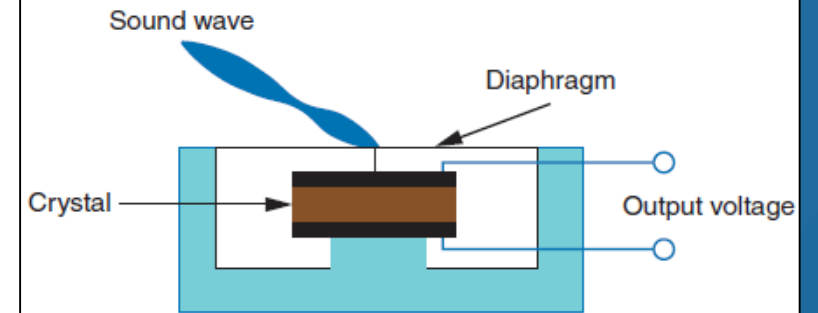
Voltage Sources

- ▶ When pressure is applied to certain crystalline materials such as quartz, tourmaline, Rochelle salts, or barium titanate, a small voltage is produced. This is referred to as the **piezoelectric effect**.
- ▶ Initially, negative and positive charges are distributed randomly throughout a piece of crystalline material, and no overall charge can be measured. However, when pressure is applied, electrons leave one side of the material and accumulate on the other side. A charge is produced as long as the pressure remains. When the pressure is removed, the charge is again distributed, so no overall charge exists.
- ▶ The voltage produced is small and must be amplified to be useful. Uses of the piezoelectric effect include crystal **microphones**, phonograph pickups (crystal cartridges), and precision oscillators (Figure 1 and Figure 2).

Crystal Microphone and how it is constructed.



(A)



(B)

Schematic diagram of a piezoelectric crystal.

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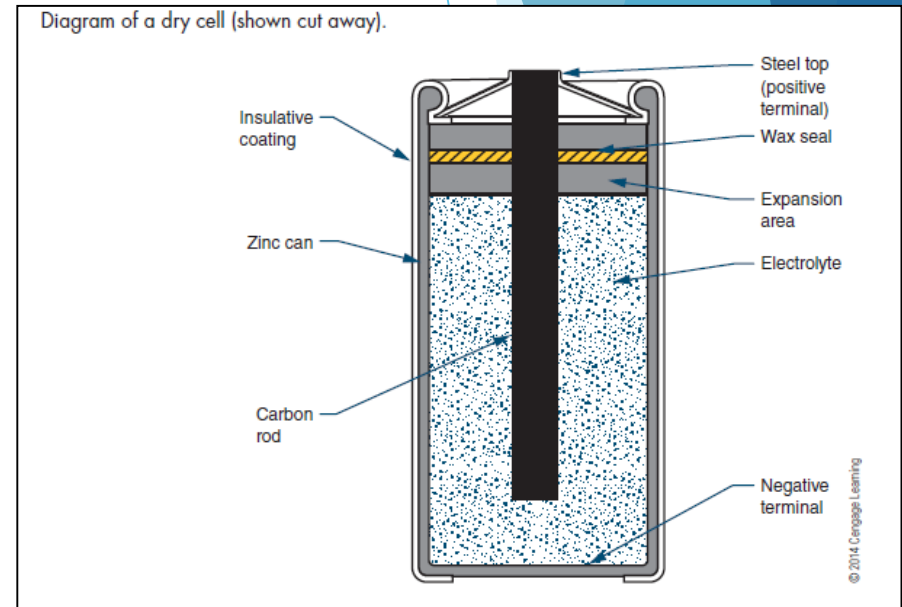


Voltage Sources

- ▶ Note that although a voltage can be produced by these means, the reverse is also true; that is, a voltage can be used to produce magnetism, chemicals, light, heat, and pressure. Magnetism is evident in motors, speakers, solenoids, and relays.
- ▶ Chemical activities can be produced through electrolysis and electroplating.
- ▶ Light is produced with lightbulbs and other optoelectric devices.
- ▶ Heat is produced with heating elements in stoves, irons, and soldering irons.
- ▶ And voltage can be applied to bend or twist a crystal.

Cells and Batteries

- ▶ A **battery** is a combination of two or more cells. There are two basic types of cells. Cells that can not be recharged are called **primary cells**. Cells that can be recharged are called **secondary cells**.
- ▶ An example of a primary cell is a **Leclanche cell**, also called a **dry cell** (Figure). This type of cell is not actually dry. It contains a moist paste as the electrolyte. A seal prevents the paste from leaking out when the cell is turned sideways or upside down. The electrolyte in a dry cell is a solution of ammonium chloride and manganese dioxide. The electrolyte dissolves the zinc electrode (the case of the cell), leaving an excess of electrons with the zinc. As the current is removed from the cell, the zinc, ammonium chloride, and manganese dioxide produce manganese dioxide, water, ammonia, and zinc chloride. The carbon rod (center electrode) gives up the extra electrons that accumulate on the zinc electrode. This type of cell produces as much as 1.75 to 1.8 volts when new.



Cells and Batteries

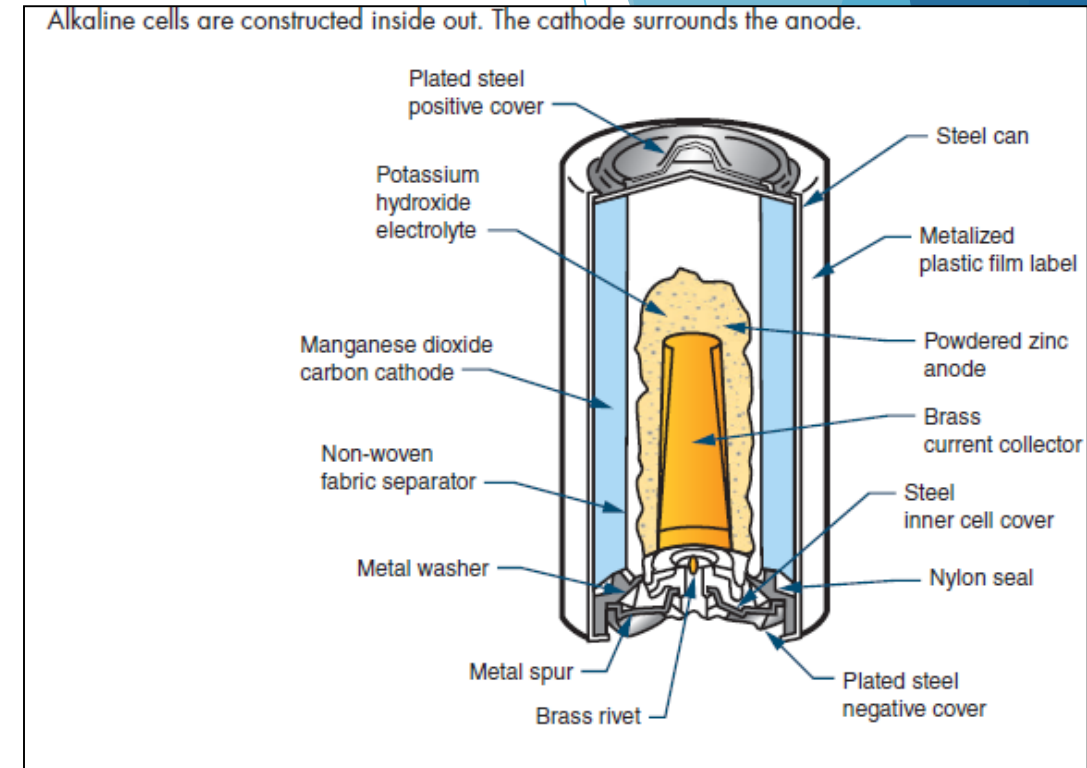
- ▶ As the cell is used, the chemical action decreases, and eventually the resulting current ceases. If the cell is not used, the electrolytic paste eventually dries out. The cell has a shelf life of about two years.
- ▶ The output voltage of this type of cell is determined entirely by the materials used for the electrolyte and the electrodes.
- ▶ The AAA cell, AA cell, C cell, and D cell (Figure) are all constructed of the same materials and therefore produce the same voltage.
- ▶ It should be noted that although the Leclanche cell is frequently referred to as a carbon-zinc (or zinc carbon) cell, the carbon does not take any part in the chemical reaction that produces electricity.

Some common examples of dry cells.



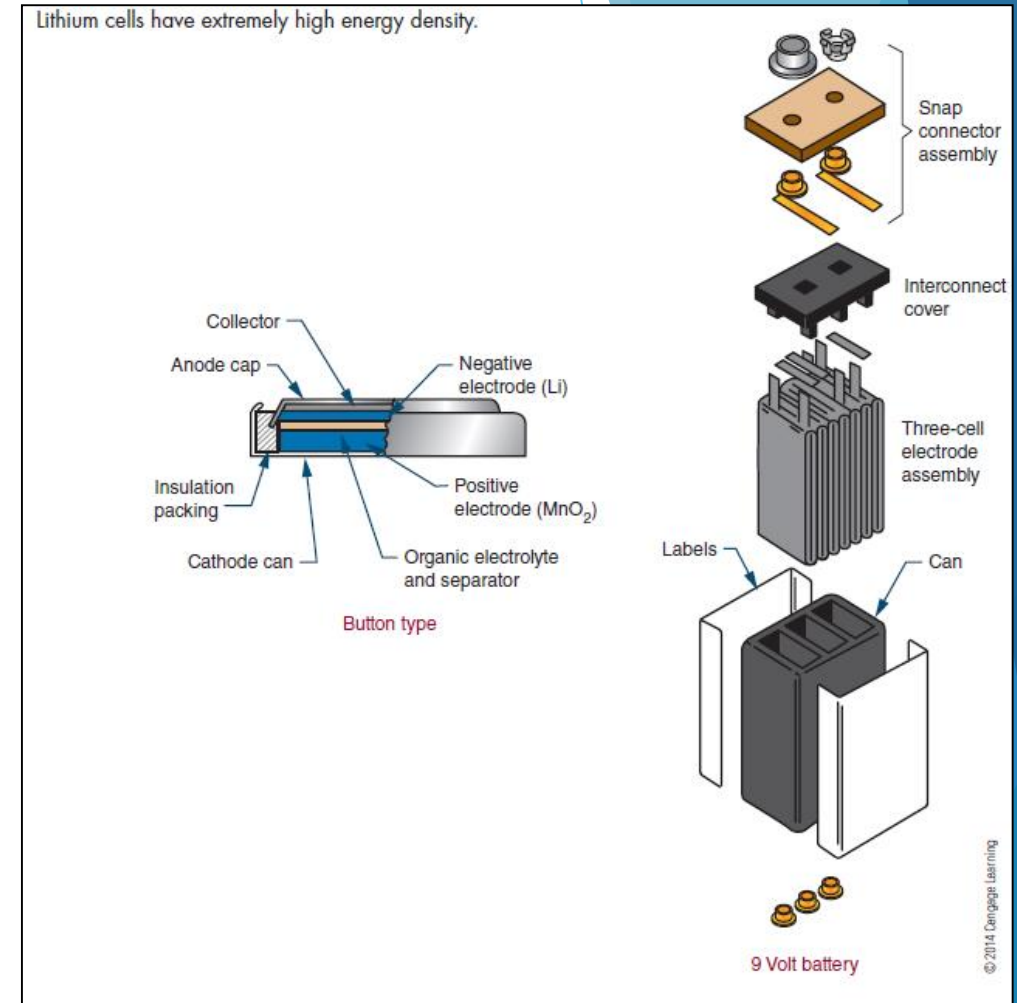
Cells and Batteries

- ▶ The **alkaline cell** is named because of the highly caustic base, potassium hydroxide (KOH), used as the electrolyte. The design of an alkaline cell on the outside is very similar to that of a carbon-zinc cell.
- ▶ However, the inside of the alkaline cell is significantly different (Figure).
- ▶ Alkaline cells have an open-circuit rating of approximately 1.52 volts, and an energy density of about 45 watt-hours per pound. The alkaline cell performs much better over temperature extremes than carbon-zinc cells.
- ▶ Alkaline cells perform best where moderate to high currents are drawn over extended periods of time.



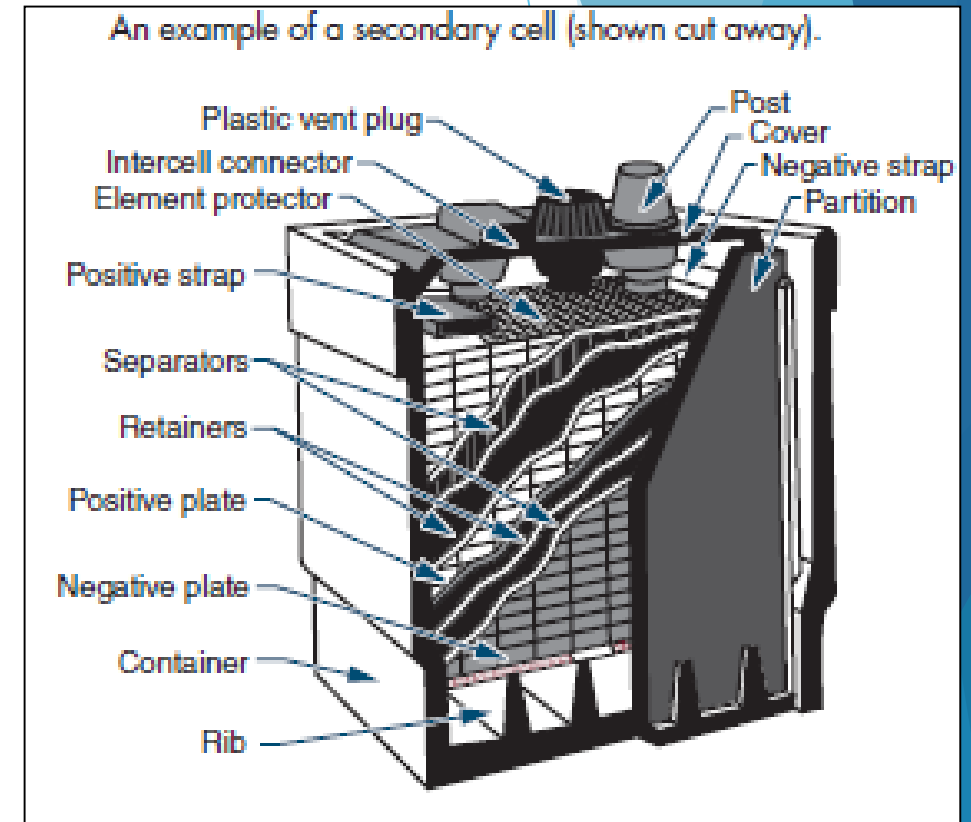
Cells and Batteries

- ▶ **Lithium cells** (Figure) have overcome the inherent properties associated with lithium.
- ▶ Lithium is extremely reactive with water.
- ▶ Lithium cell formation uses lithium, manganese dioxide (MnO_2), and a lithium perchlorate (LiClO_4) in an organic solvent (water cannot be used). The output of a lithium cell is approximately 3 volts.
- ▶ Lithium cells are very efficient, with energy densities of about 90 watt-hours per pound. The greatest benefit of lithium cells is their extremely long shelf life of 5 to 10 years.



Cells and Batteries

- ▶ A secondary cell is a cell that can be recharged by applying a reverse voltage. An example is the lead-acid battery used in automobiles (Figure).
- ▶ It is made of six 2-volt secondary cells connected in series. Each cell has a positive electrode of lead peroxide (PbO_2) and a negative electrode of spongy lead (Pb).
- ▶ The electrodes are separated by plastic or rubber and immersed in an electrolytic solution of sulfuric acid (H_2SO_4) and distilled water (H_2O). As the cell is discharged, the sulfuric acid combines with the lead sulfate, and the electrolyte converts to water.
- ▶ Recharging the cell involves applying a source of DC voltage greater than that produced by the cell.
- ▶ As the current flows through the cell, it changes the electrode back to lead peroxide and spongy lead and converts the electrolyte back to sulfuric acid and water. This type of cell is also referred to as a wet cell.



Cells and Batteries

- ▶ Another type of secondary cell is the **Nickel Cadmium (Ni-Cad) cell** (Figure). This is a dry cell that can be recharged many times and can hold its charge for long periods of time.
- ▶ It consists of a positive and a negative electrode, a separator, an electrolyte, and a package.
- ▶ The electrodes are comprised of a deposit of powdered nickel on a nickel wire screen, which is coated with a nickel salt solution for the positive electrode and a cadmium salt solution for a negative electrode.
- ▶ The separator is made of an absorbent insulating material. The electrolyte is potassium hydroxide. A steel can forms the package and is sealed tightly.
- ▶ A typical voltage from this type of cell is 1.2 volts.

A nickel-cadmium (Ni-Cad) battery is another example of a secondary cell.



Cells and Batteries

- ▶ The ability of a battery to deliver power continuously is expressed in ampere-hours.
- ▶ A battery rated at 100 ampere-hours can continuously supply any of the following:
 - ▶ 100 amperes for 1 hour ($100 \times 1 = 100$ ampere-hours),
 - ▶ 10 amperes for 10 hours ($10 \times 10 = 100$ ampere-hours),
 - ▶ or 1 ampere for 100 hours ($1 \times 100 = 100$ ampere-hours).

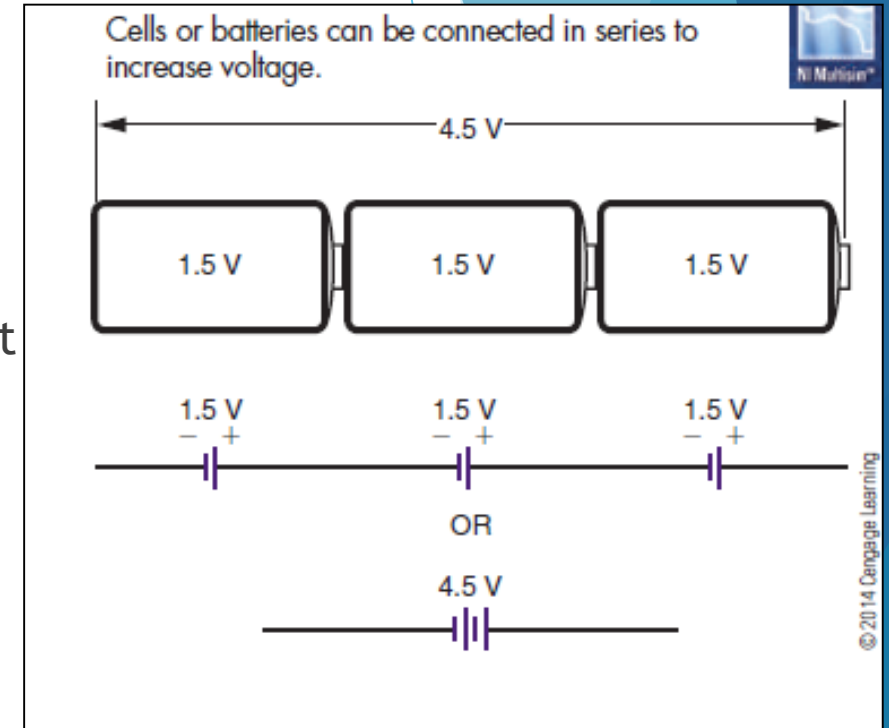
Connecting Cells and Batteries

- ▶ Cells and batteries can be connected together to increase voltage and/or current. They can be connected in **series**, in **parallel**, or in **series-parallel**.
- ▶ In series, cells or batteries can be connected in either **series-aiding** or **series-opposing** configurations.
- ▶ In a series-aiding configuration, the positive terminal of the first cell is connected to the negative terminal of the second cell; the positive terminal of the second cell is connected to the negative terminal of the third cell; and so on (Figure).
- ▶ In a series-aiding configuration, the same current flows through all the cells or batteries. This can be expressed as

$$I_T = I_1 = I_2 = I_3$$

- ▶ The subscript numbers refer to the number of each individual cell or battery. The total voltage is the sum of the individual cell voltages and can be expressed as

$$E_T = E_1 + E_2 + E_3$$



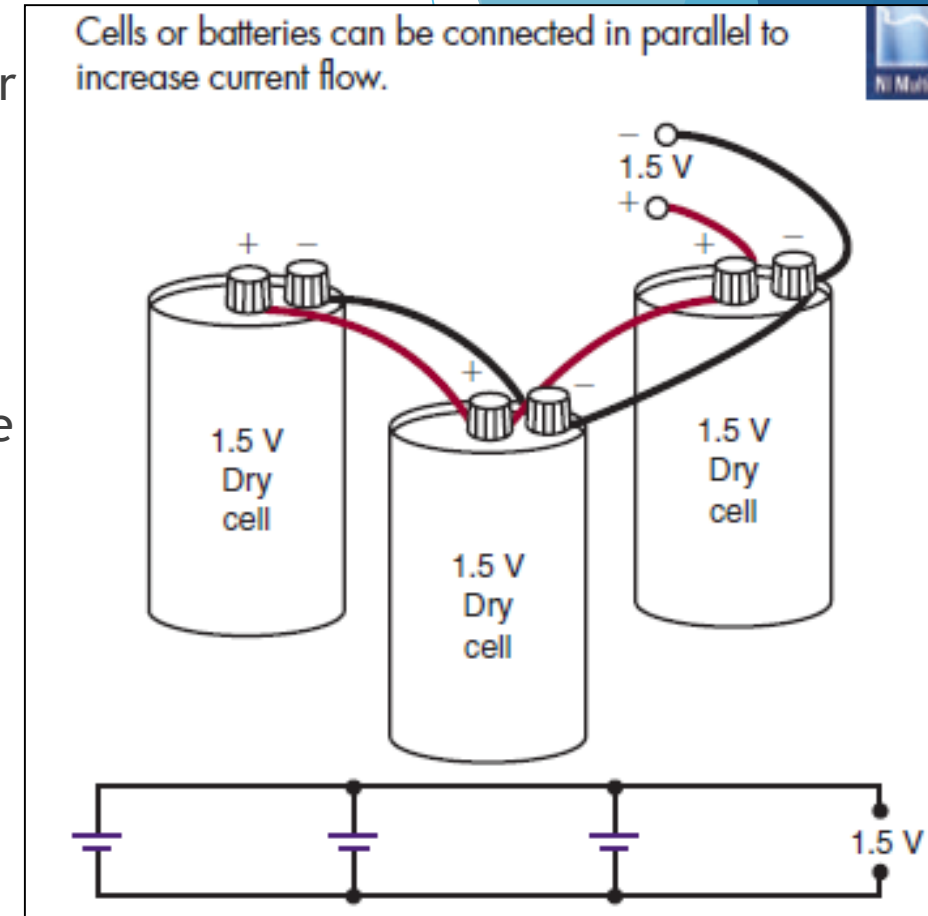
Connecting Cells and Batteries

- ▶ In a series-opposing configuration, the cells or batteries are connected with like terminals together, negative to negative or positive to positive.
- ▶ However, this configuration has little practical application.
- ▶ In a parallel configuration, all the positive terminals are connected together and all the negative terminals are connected together (Figure). The total current available is the sum of the individual currents of each cell or battery. This can be expressed as

$$I_T = I_1 + I_2 + I_3$$

- ▶ The total voltage is the same as the voltage of each individual cell or battery. This can be expressed as

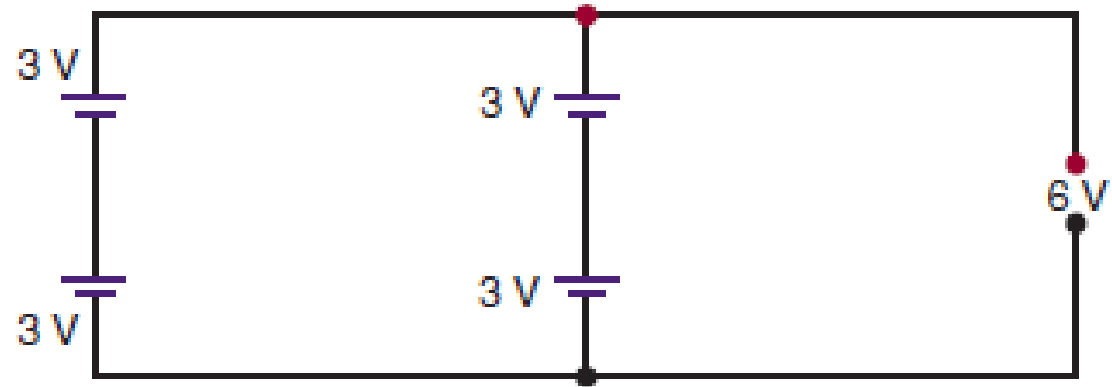
$$E_T = E_1 = E_2 = E_3$$



Connecting Cells and Batteries

- ▶ If both a higher voltage and a higher current are desired, the cells or batteries can be connected in a series-parallel configuration.
- ▶ Remember, connecting cells or batteries in series increases the voltage, and connecting cells or batteries in parallel increases the current.
- ▶ Figure shows four 3-volt batteries connected in a series-parallel configuration. This configuration produces a total voltage of 6 volts with a current twice that of an individual battery.

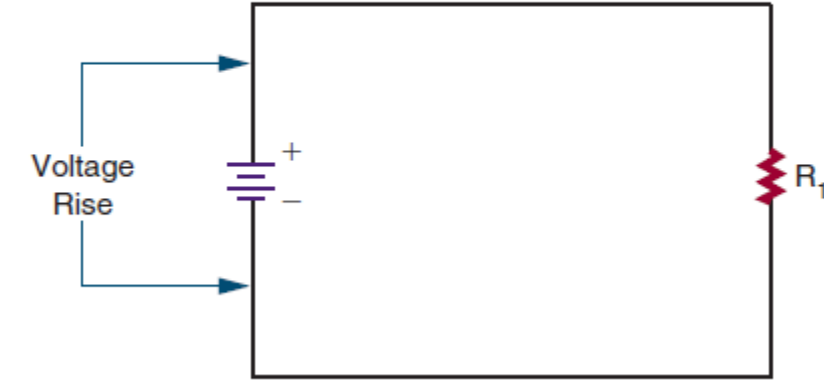
Cells and batteries can be connected in series-parallel to increase current and voltage output.



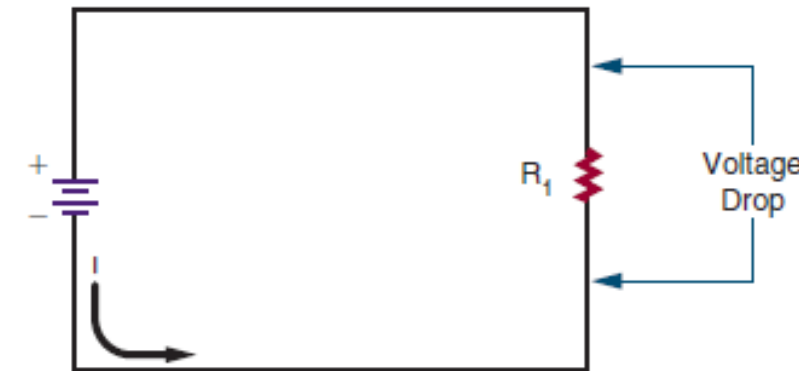
Voltage Rises and Voltage Drops

- ▶ In electric and electronic circuits, there are two types of voltage: **voltage rise** and **voltage drop**. Potential energy, or voltage, introduced into a circuit is called a voltage rise (Figure 1).
- ▶ The voltage is connected to the circuit so that the current flows from the negative terminal of the voltage source and returns to the positive terminal of the voltage source. A 12-volt battery connected to a circuit gives a voltage rise of 12 volts to the circuit.
- ▶ As the electrons flow through the circuit, they encounter a load, some resistance to the flow of electrons.
- ▶ As electrons flow through the load, they give up their energy. The energy given up is called a voltage drop (Figure 2). The energy is given up in most cases as heat. The energy that the electrons give up to a circuit is the energy given to them by the source.

A potential applied to a circuit is called a voltage rise.



The energy used by the circuit in a passing current through the load (resistance) is called a voltage drop. A voltage drop occurs when current flows in the circuit.



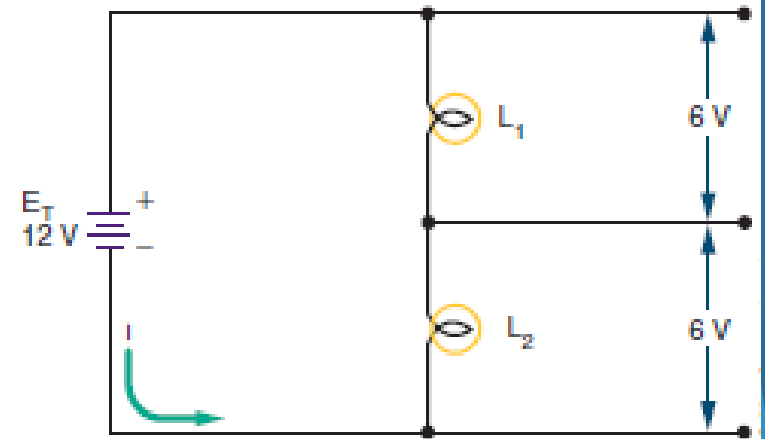
Voltage Rises and Voltage Drops

- ▶ To repeat, energy introduced into a circuit is called a voltage rise. Energy used up in a circuit by the load is called a voltage drop.
- ▶ A voltage drop occurs when there is a current flow in the circuit. Current moves through a circuit from the negative polarity to the positive polarity.
- ▶ The voltage source establishes the voltage rise from the negative terminal to the positive terminal.
- ▶ The voltage drop in a circuit equals the voltage rise of the circuit, because energy cannot be created or destroyed, only changed to another form.

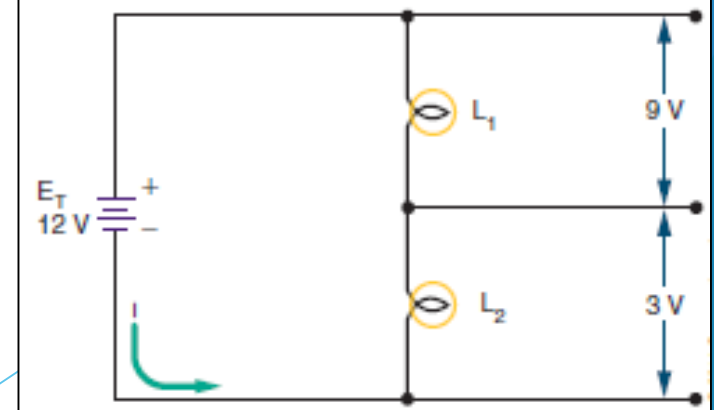
Voltage Rises and Voltage Drops

- ▶ If a 12-volt source is connected to a 12-volt lamp, the source supplies a 12-volt voltage rise, and the lamp produces a 12-volt voltage drop.
- ▶ All the energy is consumed in the circuit. If two identical 6-volt lamps are connected in series to the same 12-volt source (Figure 1), each lamp produces a 6-volt drop, for a total of 12 volts.
- ▶ If two different lamps are connected in series, such as a 9-volt lamp and a 3-volt lamp (Figure 2), the 9-volt lamp produces a voltage drop of 9 volts, and the 3-volt lamp produces a voltage drop of 3 volts. The sum of the voltage drops equals the voltage rise of 12 volts.

Two identical 6-volt lamps each produce a 6-volt drop when connected in series to a 12-volt source.



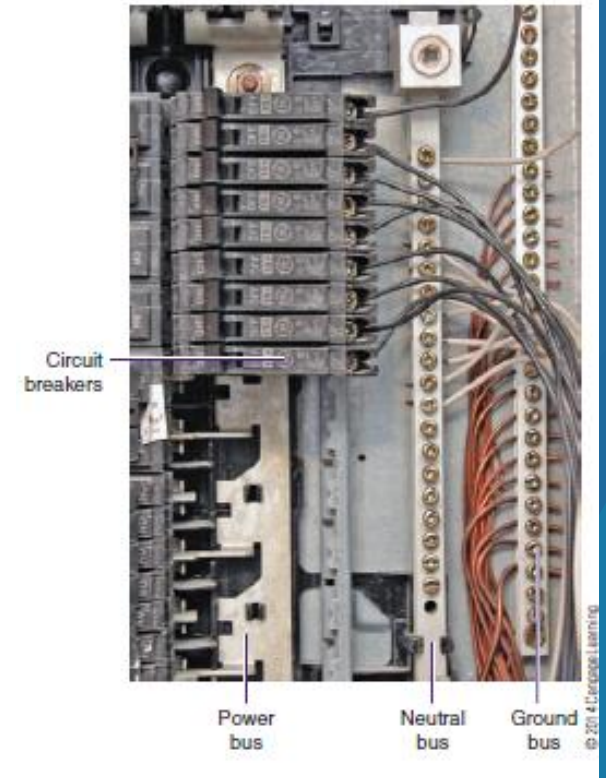
When two lamps of different voltage are connected in series to a 12-volt source, the voltage drop across each lamp differs, based on the voltage requirement of the lamp.



Ground as A Voltage Reference Model

- ▶ **Ground** is a term used to identify zero potential. All other potentials are either positive or negative with respect to ground. There are two types of grounds: earth and electrical.
- ▶ In the home, all electrical circuits and appliances are earth grounded. Consequently, no difference of potential exists between any two appliances or circuits.
- ▶ All circuits are tied to a common point in the circuit panel box (circuit breaker or fuse box) (Figure).
- ▶ This common point (the neutral bus) is then connected by a heavy copper wire to a copper rod driven into the earth or fastened to the metal pipe that supplies water to the home. This protects the user from electrical shock in case of a faulty connection.
- ▶ Electrical grounding is used in automobiles. Here the chassis of the automobile is used as a ground. This can be verified by seeing where the battery cables are attached to the automobile. Generally, the negative terminal is bolted directly to the frame of the automobile.
- ▶ This point or any other point on the frame of the automobile is considered to be ground. Ground serves as part of the complete circuit.

In a residential circuit panel box, all circuits are tied to a common point (the neutral bus).



Resistance

OBJECTIVES

After completing this section,

- ▶ Define resistance and explain its affect in a circuit.
- ▶ Determine the tolerance range of a resistor.
- ▶ Identify carbon composition, wirewound, and film resistors.
- ▶ Identify potentiometers and rheostats.
- ▶ Describe how a variable resistor operates.
- ▶ Decode a resistor's value using the color code or alphanumeric code.
- ▶ Identify the three types of resistor circuits.
- ▶ Calculate total resistance in series, parallel, and series-parallel circuits.

Resistance

- ▶ As previously mentioned, every material offers some resistance or opposition to the flow of current. Some conductors such as silver, copper, and aluminum offer very little resistance to current flow. Insulators such as glass, wood, and paper offer high resistance to current flow.
- ▶ The size and type of wires in an electric circuit are chosen to keep the electrical resistance as low as possible.
- ▶ This allows the current to flow easily through the conductor. In an electric circuit, the larger the diameter of the wire, the lower the electrical resistance to current flow.

Resistance

- ▶ Temperature also affects the resistance of an electrical conductor. In most conductors (copper, aluminum, and so on), resistance increases with temperature.
- ▶ Carbon is an exception because the resistance decreases as temperature increases. Certain alloys of metals (Manganin and Constantan) have resistance that does not change with temperature.
- ▶ The relative resistance of several conductors of the same length and cross section is shown in Figure.
- ▶ Silver is used as a standard of 1, and the remaining metals are arranged in order of ascending resistance.
- ▶ The resistance of an electric circuit is expressed by the symbol “R.” Manufactured circuit parts containing definite amounts of resistance are called resistors. Resistance (R) is measured in ohms (V). One ohm is the resistance of a circuit or circuit element that permits a steady current flow of 1 ampere (1 coulomb per second) when 1 volt is applied to the circuit.

Resistance of several conductors of the same length and cross-section area.

Conductor Material	Resistivity
Silver	1.000
Copper	1.0625
Lead	1.3750
Gold	1.5000
Aluminum	1.6875
Iron	6.2500
Platinum	6.2500

Conductance

- ▶ The term in electricity that is the opposite of resistance is **conductance (G)**.
- ▶ Conductance is the ability of a material to pass electrons. The unit of conductance is a **mho**, ohm spelled backwards. The symbol used to represent conductance is the inverted Greek letter omega (Υ).
- ▶ Conductance is the reciprocal of resistance and is measured in **Siemens (S)**. A reciprocal is obtained by dividing the number into 1.

$$R = 1/G$$

$$G = 1/R$$

- ▶ If the resistance of a material is known, dividing its value into 1 gives its conductance. Similarly, if the conductance is known, dividing its value into 1 gives its resistance.

Resistors

- ▶ Resistance is a property of all electrical components.
- ▶ Sometimes the effect of resistance is undesirable; other times it is constructive.
- ▶ **Resistors** are components manufactured to possess a specific value of resistance to the flow of current.
- ▶ A resistor is the most commonly used component in an electronic circuit.
- ▶ Resistors are available with fixed or variable resistance values. They are available in a variety of shapes and sizes to meet specific circuit, space, and operating requirements (Figure 1 and Figure 2).
- ▶ Resistors are drawn schematically as a series of jagged lines, as shown in Figure 3.

Fixed resistors come in various sizes and shapes.



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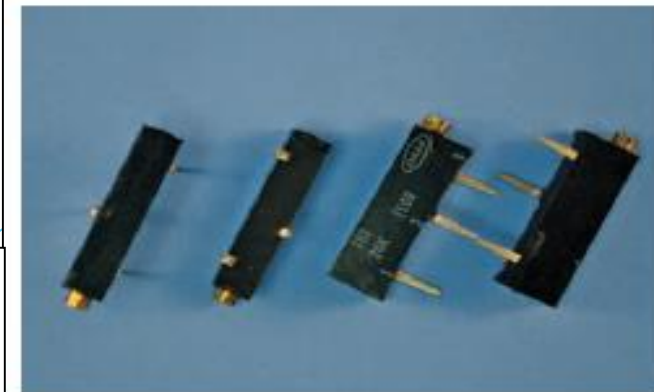
Variable resistors come in many styles to meet the needs of manufacturers of electronic equipment.



Potentiometers



Trimming potentiometers



Trim potentiometers

Schematic diagram of a fixed resistor.

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Resistors

- ▶ A resistor's **tolerance** is the amount that the resistor may vary and still be acceptable.
- ▶ It is expensive for a manufacturer to hold a resistor to a certain value when an exact value is not needed.
- ▶ Therefore, the larger the tolerance, the cheaper it is to manufacture. Resistors are available with tolerances of $\pm 20\%$, $\pm 10\%$, $\pm 5\%$, $\pm 2\%$, and $\pm 1\%$. Precision resistors are available with even smaller tolerances.
- ▶ In most electronic circuits, resistors of 10% tolerance are satisfactory.
- ▶ **Example:** How much can a 1000-ohm resistor with a 20% tolerance vary and still be acceptable?

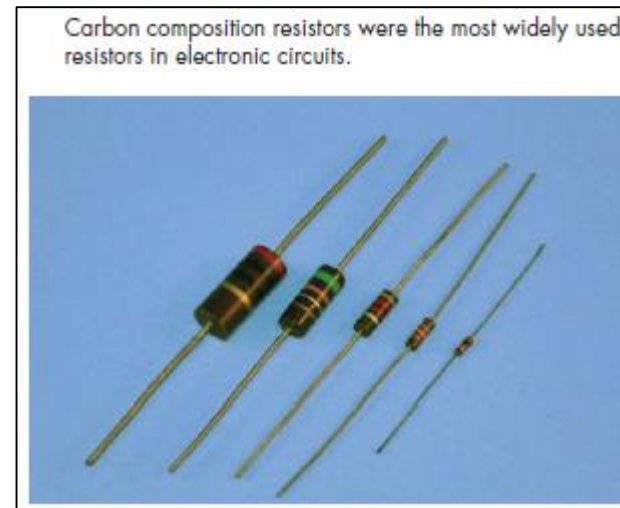
Solution:

$$1000 \times 0.20 = \pm 200 \text{ ohms}$$

- ▶ The tolerance is ± 200 ohms. Therefore, the 1000-ohm resistor may vary from 800 to 1200 ohms and still be satisfactory.

Resistors

- ▶ For the sake of uniformity, electronic manufacturers offer a number of standard resistor values. Figure 1 is a list of standard values for resistors with $\pm 5\%$, $\pm 10\%$, and $\pm 20\%$ tolerance. After the value on the chart is obtained, it is multiplied by the value associated with the color of the multiplier band.
- ▶ Resistors fall into three major categories, named for the material they are made of: molded **carbon composition resistors**, **wirewound resistors**, and **carbon film resistors**.
- ▶ Until recently, the molded carbon composition resistor was the most commonly used resistor in electronic circuits (Figure 2). It is manufactured in standard resistor values.



$\pm 2\%$ and $\pm 5\%$ Tolerance	$\pm 10\%$ Tolerance	$\pm 20\%$ Tolerance
1.0	1.0	1.0
1.1		
1.2	1.2	
1.3		
1.5	1.5	1.5
1.6		
1.8	1.8	
2.0		
2.2	2.2	2.2
2.4		
2.7	2.7	
3.0		
3.3	3.3	3.3
3.6		
3.9	3.9	
4.3		
4.7	4.7	4.7
5.1		
5.6	5.6	
6.2		
6.8	6.8	6.8
7.5		
8.2	8.2	
9.1		

Resistors

- ▶ The wirewound resistor is constructed of a nickelchromium alloy (nichrome) wire wound on a ceramic form (Figure 1). Leads are attached and the entire resistor is sealed with a coating. Wirewound resistors are used in high-current circuits where precision is necessary.
- ▶ The resistance range varies from a fraction of an ohm to several thousand ohms. Film resistors have become popular (Figure 2) because they offer the small size of the composition resistor with the accuracy of the wirewound resistor.
- ▶ A thin film of carbon is deposited on a cylindrical ceramic core and sealed in an epoxy or glass coating to form a carbon film resistor. Cutting a spiral Groove through the film, the length of the resistor, sets the value of the resistor. The closer the pitch of the spiral, the higher the resistance. Carbon film resistors are available from 10 ohms to 2.5 megohms at a $\pm 1\%$ tolerance.

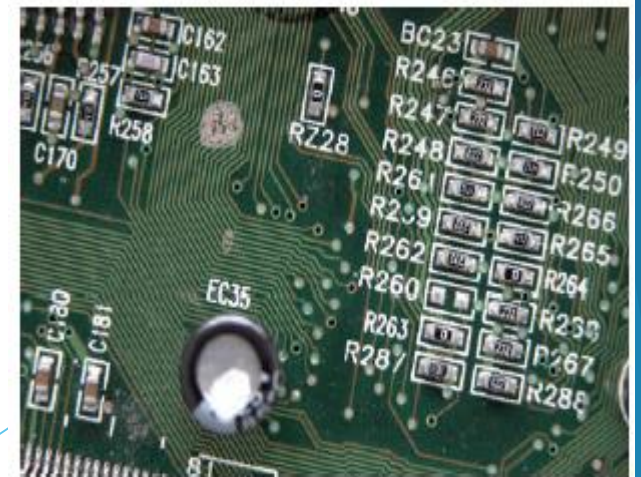
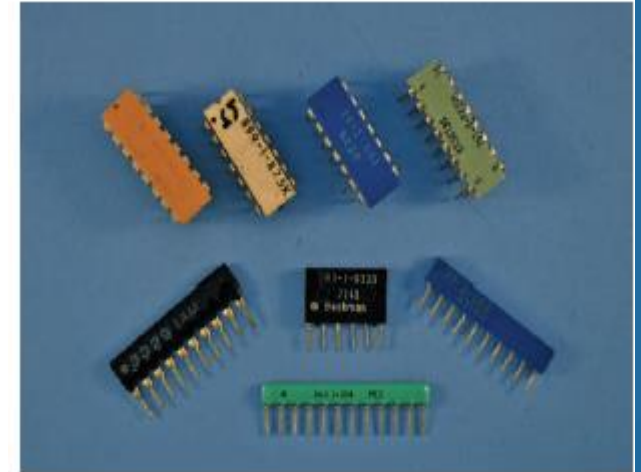
Wirewound resistors are available in many different styles.



Resistors

- ▶ **Metal film resistors** are physically similar to carbon film resistors but use a metal alloy and are more expensive.
- ▶ They are available from 10 ohms to 1.5 megohms at a $\pm 1\%$ tolerance, although tolerances down to $\pm 0.1\%$ are available. Another type of film resistor is the tin oxide resistor (Figure).
- ▶ It consists of a tin oxide film on a ceramic substrate and is also available in a single inline format or dual-inline pin format.
- ▶ **Surface-mount resistors** are ideal for small circuit applications. A thin film of carbon or metal alloy is deposited on a ceramic base or substrate.
- ▶ Contact from the resistive element to the printed circuit board is via metal end caps, or terminals, resulting in zero lead length. In application, these end caps are soldered directly to the circuit board conductive trace using an automated soldering process. The lack of long leads to solder into the printed circuit board yields several advantages. Among them are lightweight, smaller printed circuit board sizes and the use of automated assembly processes.
- ▶ Surface-mount resistors are available in both thick and thin films. They are available from 0 ohms to 10 megohms at tolerance of $\pm 5\%$ down to $\pm 0.1\%$, with power handling capabilities of 1/16 watt to 1 watt.

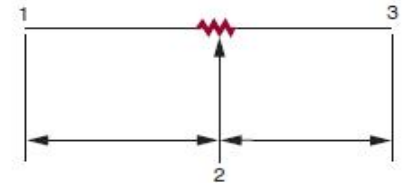
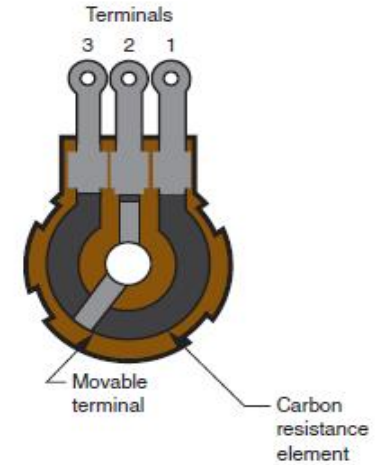
Tin oxide resistors.



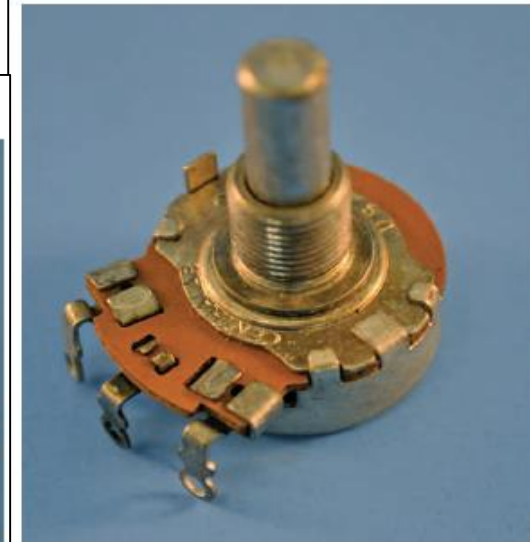
Resistors

- ▶ **Variable resistors** allow the resistance to vary.
- ▶ They have a resistive element of either carbon composition or wire that is connected to two terminals. A third terminal is attached to a movable wiper, which is connected to a shaft.
- ▶ The wiper slides along the resistive element when the shaft is rotated. As the shaft is rotated, the resistance between the center terminal and one outer terminal increases, whereas the resistance between the center terminal and the other outer terminal decreases (Figure 1).
- ▶ Variable resistors are available with resistance that varies linearly (a linear taper) or logarithmically (an audio taper).
- ▶ A variable resistor used to control voltage is called a **potentiometer**, or **pot**. A variable resistor used to control current is called a **rheostat** (Figure 2).

Variable resistors allow the resistance value to increase or decrease at random.



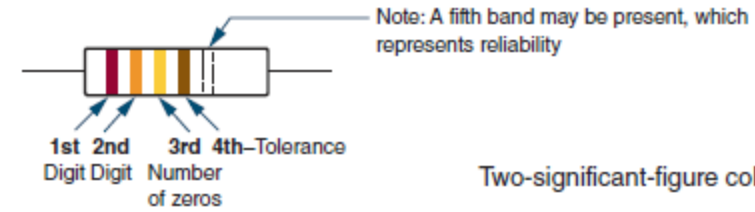
A rheostat is a variable resistor used to control current.



Resistor Identification

- ▶ The small size of the resistor prevents printing the resistance value and tolerance on its case. Therefore, a color-coded strip system is used to display the resistor value.
- ▶ The strips can be seen and read in any position that the resistor is placed. The Electronic Industries Association (EIA) color code is shown in Figure.
- ▶ The meaning of the colored bands on a resistor is as follows:
 - ▶ The first band, closest to the end of the resistor, represents the first digit of the resistor value.
 - ▶ The second band represents the second digit of the resistor value.
 - ▶ The third band represents the number of zeros to be added to the first two digits.
 - ▶ The fourth band represents the tolerance of the resistor (Figure 2).

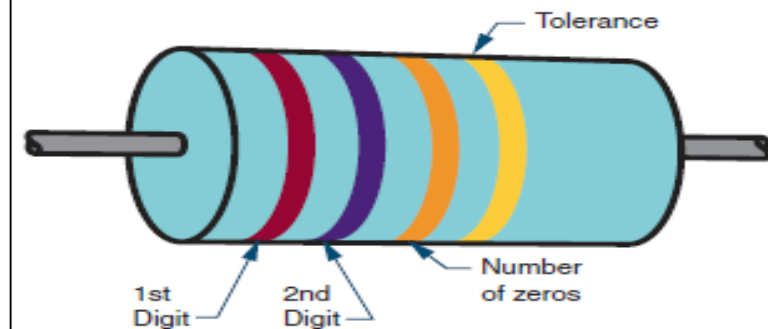
The Electronic Industries Association (EIA) two-significant digit color code.



Two-significant-figure color code

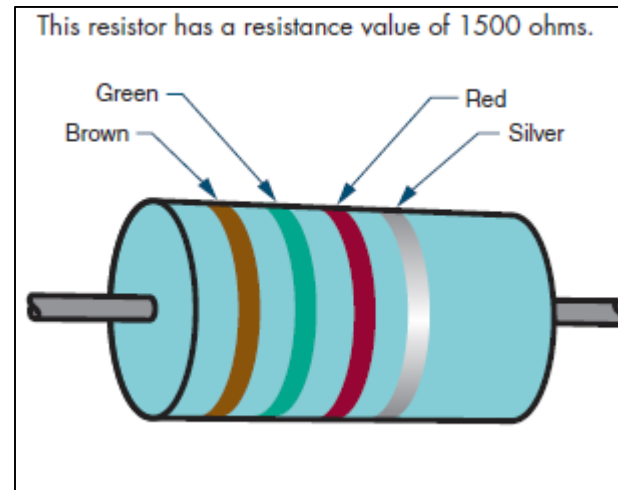
	1st Band 1st Digit	2nd Band 2nd Digit	3rd Band Number of Zeros	4th Band Tolerance
Black	0	0	—	—
Brown	1	1	0	1%
Red	2	2	00	2%
Orange	3	3	000	—
Yellow	4	4	0,000	—
Green	5	5	00,000	0.5%
Blue	6	6	000,000	0.25%
Violet	7	7		0.10%
Gray	8	8		0.05%
White	9	9		—
Gold			×0.1	5%
Silver			×0.01	10%
No color				20%

Meaning of the colored bands on a carbon composition resistor.



Resistor Identification

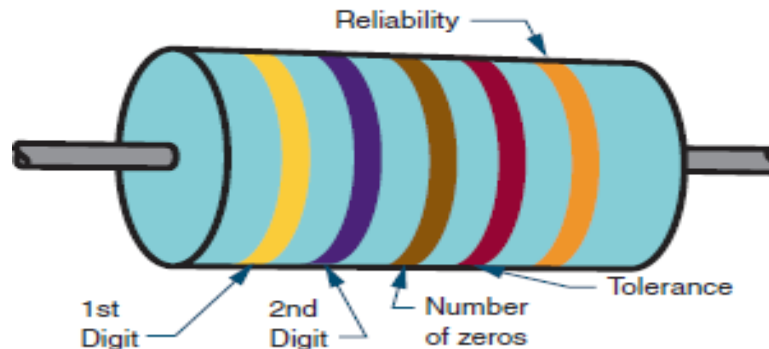
- ▶ For example, the resistor shown in Figure 3 has a resistance value of 1500 ohms.
- ▶ The brown band (first band) represents the first digit (1).
- ▶ The green band (second band) represents the second digit (5).
- ▶ The red band (third band) represents the number of zeros (2 zeros—00) to be added to the first two digits.
- ▶ The silver band (fourth band) indicates a resistance tolerance of 10%.
- ▶ Therefore, this is a 1500-ohm resistor with a $\pm 10\%$ tolerance.



Resistor Identification

- ▶ A resistor may have a fifth band (Figure). This band indicates the reliability of the resistor.
- ▶ It tells how many of the resistors (per thousand) will fail after 100 hours of operation.
- ▶ Generally, when there are five bands on a resistor, the same amount of body color shows at each end. In this case, look for the tolerance band, position it on the right, and read the resistor as described previously.
- ▶ There are two instances where the third band does not mean the number of zeros. For resistor values of less than 10 ohms, the third band is gold. This means that the first two digits should be multiplied by 0.1.
- ▶ For resistor values of less than 1 ohm, the third band is silver. This means the first two digits are multiplied by 0.01.

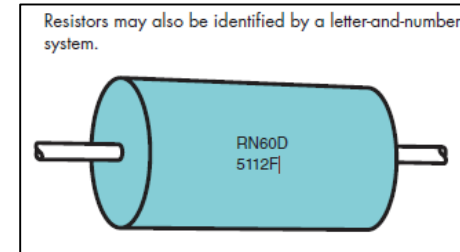
The fifth band on a resistor indicates the resistor's reliability.



Resistor Identification

- ▶ A resistor may also be identified by a letter-and-number (alphanumeric) system (Figure).
- ▶ For example, RN60D5112F has the following meaning:

RN60	Resistor style (composition, wirewound, film)
D	Characteristic (effects of temperature)
5112	Resistance value (2 represents the number of zeros)
F	Tolerance



- ▶ The resistor value is the primary concern. Three to five digits indicate the value of the resistor. In all cases, the last digit indicates the number of zeros to be added to the preceding digits. In the example given, the last digit (2) indicates the number of zeros to be added to the first three digits (511). So 5112 translates to 51,100 ohms.
- ▶ In some cases an R may be inserted into the number. The R represents a decimal point and is used when the resistor value is less than 10 ohms. For example, 4R7 represents 4.7 ohms.
- ▶ The five-digit numbering system is similar to the three- and four-digit systems. The first four digits represent significant digits, and the last digit indicates the number of zeros to be added. For values of less than 1000 ohms, the R is used to designate a decimal point.

Resistor Identification

- ▶ Surface-mount resistors are identified similar to the letter-and-number system. The part number of the resistor is interpreted as follows; the number varies between manufacturers. For example, RC0402J103T has the following meaning:
- ▶ The resistance value is indicated by three or four digits. In either case, the last digit indicates the number of zeros to be added to the preceding digits. In the example given, the first two digits are 1 and 0, followed by 3 zeroes, for a value of 10,000 ohms. For values of less than 100 or 1000 (depending on the number of digits used), D is used to designate the decimal point.
- ▶ For example, 3D9 would represent 3.9 ohms. A 0-ohm resistor or jumper is designated as 000.
- ▶ Potentiometers (variable resistors) are also imprinted with their values (Figure). These may be their actual values or an alphanumeric code.
- ▶ With the alphanumeric code system, the resistance value is determined from the last part of the code. For example, in MTC253L4, the number 253 means 25 followed by three 0s, or 25,000 ohms. The L4 indicates the resistor construction and body type.

RC	Chip resistor
0402	Size (0.04" × 0.02")
J	Tolerance (J = ±5%, F = ±1%, D = ±0.5%, B = ±0.1%)
103	Resistance (three- or four-digit code available)
T	Packaging method

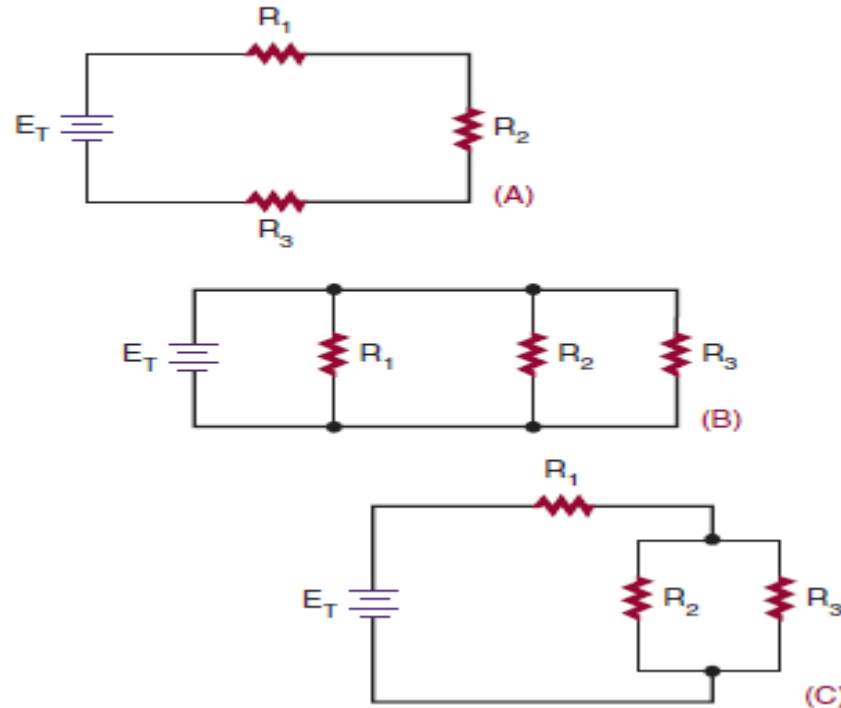
Potentiometers (variable resistors) are also labeled with their values.



Connecting Resistors

- ▶ There are three important types of resistive circuits: the **series circuit**, the **parallel circuit**, and the **series-parallel circuit** (Figure).
- ▶ A *series circuit* provides a single path for current flow. A *parallel circuit* provides two or more paths for current flow. A *series-parallel circuit* is a combination of a series circuit and a parallel circuit.

Three types of resistive circuits: (A) series circuit, (B) parallel circuit, (C) series-parallel circuit.



Connecting Resistors in Series

- ▶ A series circuit contains two or more resistors and provides one path for current to flow. The current flows from the negative side of the voltage source through each resistor to the positive side of the voltage source.
- ▶ If there is only one path for current to flow between two points in a circuit, the circuit is a series circuit.
- ▶ The more resistors connected in series, the more opposition there is to current flow. The more opposition there is to current flow, the higher the resistance in the circuit.
- ▶ In other words, when a resistor is added in series to a circuit, the total resistance in the circuit increases. The total resistance in a series circuit is the sum of the individual resistances in the circuit. This can be expressed as:

$$R_T = R_1 + R_2 + R_3 \dots + R_n$$

- ▶ The numerical subscripts refer to the individual resistors in the circuit. R_n is the last resistor in the circuit. The symbol R_T represents the total resistance in the circuit.

Connecting Resistors in Series

- What is the total resistance of the circuit shown in Figure?

Given

$$R_T = ?$$

$$R_1 = 10 \Omega$$

$$R_2 = 20 \Omega$$

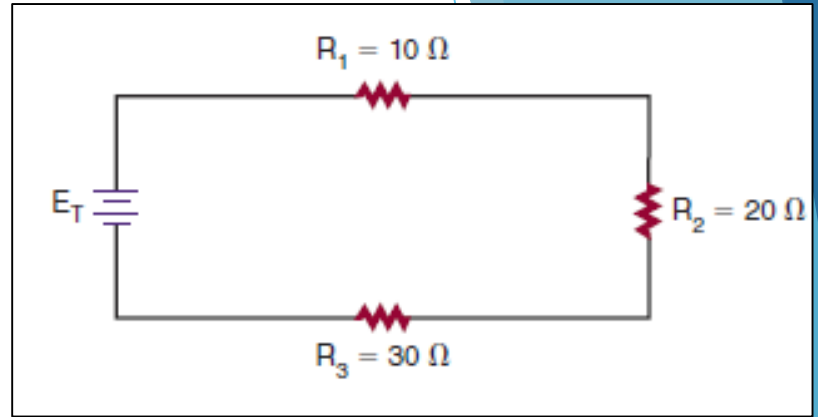
$$R_3 = 30 \Omega$$

Solution

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 10 + 20 + 30$$

$$R_T = 60 \Omega$$



- Calculate the total resistance for the circuit shown in Figure?

Given

$$R_T = ?$$

$$R_1 = 1 \text{ k}\Omega$$

$$R_2 = 4.7 \text{ k}\Omega$$

$$R_3 = 3.9 \text{ k}\Omega$$

$$R_4 = 820 \Omega$$

$$R_5 = 10 \text{ k}\Omega$$

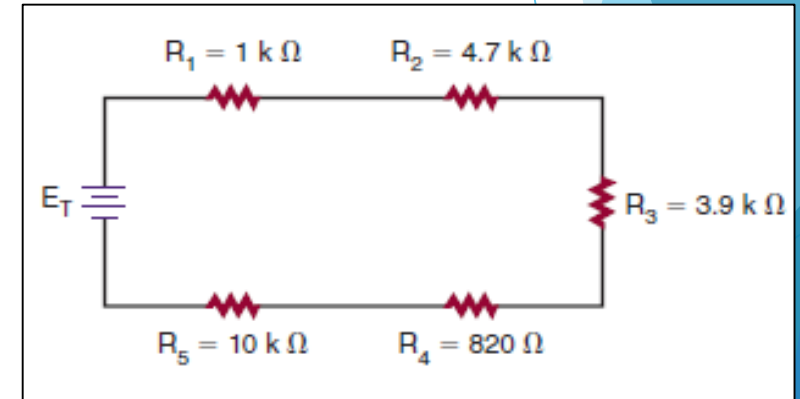
Solution

$$R_T = R_1 + R_2 + R_3 + R_4 + R_5$$

$$R_T = 1 \text{ k} + 4.7 \text{ k} + 3.9 \text{ k} + 0.82 \text{ k} + 10 \text{ k}$$

$$R_T = 1000 + 4700 + 3900 + 820 + 10,000$$

$$R_T = 20,420 \Omega$$



Connecting Resistors in Parallel

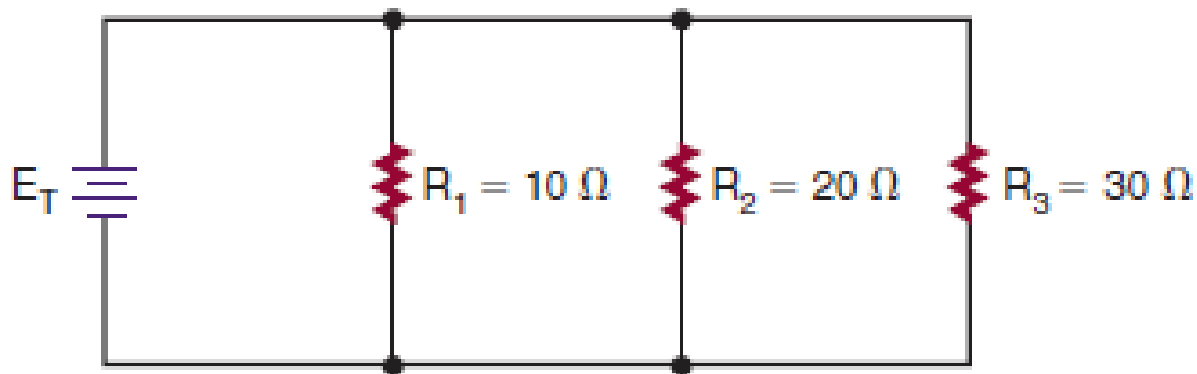
- ▶ A parallel circuit contains two or more resistors and provides two or more paths for current to flow. Each current path in a parallel circuit is called a **branch**.
- ▶ The current flows from the negative side of the voltage source, through each branch of the parallel circuit, to the positive side of the voltage source. If there is more than one path for current to flow between two points in a circuit with two or more resistors, the circuit is a parallel circuit.
- ▶ The more resistors are connected in parallel, the less opposition there is to current flow. The less opposition there is to current flow, the lower the resistance in the circuit. In other words, when a resistor is added in parallel to a circuit, the total resistance in the circuit decreases because additional paths for current flow are provided.
- ▶ In a parallel circuit, the total resistance is always less than the resistance of any branch.
- ▶ The total resistance in a parallel circuit is given by the formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots + \frac{1}{R_n}$$

- ▶ Again, R_T is the total resistance, R_1 , R_2 , and R_3 are the individual (branch) resistors, and R_n is the number of the last resistor in the circuit.

Connecting Resistors in Parallel

- What is the total resistance of the circuit shown in Figure?



Given

$$\begin{aligned}R_T &= ? \\R_1 &= 10 \Omega \\R_2 &= 20 \Omega \\R_3 &= 30 \Omega\end{aligned}$$

Solution

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} \quad (\text{common denominator is 60})$$

$$\frac{1}{R_T} = \frac{6}{60} + \frac{3}{60} + \frac{2}{60}$$

$$\frac{1}{R_T} = \frac{11}{60}$$

$$\frac{1}{R_T} \times \frac{11}{11} = \frac{11}{60} \times \frac{11}{11}$$

$$(11)(R_T) = (1)(60)$$

$$11R_T = 60$$

$$\frac{11R_T}{11} = \frac{60}{11} \quad (\text{divide both sides by 11})$$

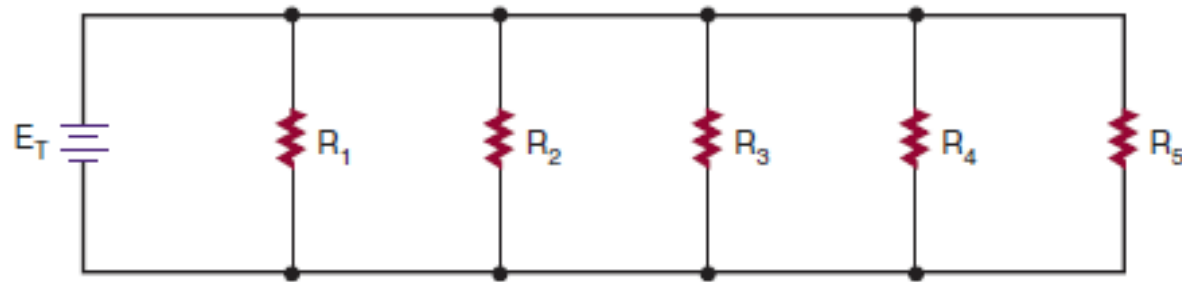
$$1R_T = \frac{60}{11}$$

$$R_T = 5.45 \Omega$$

The circuit shown in Figure 13-21 could be replaced with one 5.45Ω resistor.

Connecting Resistors in Parallel

- Calculate the total resistance for the circuit shown in Figure.



Given

$$R_T = ?$$

$$R_1 = 1 \text{ k}\Omega \text{ (1000 ohms)}$$

$$R_2 = 4.7 \text{ k}\Omega \text{ (4700 ohms)}$$

$$R_3 = 3.9 \text{ k}\Omega \text{ (3900 ohms)}$$

$$R_4 = 820 \Omega$$

$$R_5 = 10 \text{ k}\Omega \text{ (10,000 ohms)}$$

Solution

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_T} = \frac{1}{1000} + \frac{1}{4700} + \frac{1}{3900} + \frac{1}{820} + \frac{1}{10,000}$$

It is too complicated to find a common denominator, so work with decimals.

$$\frac{1}{R_T} = 0.001 + 0.000213 + 0.000256 + 0.00122 + 0.0001$$

$$\frac{1}{R_T} = 0.002789$$

$$\frac{1}{R_T} \times \frac{0.002789}{1} \text{ (Cross-multiply)}$$

$$(0.002789)(R_T) = (1)(1)$$

$$0.002789R_T = 1$$

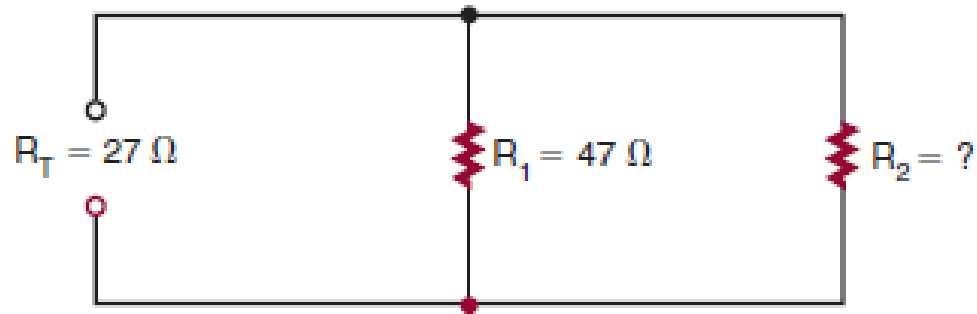
$$\frac{0.002789R_T}{0.002789} = \frac{1}{0.002789} \text{ (Divide both sides by 0.002789.)}$$

$$1R_T = \frac{1}{0.002789}$$

$$R_T = 358.55 \Omega$$

Connecting Resistors in Parallel

- What resistor value must be connected in parallel with a 47-ohm resistor to provide a total resistance of 27 ohms? See Figure.



Given

$$R_T = 27 \Omega$$

$$R_1 = 47 \Omega$$

$$R_2 = ?$$

Solution

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{27} = \frac{1}{47} + \frac{1}{R_2}$$

$$\frac{1}{27} - \frac{1}{47} = \frac{1}{47} - \frac{1}{47} + \frac{1}{R_2} \quad \text{Subtract } \frac{1}{47} \text{ from both sides.}$$

$$\frac{1}{27} - \frac{1}{47} = \frac{1}{R_2} \quad (\text{easier to work with decimals})$$

$$0.00370 - 0.0213 = \frac{1}{R_2}$$

$$0.0157 = \frac{1}{R_2}$$

$$63.69 \Omega = R_2$$

Note that 63.69 ohms is not a standard resistor value. Use the closest standard resistor value, which is 62 ohms.

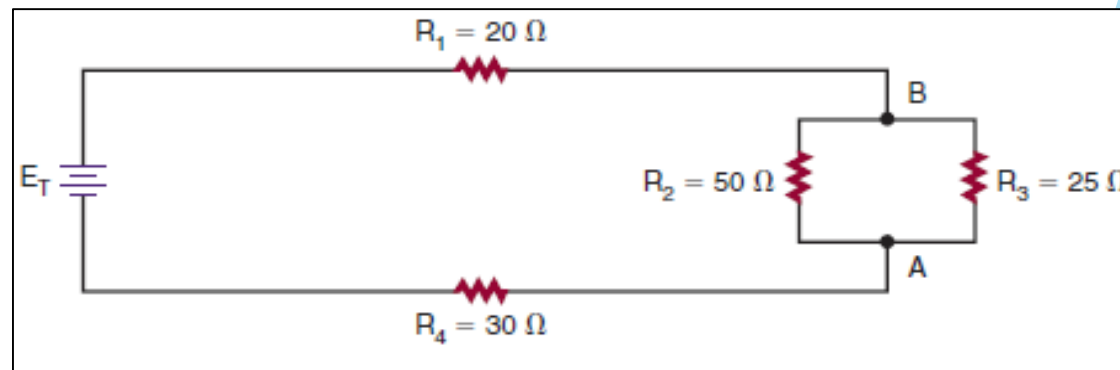
Connecting Resistors in Series and Parallel

- ▶ A series-parallel circuit is a combination of a series and a parallel circuit. Figure shows a simple series-parallel circuit with resistors.
- ▶ Notice that R2 and R3 are in parallel and that this parallel combination is in series with R1 and R4.
- ▶ The current flows from the negative side of the voltage source through resistor R4 and divides at point A to flow through the two branches, R2 and R3. At point B, the current recombines and flows through R1.
- ▶ The total resistance for a series-parallel circuit or compound circuit is computed using the series formula:

$$R_T = R_1 + R_2 + R_3 \dots + R_n$$

and the parallel formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots + \frac{1}{R_n}$$

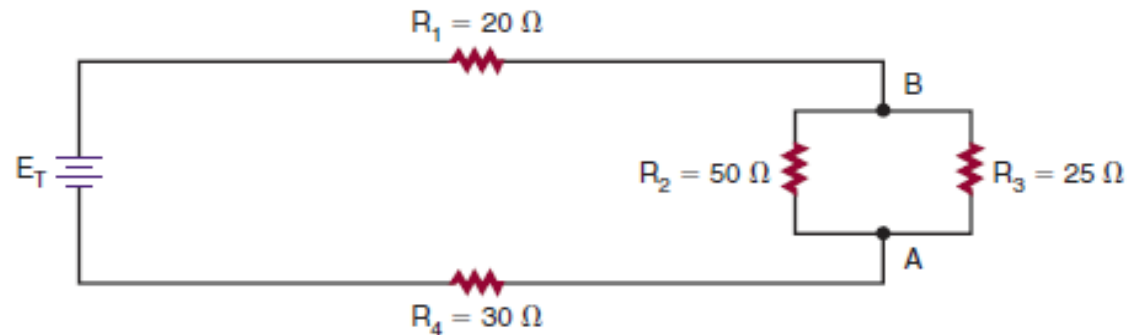


Connecting Resistors in Series and Parallel

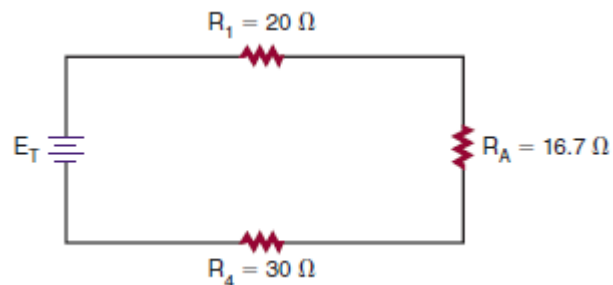
- ▶ Most circuits can be broken down to a simple parallel or series circuit. The procedure is as follows:
 1. Calculate the parallel portion of the circuit first to determine the equivalent resistance.
 2. If there are series components within the parallel portion of the circuit, determine the equivalent resistance for the series components first.
 3. After the equivalent resistance is determined, redraw the circuit, substituting the equivalent resistance for the parallel portion of the circuit.
 4. Do final calculations.

Connecting Resistors in Series and Parallel

- ▶ What is the total resistance for the circuit shown in Figure 1?



- ▶ *The first step is to determine the equivalent resistance (R_A) for R_2 and R_3 . Redraw the circuit, substituting the equivalent resistance for the parallel portion of the circuit. See Figure 2. Now determine the total series resistance for the redrawn circuit.*



Given

$$R_A = ?$$

$$R_2 = 50 \Omega$$

$$R_3 = 25 \Omega$$

Solution

$$\frac{1}{R_A} = \frac{1}{R_2} + \frac{1}{R_3}$$

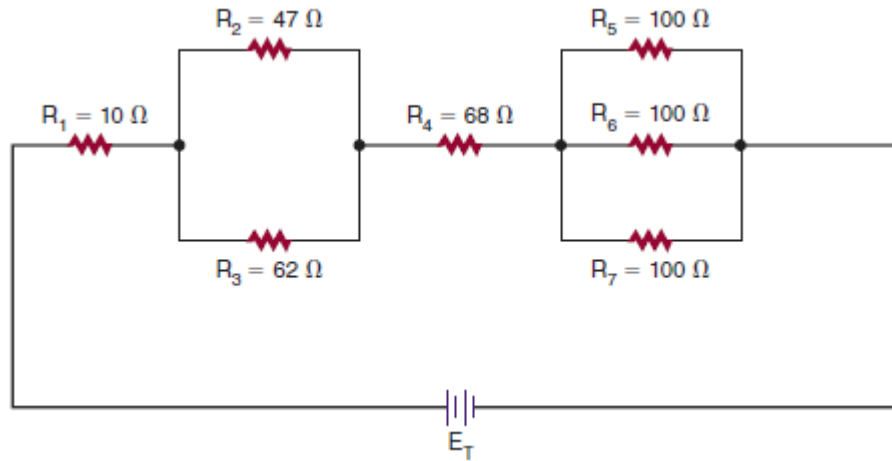
$$\frac{1}{R_A} = \frac{1}{50} + \frac{1}{25}$$

$$\frac{1}{R_A} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_A = 16.7 \Omega$$

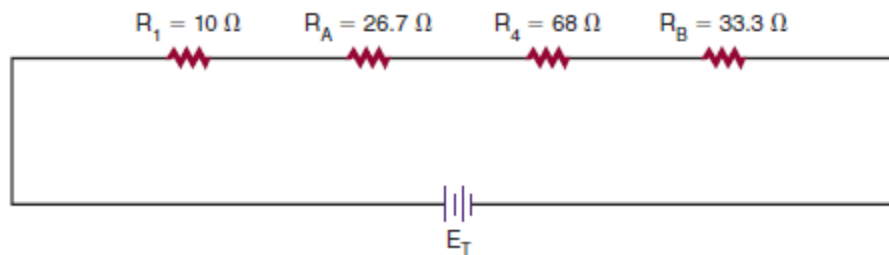
Connecting Resistors in Series and Parallel

- Calculate the total resistance for the circuit shown in Figure.



Given	Solution	Given	Solution
$R_A = ?$	$\frac{1}{R_A} = \frac{1}{R_2} + \frac{1}{R_3}$	$R_B = ?$	$\frac{1}{R_B} = \frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_7}$
$R_2 = 47 \Omega$		$R_5 = 100 \Omega$	
$R_3 = 62 \Omega$	$\frac{1}{R_A} = \frac{1}{47} + \frac{1}{62}$	$R_6 = 100 \Omega$	
	$R_A = 26.7 \Omega$	$R_7 = 100 \Omega$	$\frac{1}{R_B} = \frac{1}{100} + \frac{1}{100} + \frac{1}{100}$
			$R_B = 33.3 \Omega$

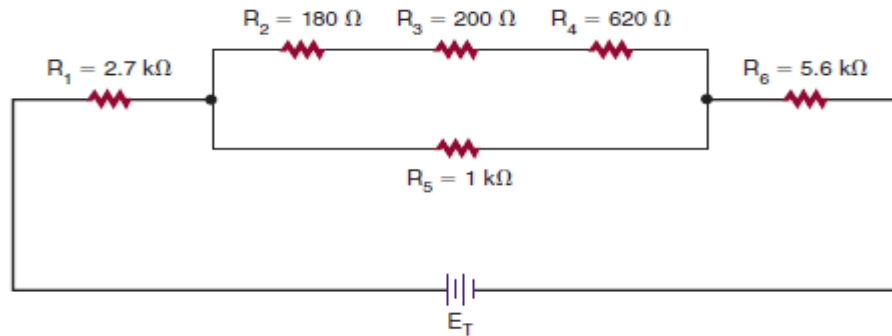
- First find the equivalent resistance (R_A) for parallel resistors R_2 and R_3 . Then find the equivalent resistance (R_B) for resistors R_5 , R_6 , and R_7 .



Given	Solution
$R_T = ?$	$R_T = R_1 + R_A + R_4 + R_B$
$R_1 = 10 \Omega$	$R_T = 10 + 26.7 + 68 + 33.3$
$R_A = 26.7 \Omega$	$R_T = 138 \Omega$
$R_4 = 68 \Omega$	
$R_B = 33.3 \Omega$	

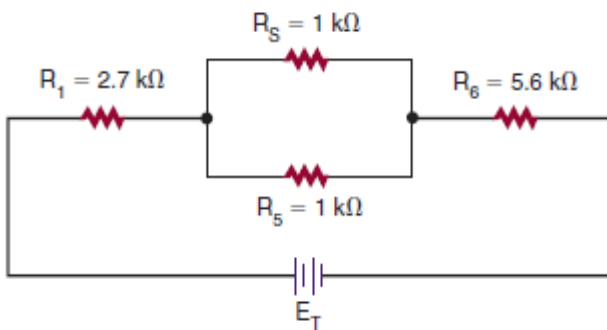
Connecting Resistors in Series and Parallel

- Find the total resistance for the circuit shown in Figure 1.

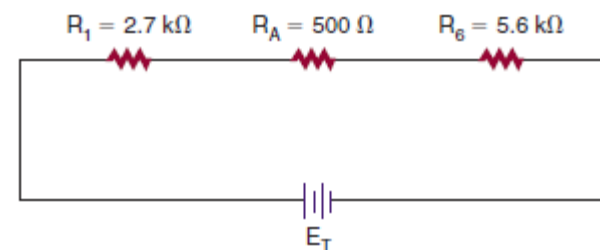


Given	Solution
$R_S = ?$	$R_S = R_2 + R_3 + R_4$
$R_2 = 180 \Omega$	$R_S = 180 + 200 + 620$
$R_3 = 200 \Omega$	$R_S = 1000 \Omega$
$R_4 = 620 \Omega$	

- The equivalent resistance of the series in the parallel portion of the circuit must be determined first. This is labeled R_S . Redraw the circuit, substituting equivalent resistance R_S for the series resistors R_2 , R_3 , and R_4 . See Figure 2. Determine the equivalent parallel resistance R_A for R_S and R_5 . Redraw the circuit again, substituting equivalent resistance R_A for parallel resistors R_S and R_5 , and determine the total series resistance for the redrawn circuit. See Figure 3.



Given	Solution
$R_A = ?$	$\frac{1}{R_A} = \frac{1}{R_S} + \frac{1}{R_5}$
$R_S = 1000 \Omega$	$\frac{1}{R_A} = \frac{1}{1000} + \frac{1}{1000}$
$R_5 = 1000 \Omega$	$R_A = 500 \Omega$



Given	Solution
$R_T = ?$	$R_T = R_1 + R_A + R_6$
$R_1 = 2700 \Omega$	$R_T = 2700 + 500 + 5600$
$R_A = 500 \Omega$	$R_T = 8800 \Omega$
$R_6 = 5600 \Omega$	

Ohm's Law

OBJECTIVES

After completing this chapter, the student will be able to:

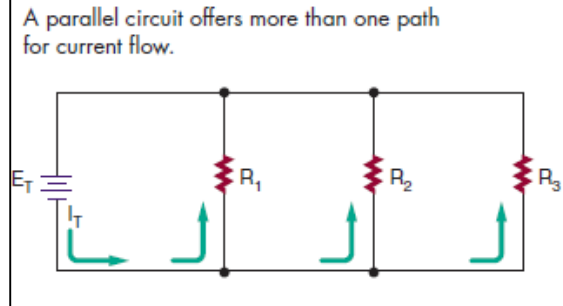
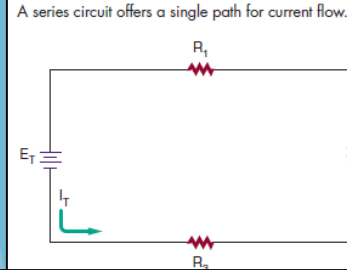
- ▶ Identify the three basic parts of a circuit.
- ▶ Identify three types of circuit configurations.
- ▶ Describe how current flow can be varied in a circuit.
- ▶ State Ohm's law with reference to current, voltage, and resistance.
- ▶ Solve problems using Ohm's law for current, resistance, or voltage in series, parallel, and series-parallel circuits.
- ▶ Describe how the total current flow differs between series and parallel circuits.
- ▶ Describe how the total voltage drop differs between series and parallel circuits.
- ▶ Describe how the total resistance differs between series and parallel circuits.
- ▶ State and apply Kirchhoff's current and voltage laws.
- ▶ Verify answers using Ohm's law with Kirchhoff's law.

Electrical Circuits

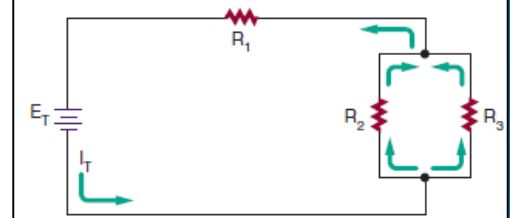
- ▶ As stated earlier, current flows from a point with an excess of electrons to a point with a deficiency of electrons. The path that the current follows is called an **electric circuit**. All electric circuits consist of a voltage source, a load, and a conductor. The voltage source establishes a difference of potential that forces the current to flow. The source can be a battery, a generator, or another of the devices described in Chapter of Voltage. The **load** consists of some type of resistance to current flow. The resistance may be high or low, depending on the purpose of the circuit.
- ▶ The current in the circuit flows through a conductor from the source to the load. The conductor must give up electrons easily. Copper is used for most conductors.

Electrical Circuits

- ▶ The path the electric current takes to the load may be through any of three types of circuits: a series circuit, a parallel circuit, or a series-parallel circuit.
- ▶ A series circuit (Figure 1) offers a single continuous path for the current flow, going from the source to the load.
- ▶ A parallel circuit (Figure 2) offers more than one path for current flow. It allows the source to apply voltage to more than one load. It also allows several sources to be connected to a single load.
- ▶ A seriesparallel circuit (Figure 3) is a combination of the series and parallel circuits.
- ▶ Current in an electric circuit flows from the negative side of the voltage source through the load to the positive side of the voltage source (Figure 4).
- ▶ As long as the path is not broken, it is a closed circuit and current flows (Figure 5). However, if the path is broken, it is an open circuit and no current can flow (Figure 6).



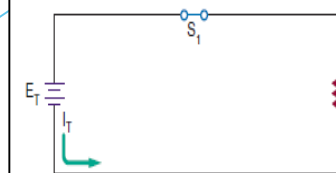
A series-parallel circuit is a combination of a series circuit and a parallel circuit.



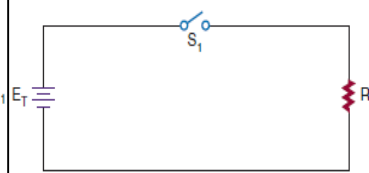
Current flow in an electric circuit flows from the negative side of the voltage source, through the load, and returns to the voltage source through the positive terminal.



A closed circuit supports current flow.

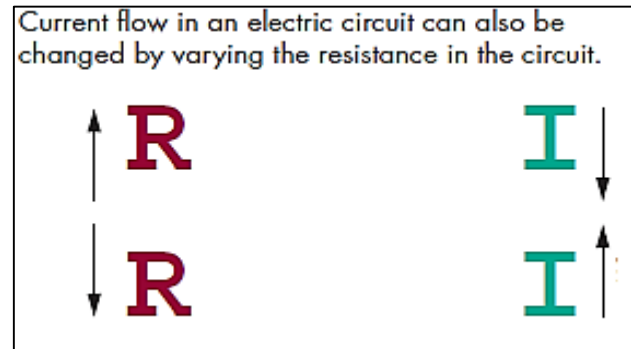
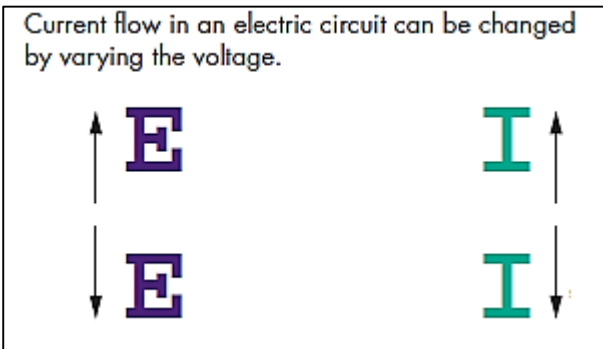


An open circuit does not support current flow.



Electrical Circuits

- ▶ Changing either the voltage applied to the circuit or the resistance in the circuit can vary the current flow in an electric circuit. The current changes in exact proportion to the change in the voltage or resistance.
- ▶ If the voltage is increased, the current also increases.
- ▶ If the voltage is decreased, the current also decreases (Figure 1).
- ▶ On the other hand, if the resistance is increased, the current decreases (Figure 2).



Ohm's Law

- ▶ In 1827, George Ohm first observed **Ohm's law**, or the relationship among current, voltage, and resistance.
- ▶ Ohm's law states that the current in an electric circuit is directly proportional to the voltage and inversely proportional to the resistance in a circuit.
- ▶ This may be expressed as follows:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or} \quad I = \frac{E}{R}$$

where

I = current in amperes

E = voltage in volts

R = resistance in ohms

- ▶ Whenever two of the three quantities are known, the third quantity can always be determined.

Ohm's Law

- ▶ How much current flows in the circuit shown in Figure 1?



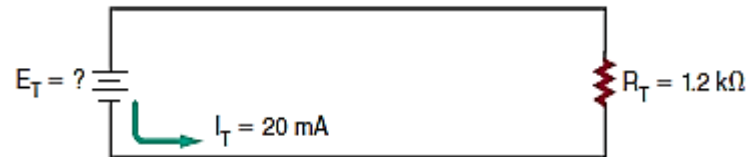
Solution

$$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{12}{1000}$$

$$I_T = 0.012\text{ amp, or 12 milliamps}$$

- ▶ In the circuit shown in Figure 2, how much voltage is required to produce 20 milliamps of current flow?



Given

$$I_T = 20\text{ mA} = 0.02\text{ amp}$$

$$E_T = ?$$

$$R_T = 1.2\text{ k}\Omega = 1200\text{ ohms}$$

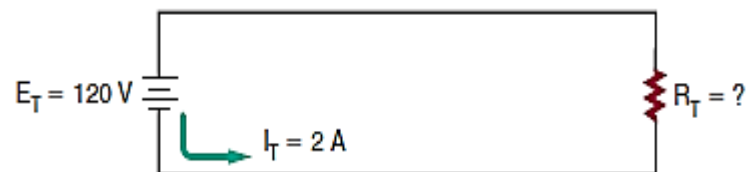
Solution

$$I_T = \frac{E_T}{R_T}$$

$$0.02 = \frac{E_T}{1200}$$

$$E_T = 24\text{ volts}$$

- ▶ What resistance value is needed for the circuit shown in Figure 3 to draw 2 amperes of current?



Given

$$I_T = 2\text{ amps}$$

$$E_T = 120\text{ volts}$$

$$R_T = ?$$

Solution

$$I_T = \frac{E_T}{R_T}$$

$$2 = \frac{120}{R_T}$$

$$60\text{ ohms} = R_T$$

Application of Ohm's Law

- ▶ In a series circuit (Figure 1), the same current flows throughout the circuit.

$$I_T = I_{R_1} = I_{R_2} = I_{R_3} \dots = I_{R_n}$$

- ▶ The total voltage in a series circuit is equal to the voltage drop across the individual loads (resistance) in the circuit.

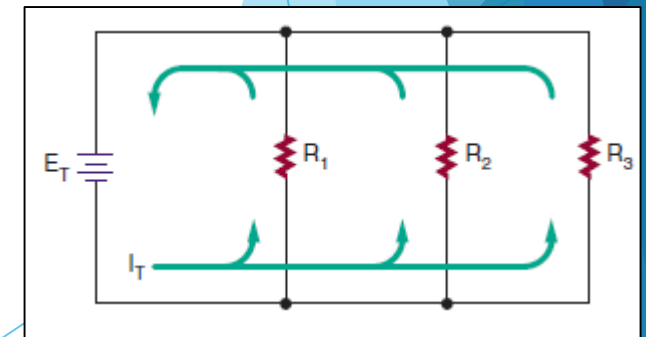
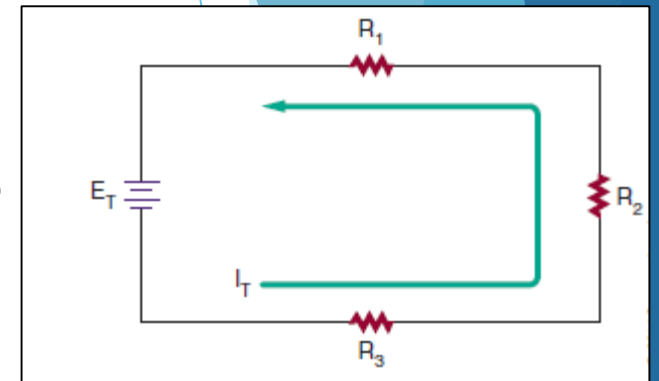
$$E_T = E_{R_1} + E_{R_2} + E_{R_3} \dots + E_{R_n}$$

- ▶ The total resistance in a series circuit is equal to the sum of the individual resistances in the circuit.

$$R_T = R_1 + R_2 + R_3 \dots + R_n$$

- ▶ In a parallel circuit (Figure 2), the same voltage is applied to each branch in the circuit.

$$E_T = E_{R_1} = E_{R_2} = E_{R_3} \dots = E_{R_n}$$



Application of Ohm's Law

- ▶ The total current in a parallel circuit is equal to the sum of the individual branch currents in the circuit.

$$I_T = I_{R_1} + I_{R_2} + I_{R_3} \dots + I_{R_n}$$

- ▶ The reciprocal of the total resistance is equal to the sum of the reciprocals of the individual branch resistances.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots + \frac{1}{R_n}$$

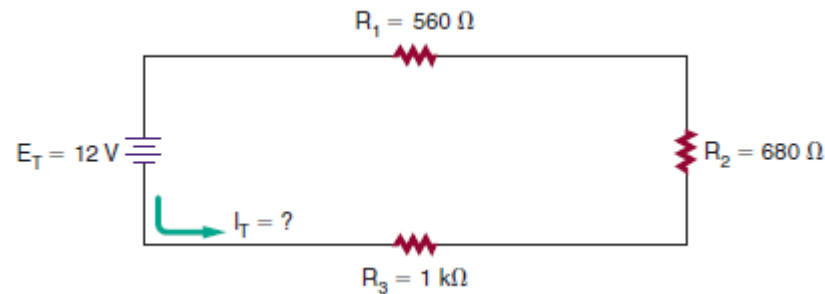
- ▶ The total resistance in a parallel circuit will always be smaller than the smallest branch resistance.
- ▶ Ohm's law states that the current in a circuit (series, parallel, or series-parallel) is directly proportional to the voltage and inversely proportional to the resistance.

$$I = \frac{E}{R}$$

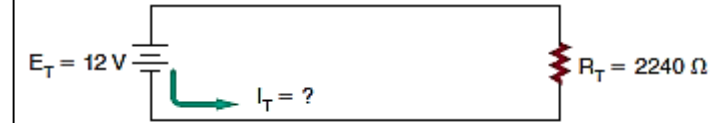
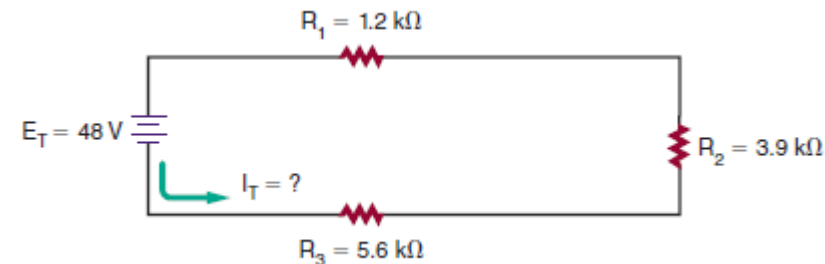
- ▶ In determining unknown quantities in a circuit, follow these steps:
 1. Draw a schematic of the circuit and label all known quantities.
 2. Solve for equivalent circuits and redraw the circuit.
 3. Solve for the unknown quantities.

Application of Ohm's Law

- What is the total current flow in the circuit shown in Figure 1?



- How much voltage is dropped across resistor R_2 in the circuit shown in Figure 2?



Given

$$I_T = ?$$

$$E_T = 12\text{ volts}$$

$$R_T = ?$$

$$R_1 = 560\text{ ohms}$$

$$R_2 = 680\text{ ohms}$$

$$R_3 = 1\text{ k}\Omega = 1000\text{ ohms}$$

Solution

First solve for the total resistance of the circuit:

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 560 + 680 + 1000$$

$$R_T = 2240\text{ ohms}$$

Draw an equivalent circuit. See Figure 14-15. Now solve for the total current flow:

$$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{12}{2240}$$

$$I_T = 0.0054\text{ amp, or } 5.4\text{ milliamp}$$

Given

$$I_T = ?$$

$$E_T = 48\text{ volts}$$

$$R_T = ?$$

$$R_1 = 1.2\text{ k}\Omega = 1200\text{ ohms}$$

$$R_2 = 3.9\text{ k}\Omega = 3900\text{ ohms}$$

$$R_3 = 5.6\text{ k}\Omega = 5600\text{ ohms}$$

Solution

First solve for the total circuit resistance:

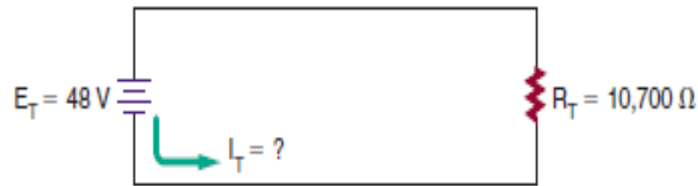
$$R_T = R_1 + R_2 + R_3$$

$$R_T = 1200 + 3900 + 5600$$

$$R_T = 10,700\text{ ohms}$$

Application of Ohm's Law

- Draw the equivalent circuit. See Figure 1. Solve for the total current in the circuit



$$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{48}{10,700}$$

$$I_T = 0.0045 \text{ amp, or 4.5 milliamps}$$

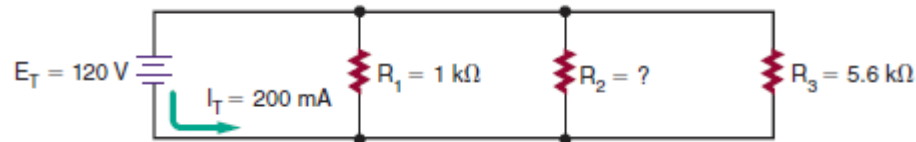
Remember, in a series circuit, the same current flows throughout the circuit. Therefore, $I_{R_2} = I_T$.

$$I_{R_2} = \frac{E_{R_2}}{R_2}$$

$$0.0045 = \frac{E_{R_2}}{3900}$$

$$E_{R_2} = 17.55 \text{ volts}$$

- What is the value of R_2 in the circuit shown in Figure ?



First solve for the current that flows through R_1 and R_3 . Because the voltage is the same in each branch of a parallel circuit, each branch voltage is equal to the source voltage of 120 volts.

Given

$$I_{R_1} = ?$$

$$E_{R_1} = 120 \text{ volts}$$

$$R_1 = 1000 \text{ ohms}$$

Solution

$$I_{R_1} = \frac{E_{R_1}}{R_1}$$

$$I_{R_1} = \frac{120}{1000}$$

$$I_{R_1} = 0.12 \text{ amp}$$

Given

$$I_{R_3} = ?$$

$$E_{R_3} = 120 \text{ volts}$$

$$R_3 = 1000 \text{ ohms}$$

Solution

$$I_{R_3} = \frac{E_{R_3}}{R_3}$$

$$I_{R_3} = \frac{120}{5600}$$

$$I_{R_3} = 0.021 \text{ amp}$$

In a parallel circuit, the total current is equal to the sum of the currents in the branch currents.

Given

$$I_T = 0.200 \text{ amp}$$

$$I_{R_1} = 0.120 \text{ amp}$$

$$I_{R_2} = ?$$

$$I_{R_3} = 0.021 \text{ amp}$$

Solution

$$I_T = I_{R_1} + I_{R_2} + I_{R_3}$$

$$0.200 = 0.120 + I_{R_2} + 0.021$$

$$0.200 = 0.141 + I_{R_2}$$

$$0.200 - 0.141 = I_{R_2}$$

$$0.059 \text{ amp} = I_{R_2}$$

Resistor R_2 can now be determined using Ohm's law.

Given

$$I_{R_2} = 0.059 \text{ amp}$$

$$E_{R_2} = 120 \text{ volts}$$

$$R_2 = ?$$

Solution

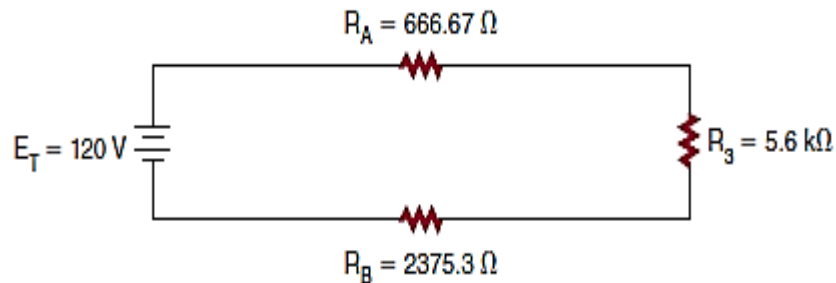
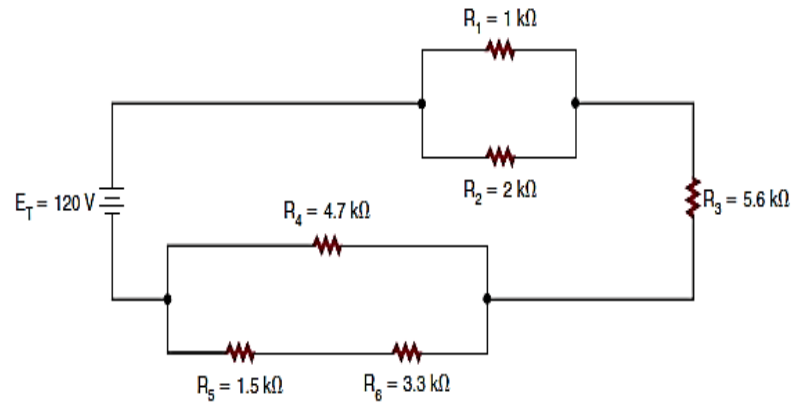
$$I_{R_2} = \frac{E_{R_2}}{R_2}$$

$$0.059 = \frac{120}{R_2}$$

$$R_2 = 2033.9 \text{ ohms}$$

Application of Ohm's Law

- What is the current through R3 in the circuit shown in Figure 1?



First determine the equivalent resistance (R_A) for resistors R_1 and R_2 .

Given

$$\begin{aligned} R_A &= ? \\ R_1 &= 1000 \text{ ohms} \\ R_2 &= 2000 \text{ ohms} \end{aligned}$$

Solution

$$\begin{aligned} \frac{1}{R_A} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_A} &= \frac{1}{1000} + \frac{1}{2000} \\ R_A &= 666.67 \text{ ohms} \end{aligned}$$

Then determine the equivalent resistance (R_B) for resistors R_4 , R_5 and R_6 . First, find the total series resistance (R_S) for resistors R_5 and R_6 .

Given

Solution

$$\begin{aligned} R_S &= ? & R_S &= R_5 + R_6 \\ R_5 &= 1500 \text{ ohms} & R_S &= 1500 + 3300 \\ R_6 &= 3300 \text{ ohms} & R_S &= 4800 \text{ ohms} \end{aligned}$$

Given

$$\begin{aligned} R_B &= ? \\ R_4 &= 4700 \text{ ohms} \\ R_S &= 4800 \text{ ohms} \end{aligned}$$

Solution

$$\begin{aligned} \frac{1}{R_B} &= \frac{1}{R_4} + \frac{1}{R_S} \\ \frac{1}{R_B} &= \frac{1}{4700} + \frac{1}{4800} \\ R_B &= 2374.74 \text{ ohms} \end{aligned}$$

Redraw the equivalent circuit substituting R_A and R_B and find the total series resistance of the equivalent circuit. See Figure 14-20.

Given

$$\begin{aligned} R_T &= ? \\ R_A &= 666.67 \text{ ohms} \\ R_3 &= 5600 \text{ ohms} \\ R_B &= 2374.74 \text{ ohms} \end{aligned}$$

Solution

$$\begin{aligned} R_T &= R_A + R_3 + R_B \\ R_T &= 666.67 + 5600 + 2374.74 \\ R_T &= 8641.41 \text{ ohms} \end{aligned}$$

Now solve for the total current through the equivalent circuit, using Ohm's law.

Given

$$\begin{aligned} I_T &= ? \\ E_T &= 120 \text{ volts} \\ R_T &= 8641.41 \text{ ohms} \end{aligned}$$

Solution

$$\begin{aligned} I_T &= \frac{E_T}{R_T} \\ I_T &= \frac{120}{8641.41} \\ I_T &= 0.0139 \text{ amp, or } 13.9 \text{ milliamps} \end{aligned}$$

In a series circuit, the same current flows throughout the circuit. Therefore, the current flowing through R_3 is equal to the total current in the circuit.

$$\begin{aligned} I_{R_3} &= I_T \\ I_{R_3} &= 13.9 \text{ milliamps} \end{aligned}$$

Kirchhoff's Current Law

- ▶ In 1847, G. R. Kirchhoff extended Ohm's law with two important statements that are referred to as Kirchhoff's laws. The first law, known as **Kirchhoff's current law**, states the following:
- ▶ The algebraic sum of all the currents entering and leaving a junction is equal to 0.
- ▶ Here is another way of stating Kirchhoff's current law:
- ▶ The total current flowing into a junction is equal to the sum of the current flowing out of that junction.
- ▶ A junction is defined as any point of a circuit at which two or more current paths meet. In a parallel circuit, the junction is where the parallel branches of the circuit connect.

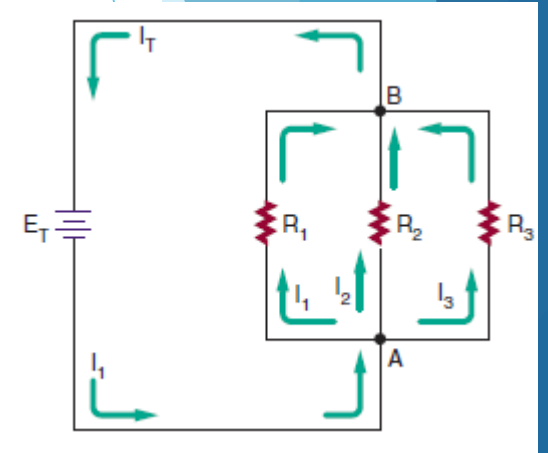
Kirchhoff's Current Law

- ▶ In Figure, point A is one junction and point B is the second junction.
- ▶ Following the current in the circuit, I_T flows from the voltage source into the junction at point A. There the current splits among the three branches as shown. Each of the three branch currents (I_1 , I_2 , and I_3) flows out of junction A. According to Kirchhoff's current law, which states that the total current into a junction is equal to the total current out of the junction, the current can be stated as

$$I_T = I_1 + I_2 + I_3$$

- ▶ Following the current through each of the three branches finds them coming back together at point B. Currents I_1 , I_2 , and I_3 flows out into junction B, and I_T flows out. Kirchhoff's current law formula at this junction is the same as at junction A:

$$I_1 + I_2 + I_3 = I_T$$



Kirchhoff's Voltage Law

- ▶ Kirchhoff's second law is referred to as **Kirchhoff's voltage law**, and it states the following:
- ▶ The algebraic sum of all the voltages around a closed circuit equals 0.
- ▶ Here is another way of stating Kirchhoff's voltage law:
- ▶ The sum of all the voltage drops in a closed circuit equals the voltage source.

Kirchhoff's Voltage Law

- ▶ In Figure, there are three voltage drops and one voltage source (voltage rise) in the circuit. If the voltages are summed around the circuit as shown, they equal 0.

$$E_T - E_1 - E_2 - E_3 = 0$$

- ▶ Notice that the voltage source (E_T) has a sign opposite that of the voltage drops. Therefore the algebraic sum equals 0.
- ▶ Looking at this another way, the sum of all the voltage drops equals the voltage source.

$$E_T = E_1 + E_2 + E_3$$

- ▶ Both of the formulas shown are stating the same thing and are equivalent ways of expressing Kirchhoff's voltage law.
- ▶ The key to remember is that the polarity of the voltage source in the circuit is opposite to that of the voltage drops.

