Lesson 8
Electricity

Introduction: Connecting Your Learning

In previous lessons, the gravitational force between two objects was described as an action-at-a-distance force that is proportional to the product of the masses and inversely proportional to the square of the distance between the two masses. A much stronger force exists between two charged particles, and it is directly proportional to the product of the two charges and inversely proportional to the square of the distance between the charges. The form of the equation is very similar. The gravitational force is always attractive, whereas an electric force can be either attractive or repulsive depending on the type of charge. Charges that are alike (both positive or both negative) repel one another, while unlike charges attract. This lesson considers stationary charges as well as moving charges.

Readings, Resources, and Assignments	
Required Textbook Readings	*Conceptual Physics* Chapter 5

Check Prior Knowledge

Before reading Chapter 5 in the *Conceptual Physics* textbook, check your prior knowledge by matching these terms. Check your answers at the end of the lesson.

Term	**Definition**
Coulomb	Force per unit charge
Insulator	Battery, for example
Conductor	Units are watts
Electric field	Moving electric charge
Electric potential	Prevents electrical overloading
Capacitor	"Loose" electrons in outer shell
Electrical current	Poor conductor of electricity
Voltage source	Electrical potential energy per unit charge
Electrical power	Unit of electrical charge
Fuse	Electrical energy storage device

Focusing Your Learning

Lesson Objectives

By the end of this lesson, you should be able to:

1. Discuss electric force and the concept of electric charge in terms of Coulomb's Law.
2. Differentiate between conductors and insulators.
3. Employ Ohm's Law to calculate current, voltage, and resistance using any two of the three variables.
4. Explain the relationship between electric field and electric potential.
5. Identify simple series and parallel electric circuits. Find the power supplied by or dissipated by each electrical component in a DC circuit.

Approaching the Objectives

This lesson is comprised of four sections:

Section 1: Coulomb's Law

Section 2: Conductors and Insulators

Section 3: Ohm's Law

Section 4: Electric Circuits and Power

Section 1: Coulomb's Law

Start this lesson by reading Chapter 5, Sections 5.1 and 5.2, pp. 72 to 102 in the *Conceptual Physics* textbook.

View the video from Kahn Academy on Introduction to Charge and Coulomb's Law

Coulomb's Law predicts the force that one charged particle exerts on another charged particle in the same way that Newton's Universal Law of Gravitation predicts the force of one mass on another. Although the electric force is much, much stronger, both forces are inverse square laws. The gravitational force is always attractive whereas the electric force can be attractive (unlike charges) or repulsive (like charges). After reading the sections in the textbook, check your comprehension by matching terms.

Some materials allow electrons to easily flow through them (conductors); other materials make it difficult for the electrons to pass through (insulators). Both cases are related to the type of bonding between the atoms or molecules of the material. This is the subject of the next section.

Section 2: Conductors and Insulators

Heat flow results when electrons are available to move between hot and cold objects. The temperature difference provides the "driving force" to move thermal energy between the objects. Likewise, with electrical conductors, the electrons carry the energy from one location to another. Instead of a temperature difference, a voltage difference provides the "electromotive force" to carry the electrical energy from one location to another. This can only happen if there is a source of free electrons that can overcome the attractive forces holding them to their parent atoms. In metals, these electrons are much freer to move than in non-metallic substances such as paper or plastic. In the table below, predict whether the material is a conductor or an insulator. (Check your answers at the end of the lesson.)

Material	**Conductor or Insulator**
Brick	
Copper wire	
Styrofoam	
Pure water	
Tap water	
Air	
Ocean water	
Vinyl or rubber	

The next section provides the relationship between the voltage applied across an electrical component, the component's resistance to the flow of electric charge, and the resulting electric charge that flows per unit of time. This relationship is referred to as Ohm's Law.

Section 3: Ohm's Law

Start this section by reading Chapter 5, Sections 5.3, 5.4, and 5.5, pp. 102 to 110 in the *Conceptual Physics* textbook. View this video by the Kahn Academy on Circuits (Part 1)

A simple electrical circuit is analogous to water flowing through a hose or pipe. When water flows, there must be an energy source that allows the water to overcome obstacles such as friction, gravity, etc. In a water circuit, the energy source can be a water pump. In an electrical circuit, the energy may come from a battery that converts chemical energy to electrical energy. The energy per unit charge is referred to as the voltage (V). The resistance in the water line is analogous to the electrical resistance (R) in an electrical component referred to as a resistor. The flow of water is analogous to the flow of electrons. The flow of charge is referred to as current (I).

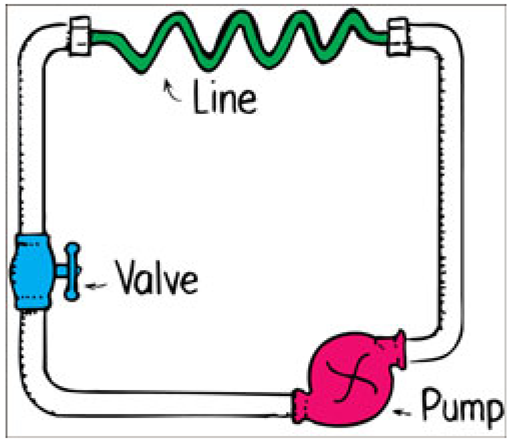
Higher voltage causes more current to flow. More resistance causes less current to flow. The former statement is a direct proportion; the latter statement is an inverse proportion.

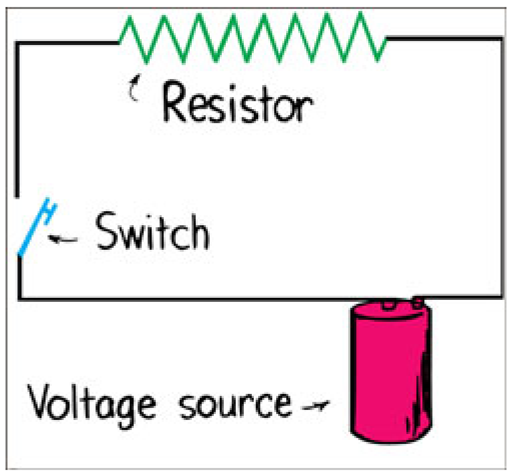
$$I = V/R$$

Current (I) is measured in amperes (amps). One amp flows when one coulomb of charge flows past a given point in the circuit per second. One coulomb of charge is equivalent to about 6.25×10^{18} electrons.

Voltage (V) is measured in volts. As a point of reference, car batteries are 12 volts. Batteries for a calculator are 1.5 volts.

Resistance is measured in Ohms (Ω), and the symbol is an uppercase Greek letter Omega. A resistance of 1 Ω will limit current flow to 1 amp if 1 volt is applied across the electrical component carrying the current.



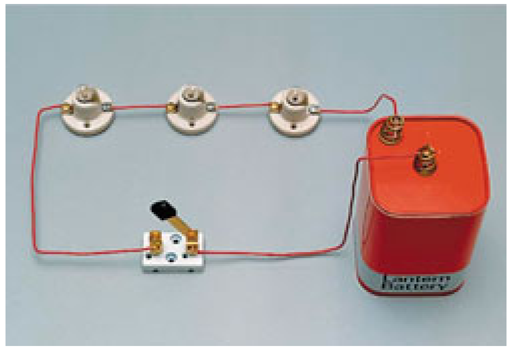


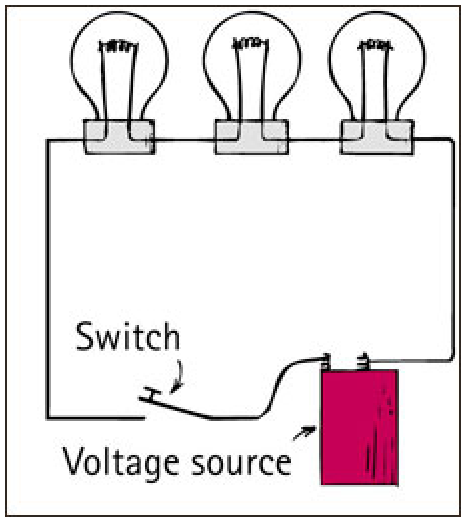
The next section arranges the electrical components in various ways to create series and parallel circuits. These circuits can be further combined into even more challenging combinations.

Section 4: Electric Circuits and Power

View these videos by the Kahn Academy on Circuits (Part 2) and (Part 3)

A simple series circuit is shown in the diagram below.

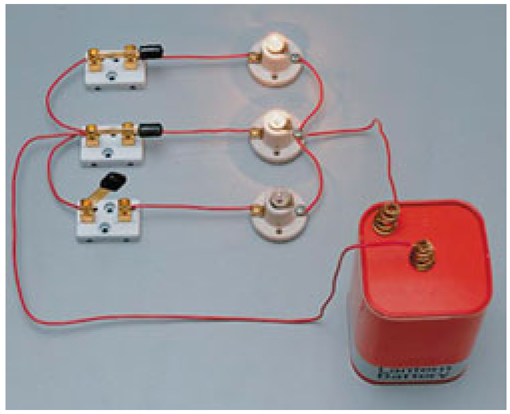


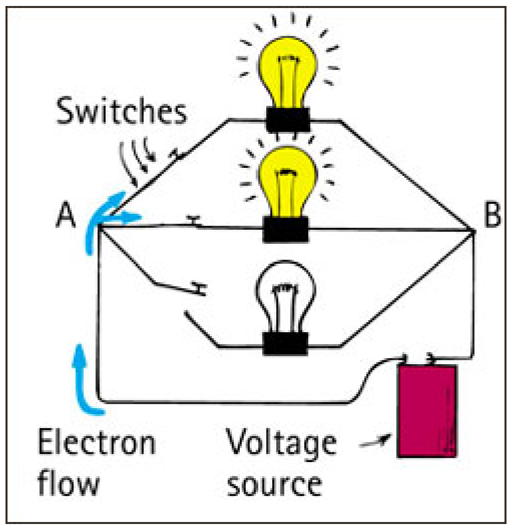


Each of the three light bulbs has resistance. From left to right, label the bulbs R_1, $R_{2,}$ and R_3. The total resistance (R_T) in a series circuit is the sum of the resistors ($R_1 + R_2 + R_3$). The voltage source is V. When the switch is open (as shown), no current flows in the circuit. There must be a complete path for the current to flow into and out of the voltage source. Determine the missing values in the table below. (Check your answers at the end of the lesson.)

R1 (Ω)	R2 (Ω)	R3 (Ω)	RT (Ω)	V (volts)	I (amps)
10	10	10		30	
10	20		50		5
	15	15		100	2
15		30	50	300	
15	50	10		150	

A simple parallel circuit is shown in the two images below.





Label the resistance of the bulbs R_1, R_2, and R_3. The total resistance (R_T) in a parallel circuit is NOT the sum of the resistors ($R_1 + R_2 + R_3$). In a parallel circuit, the voltage across each resistor is the same (whereas in a series circuit, the current was the same). Since the current has more paths to follow, the total resistance is less than the resistance of the least resistant resistor. The resistance is found by the following equation:

$$\mathbf{1/\ R_T = 1/\ R_1 + 1/\ R_2 + 1/\ R_3}$$

Math Challenge: Use the equation above to show that the total resistance for two resistors in parallel is the product of the resistors divided by the sum of the resistances.

$$\mathbf{R_T = (R_1 \cdot R_2)/(R_1 + R_2)}$$

Determine the missing values in the table below. (Check your answers at the end of the lesson.)

R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_T (Ω)	V (volts)	I (amps)
10	10	10		30	
10	20		2		5
30	30	30		100	

50		50	10		5
	50	100	25	150	

Electric power is the rate that electrical energy is used. Power is the product of the current and voltage. The units for power are watts. This can be combined with Ohm's Law to produce the jingle:

Twinkle, twinkle little star . . . power equals I squared R. ($P = I^2R$). What other expressions for power can be made?

The above series and parallel circuits show that the power produced by the battery is equal to the power consumed by the resistors in each case. This is another way to emphasize the conservation of energy.

Prior to going to the next lesson, perform a unit check with the matching activity below. (Check your answers at the end of the lesson.)

Activity: Select the correct SI unit of measurement for each of the following.	
Choice	**Correct Answer**
Voltage	
Charge	
Current	
Power	
Electric field	
Potential difference	
Use these terms: (some may be used twice) *newtons/coulomb* *coulombs* *volts* *amps* *watts*	

Summarizing Your Learning

This lesson provided a brief survey of some of the principles and concepts underlying electricity and electrical circuits. Electricity provides energy sources that the world has become very dependent on. There is little to no chance that humanity will relinquish its desire for electricity in the near future. The challenge now is to find methods to produce electricity that are kinder to planet Earth. This is one of the major scientific challenges that await humanity if there is any chance for planet Earth to survive.

Practice Answers

Check Prior Knowledge

Term	Definition
Coulomb	Unit of electrical charge
Insulator	Poor conductor of electricity
Conductor	"Loose" electrons in outer shell
Electric field	Force per unit charge
Electric potential	Electrical potential energy per unit charge
Capacitor	Electrical energy storage device
Electrical current	Moving electric charge
Voltage source	Battery, for example
Electrical power	Units are watts
Fuse	Prevents electrical overloading

Section 2: Conductors and Insulators

In the table below, predict whether the material is a conductor or an insulator.

Material	Conductor or Insulator
Brick	INSULATOR
Copper wire	CONDUCTOR
Styrofoam	INSULATOR
Pure Water	INSULATOR
Tap Water	CONDUCTOR
Air	INSULATOR
Ocean Water	CONDUCTOR
Vinyl or Rubber	INSULATOR

Section 4: Electric Circuits and Power

Determine the missing values in the table below for the series circuit:

R1 (Ω)	R2 (Ω)	R3 (Ω)	RT (Ω)	V (volts)	I (amps)
10	10	10	30	30	1
10	20	20	50	250	5
20	15	15	50	100	2
15	5	30	50	300	6
15	50	10	75	150	2

Determine the missing values in the table below for the parallel circuit:

R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_T (Ω)	V (volts)	I (amps)
10	10	10	3.33	30	9.01
10	20	2.86	2	10	5
30	30	30	10	100	10
50	16.67	50	10	50	5
100	50	100	25	150	6

Select the correct SI unit of measurement for each of the following.

Choice	Correct Answer
Voltage	volts
Charge	coulombs
Current	amps
Power	watts
Electric field	newtons/coulomb
Potential difference	volts