Science - - PHYSICAL SCIENCE GRADE 9

Unit 8: ELECTRICTY (3 WEEKS)

SYNOPSIS: In this unit students will the movement of electrons as electricity. They will explore circuits and current by creating them and measuring their voltage and resistance. Student will investigate what resistors inhibit or increase the transfer of energy and how they are used in today's electronics.

STANDARDS

III. ENERGY AND WAVES

E. Electricity

1. Electricity involves the movement of electrons.
   a. circuits are explained by the flow of electrons, current, voltage, and resistance
   b. conductors and insulators explain how freely the electrons flow throughout the material due to how firmly electrons are held to the nucleus
   c. separation of charges in a battery causes electrons to flow in circuit

2. Current describes the flow of electrons in a circuit.
   a. current is the rate at which a positive charge flows in a circuit; in reality, negatively charged electrons actually move
   b. current is measured in *amperes; (A) = 1 coulomb of charge per second (C/s)*
   c. current increases as potential difference increases and as resistance decreases

3. Power is measured in **e**lectric potential (i.e., voltage).
   a. a power source supplies the electrons already in a circuit with electric potential energy by doing work to separate charges
      (1) in a battery, energy is provided by a chemical reaction that separates charges on positive and negative sides of the battery
      (2) potential difference (voltage) = one Joule of energy supplied to each coulomb of charge
      (3) v*olt (V) = one Joule of energy per coulomb of charge (1 J/C)*
   b. potential difference across a circuit is a property of the energy source; it does not depend on devices of the circuit
4. Resistors inhibit or increase the transfer of energy.
   a. electrons flow and transfer energy to other objects
   b. and transform electrical energy into other forms (e.g., heat, light, sound) in resistors
   c. resistors oppose the rate of charge flow in the circuit
   d. experiments and investigations are useful to test transfer of energy (3-D or the virtual) to construct circuits and to measure and compare potential difference in voltage and current

LITERACY STANDARDS: READING (RST) and WRITING (WHST)

RST.4 Determine the meaning of symbols, key terms, and other domain specific words and phrases as they are used in a specific scientific or technical context relevant to texts and topics.

WHST.9 Draw evidence from informational texts to support analysis, reflection, and research. Reflection and research on IIIE1

VOCABULARY:

Science Technical Words		
Electricity	Amperes	Volt
Current	Coulomb	Joule
Circuit	Potential difference	heat
Electron	Power	Resistance
Voltage	Electric potential	Conductor
		Battery

VOCABULARY: Post words in room and leave up for the unit. Create a word wall where students know to look for new words.

Address roots and affixes of new words
Use a diagram to show meaning of new words
Relate the new word to a similar and/or familiar word
In the course of teaching, define the word in the context of where if falls in the unit rather than in isolation
Throughout the teaching of the unit, use the word in conversation/discussion
Require students to use the word(s) in: discussion, investigations, and in 2-and 4-point response questions
Use new words in Rubric for the Authentic Assessments

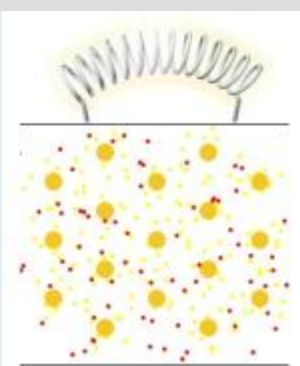
MOTIVATION	TEACHER NOTES
1. Before starting the tutorial, ask the students the question: What do you know about electricity? Compile a list of their answers so the entire classroom can refer to them later. 2. Procedure: Direct students to the following links and have them read through each lesson: 1. What is an Electric Circuit? (http://www.physicsclassroom.com/Class/circuits/U9L2a.cfm) 2. Requirements of a Circuit (http://www.physicsclassroom.com/Class/circuits/U9L2b.cfm) 3. Common Misconceptions Regarding Electric Circuits (http://www.physicsclassroom.com/Class/circuits/U9L2e.cfm) Note: Encourage students to attempt any quiz questions and check answers 3. Cool-Down Question: After the students are done reading through the tutorial, ask them to write down revised answers to the question: What have you learned about electricity? Compile a new list of answers. Have them compare their new answers to their old answers to look for similarities and misconceptions.	**Note: See attached for printable info from each lesson #1 - 3**

TEACHING-LEARNING	TEACHER NOTES
1. Students are encouraged to "clear their brains" and assume the role of a 19th-century scientist trying to figure out how to sustain an electrical current. Today's activities are designed to: 1) help students understand how a battery operates to conduct voltage in an electrical circuit, and 2) gain an appreciation of the challenges faced by pioneers in the field of electricity. This short biography provides background information for the students about Alessandro Volta and his voltaic pile invention that was the beginnings of the modern-day battery. Have students read through the material to prepare for the lesson Warm-Up Question https://nationalmaglab.org/education/magnet-academy/history-of-electricity-magnetism/pioneers/alessandro-volta **Warm-Up Question:** Ask the students the question: How does a battery work? Compile a list of student answers that can be viewed by the entire classroom later in the lesson.	

TEACHING-LEARNING	TEACHER NOTES
Computer Lab Procedure: Direct students to the Interactive Voltaic Pile Tutorial. https://nationalmaglab.org/education/magnet-academy/history-of-electricity-magnetism/museum/voltaic-pile-1800 2. ***Hands-On Lab Activity:*** *This lab includes lab activities that involve the in-class construction of several different kinds of batteries. The first experiment, entitled "A Voltaic Pile, the first battery," was chosen for this model unit. This experiment allows students to recreate Alessandro Volta's voltaic pile experiment. Students will be able to adjust the voltage of their battery by adding voltaic piles with different metallic properties.* **Materials Needed:** +Metals: Strips or coins made of copper, nickel, zinc (strip or squares), and magnesium (ribbon) +Filter paper, small circles or squares or cut to size +Scissors +Clamps to hold metal strips or coins together +Electrolyte solution, 0.1 M NaCl +Dropper +Test leads (with alligator clip connectors, if available) +Steel wool, extra fine +Voltmeter or multimeter +Small motor +Small light bulb and socket assembly or LED +Copper wire ***Safety Precautions:*** Goggles should be worn at all times in the lab. Materials are not hazardous and 0.1 M NaCl solution can be poured down the drain. **Lab Procedure:** Print out this handout or direct students to http://www.chymist.com/batteries.pdf and ask students to do the first experiment: "The Voltaic Pile, the first battery" and write out answers to the corresponding questions. Teachers may have students work in groups of two, three, or four depending on the number of students and quantity of materials. 3. **Current and Voltage - What's the Difference?** (3 resources)Students will begin an investigation of the difference between current and voltage. To start the investigation, we chose interactive online tutorials from the Physics Classroom that introduce the concepts with analogy-driven examples, kid-friendly language, and question sets that provide immediate (but private) feedback. Students will then begin a Problem-Based Learning (PBL) activity that allows them to build a flashlight out of salvage materials (and have some fun in the process).	

TEACHING-LEARNING	TEACHER NOTES
The Physics Classroom: Electric Potential ***Interactive Student Tutorial*** *This is an interactive tutorial for high school physics on electric potential in circuits and electric potential difference. It will help students understand how electric potential energy is related to the magnitude of charge and location of the charge in the electric field. In the second section, the author explains electric potential difference in terms of the role of the electrochemical cell, which supplies the energy to do work upon the charge in moving it from negative to positive terminals. Both sections contain diagrams, analogies, and quizzes to self-test understanding of the concepts.* (description written by Caroline Hall) **Teacher Preparations:** Reserve the computer lab (two students per computer) or demonstrate to the classroom using a projector. **Warm-Up Question:** Ask the students the question: Where in your everyday life do you see references to voltage? What about current? Compile a list of student answers that can be viewed by the entire classroom later in the lesson. (Students may gives examples such as "air current" that might be useful to describe the concept of electric current - air current as a change in the atmosphere, similar to how electric current is the time rate of change of charge.) **Computer Lab Procedure:** Direct students to the The Physics Classroom: Electric Potential. detail page - website **The Physics Classroom: Electric Current** ***Interactive Student Tutorial*** *This is an interactive tutorial for high school physics on electric current and the requirements of an electric circuit. From a conceptual standpoint, it explores the nature of charge flow and the function of the charge carriers. From the mathematical standpoint, it explains current as a rate quantity and provides simple exercises to calculate the flow of current.* (description written by Caroline Hall) **Computer Lab Procedure:** Direct students to the The Physics Classroom: Electric Current. detail page - website **CASES Online: Lights Out! - A Circuit Activity** ***Problem-Based Learning Activity:*** *This item is Problem-Based Learning (PBL) activity for high school physics that asks learners to construct a flashlight using only broken and salvaged parts. In the opening scenario, a group of students are lost in a fully dark cave. One flashlight breaks in a fall and the battery dies in the other. Students have a time limit to figure out how to make the circuit work with only "salvage" items provided for the lesson.* (description written by Caroline Hall) For teacher materials: Lights Out! - Teacher Guide. **Computer Lab Procedure:** Direct students to Lights Out! - A Circuit Activity. On day 3, teachers should ask students to read the Lights Out! script in class. The assignment and grading rubric should be kept by the teacher until day 4.	

TEACHING-LEARNING	TEACHER NOTES
Cool-Down Question: Without revealing the materials being given to the students the next day, the teacher should ask the students, "What kinds of materials might the explorers have with them that could be used to build a flashlight?" Students should discuss the possibilities with the teacher on what would and would not work to help the explorers light their way out of the darkness. 4. **Lights Out! - Problem Solving with Circuits** (1 resource) Students will continue and finish the Lights Out! PBL activity and complete the assignments. **Student preparation for 5:** Print the following material for students: All About Circuits - Resistance. Have students read through the material outside of class to prepare for discussion and activities on 5. **CASES Online: Lights Out! - A Circuit Activity** ***Problem-Based Learning Activity (continued):*** *This item is Problem-Based Learning (PBL) activity for high school physics that asks learners to construct a flashlight using only broken and salvaged parts. In the opening scenario, a group of students are lost in a fully dark cave. One flashlight breaks in a fall and the battery dies in the other. Students have a time limit to figure out how to make the circuit work with only "salvage" items provided for the lesson.* (description written by Caroline Hall) ***Teacher Preparations:*** Students should be placed into groups of three or four students. Teachers should print the student manual .pdf file for each student. **Materials Needed:** +Flashlight bulb +Two AAA batteries +Assorted small items, such as: -a ball point pen with removable cap a small -spiral bound notepad plastic sandwich bags a half-eaten sandwich -wrapped in aluminum foil loose change a pack of gum (with or without foil gum wrappers) For teacher materials: Lights Out! - Teacher Guide. **Computer Lab Procedure:** Direct students to Lights Out! - A Circuit Activity. On day 3, students read the Lights Out! scene script during class. On day 4, students should be asked to complete the rest of the assignment (parts I and II) and be given the grading rubric. Students should not be given the materials for part II of the assignment until the end of the class when the final Lights Out! activity begins. 5. **Introducing Resistance and Ohm's Law** (5 resources) Students will be introduced to the concepts of resistance and Ohm's Law through a series of student tutorials. The relationship among voltage, current, and resistance will also be emphasized in this day's lesson.	

TEACHING-LEARNING	TEACHER NOTES
Molecular Expressions: Java Tutorial - Ohm's Law ***Interactive Student Tutorial*** *This item is an interactive java simulation that demonstrates the relationship among current, voltage, and resistance. As resistance and voltage are adjusted up or down, the current flow is registered in milliamperes. The simulation is intended to help users gain an understanding of the concepts underlying Ohm's Law; i.e., an increase in voltage increases current flow, and an increase in resistance decreases current flow. This item is part of a larger collection on Electricity and Magnetism sponsored by Florida State University.* (description written by Caroline Hall) **Teacher Preparations:** Reserve the computer lab (two students per computer) or demonstrate to the classroom using a projector. **Warm-Up Question:** From the previous day's reading, ask students the question: "What is resistance?" **Computer Lab Procedure:** Direct students to the Molecular Expressions: Java Tutorial - Ohm's Law. Have students try 10 different voltages while keeping resistance constant, followed by a trial of 10 different resistances while keeping voltage constant. Students should keep track of their findings on a separate sheet of paper. Have them write down the corresponding current readings as well. Ask students about trends in their numbers and have them relate their findings to the theory and mathematical expression for Ohm's law (i.e. Have students demonstrate that I=E/R by substituting their chosen numbers for voltage ((E)) and resistance ((R)) and solving for current ((I)).) website  **Molecular Expressions: Electricity & Magnetism - Resistance at the Molecular Level** ***Interactive Student Tutorial*** *This item is an interactive Java tutorial that simulates the movement of free electrons when voltage is applied across a conductor. As the user adjusts the current flow, the resulting changes are represented on both a macro and nanoscale. The design of the simulation helps the beginner understand how electron collision causes resistance within a system. This applet is part of a larger collection sponsored by Florida State University.* (description written by Caroline Hall) **Computer Lab Procedure:** Direct students to the Molecular Expressions: Java Tutorial - Resistance at the Molecular Level.	

TEACHING-LEARNING	TEACHER NOTES
website **The Physics Classroom: Electrical Resistance** ***Interactive Student Tutorial*** *This item is an interactive java simulation that demonstrates the relationship among current, voltage, and resistance. As resistance and voltage are adjusted up or down, the current flow is registered in milliamperes. The simulation is intended to help users gain an understanding of the concepts underlying Ohm's Law; i.e., an increase in voltage increases current flow, and an increase in resistance decreases current flow. This item is part of a larger collection on Electricity and Magnetism sponsored by Florida State University.* (description written by Caroline Hall) **Computer Lab Procedure:** Direct students to the The Physics Classroom: Electrical Resistance. website **The Physics Classroom: Ohm's Law** ***Interactive Student Tutorial*** *This interactive tutorial on Ohm's Law, part of The Physics Classroom tutorial collection, provides a thorough conceptual foundation for understanding one of the most powerful formulas in physics. Multiple circuit diagrams and tables illustrate the relationships among voltage, current before users explore the mathematics. The author includes two quizzes for users to gauge their own understanding and perform simple calculations related to resistance.* (description written by Caroline Hall) **Computer Lab Procedure:** Direct students to the The Physics Classroom: Ohm's Law. **Cool-Down Question:** Now that the students have thoroughly explored the concepts of voltage, current, and resistance, ask them the question: "What are the differences among the concepts of voltage, current, and resistance?" Compile their answers and try to correct any misconceptions. website **All About Circuits: Worksheets** ***Assessment:*** Direct students to the website Worksheets: Voltage, Current, and Resistance or retype and print the questions for students to answer on their own. Teachers may choose to go over the answers in class or to collect and grade the assignment as an assessment of understanding. If presented as a graded assessment, students should have until day 6 to complete the questions. 6. **Series and Parallel Circuits - Simulate and Explore** (2 resources) An inquiry-based lesson for students to discover the concepts of series and parallel circuits on their own with limited teacher guidance. Students will complete an in-class assignment that uses the components of a circuit simulation as the tools of discovery.	

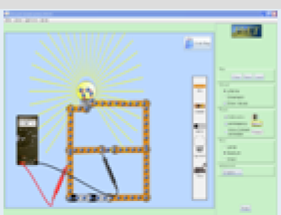
TEACHING-LEARNING	TEACHER NOTES

Supplemental material to be printed for students for this lesson:
All About Circuits - Simple Series Circuits
All About Circuits - Simple Parallel Circuits

PhET Simulation: Circuit Construction Kit (DC Only)
Interactive Student Tutorial
This interactive java application gives students a virtual circuit simulator for building DC circuits. Wires, batteries, resistors, light bulbs, and switches are available to be added to the circuit, along with common "real world" objects. Parameters, such as resistance and voltage, can be modified as desired. Meters are available for measuring voltages and currents. Circuit elements can be arranged in any geometry desired by the user; circuit elements are not required to connect to a grid. The circuits can be viewed using either images of the objects or using schematic symbols. This is part of a large collection of simulations freely available from the Physics Education Technology group at the University of Colorado. (description written by Caroline Hall)

Teacher Preparation:
Students will require computer access for today's activity.

Teachers should download and have students download this application so that the Circuit Construction Kit (CCK) can be used for today's simulation experiment.
website



PhET Teacher Ideas and Activities: Properties of Electric Circuits Using Circuit Simulator Kit

Simulation Experiment
This is an inquiry-based lesson developed for use with the PhET DC Circuit Construction Kit, an interactive simulation that lets users build circuits with virtual wires, batteries, resistors, light bulbs, and switches. Students will build virtual circuits from schematic drawings, use a multimeter to take readings, and analyze the difference between real and simulated circuits. Also included are "clicker questions", designed to elicit prior understanding. (description written by Caroline Hall)

Computer Lab Procedure:
Print the .doc or .pdf files from this location: Circuit 1: Properties of Electric Circuits Using Only CCK (Inquiry-Based). Students should work on the assignment in groups of two or three. Students should be able to complete the activities on their own with teacher assistance as needed.

TEACHING-LEARNING	TEACHER NOTES

7. **Tesla - The Forgotten Pioneer of AC Current** (1 resource)

PBS: Tesla - Master of Lightning

This interactive PBS-sponsored website takes a close look at Nikola Tesla's turbulent life, the scientist whose crucial work is often overlooked. Tesla's inventions formed the basis of modern alternating current power systems and wireless transmission of energy. He was first to patent the invention of radio, though Marconi is more often given credit for the discovery. Explore Tesla's key inventions, such as the AC motor, Tesla coil, remote control, and improved lighting techniques. Don't miss the virtual tour of Tesla's Niagara power system. Go to Web Site

Editor's Note: Why should you include a lesson on Nikola Tesla? Here's what noted contemporary author/scientists say:

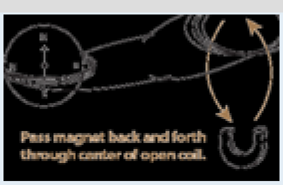
Margaret Cheney*: "He was so far ahead of his time, so much a visionary, that his contemporary scientists really didn't understand what he was doing."*

Jim Hardesty*: "Tesla was a man who understood what no other scientist of the time understood -- electrical resonance. He understood the idea that energy passed back and forth in an electrical system.......the simple fact about Marconi's 'S' is that he used the Tesla system to transmit signals and claimed that these were ideas he had developed himself."*

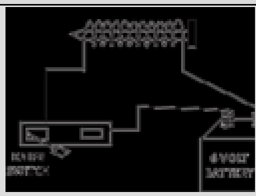
Bernard Finn*: "Our history is of people. It's not just inventions and developments.......What was it that allowed and encouraged a person like Nikola Tesla to come here, to thrive here, to interact with bankers and others?... How could he be this lone inventor and still contribute in various ways? That's the way we should understand him, within that broader context."*

8. **Alternating Current - Illuminating the World** (3 resources)

Teachers' Domain: AC / DC: What's The Difference?
website



PBS: Tesla Teaching Resources - Converting Mechanical Energy into Electrical Energy
website

TEACHING-LEARNING	TEACHER NOTES
 **PBS: Tesla Teaching Resources - Converting Electrical Energy into Mechanical Energy** website	

TRADITIONAL ASSESSMENT	TEACHER NOTES
1. Multiple-Choice **Unit Test**	

TEACHER CLASSROOM ASSESSMENT	TEACHER NOTES
1. Teacher Classroom Assessments:	

AUTHENTIC ASSESSMENT (optional)	TEACHER NOTES
1. Students evaluate progress on their goals 2. Students can create a working circuit for an electronic device, measure the voltage and, and draw a circuit diagram of the circuit.	

#1

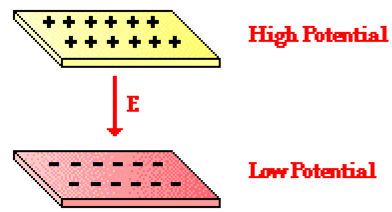
The Physics Classroom » Physics Tutorial » Current Electricity » What is an Electric Circuit?

Current Electricity - Lesson 2 - Electric Current

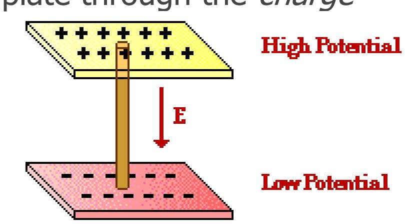
What is an Electric Circuit?

- What is an Electric Circuit?
- Requirements of a Circuit
- Electric Current
- Power: Putting Charges to Work
- Common Misconceptions Regarding Electric Circuits

In Lesson 1, the concept of electric potential difference was discussed. Electric potentialis the amount of electric potential energy per unit of charge that would be possessed by a charged object if placed within an electric field at a given location. The concept of potential is a location-dependent quantity - it expresses the quantity of potential energy on a per charge basis such that it is independent on the amount of charge actually present on the object possessing the electric potential. Electric potential difference is simply the difference in electric potential between two different locations within an electric field.



To illustrate the concept of electric potential difference and the nature of an electric circuit, consider the following situation. Suppose that there are two metal plates oriented parallel to each other and each being charged with an opposite type of charge - one being positive and the other being negative. This arrangement of charged plates would create an electric field in the region between the plates that is directed away from the positive plate and towards the negative plate. A positive test charge placed between the plates would move away from the positive plate and towards the negative plate. This movement of a positive test charge from the positive plate to the negative plate would occur without the need of energy input in the form of work; it would occur naturally and thus lower the potential energy of the charge. The positive plate would be the high potential location and the negative plate would be the low potential location. There would be a difference in electric potential between the two locations.



Now suppose that the two oppositely charged plates are connected by a metal wire. What would happen? The wire serves as a sort of charge pipe through which charge can flow. Over the course of time, one could think of positive charges moving from the positive plate through the *charge pipe* (wire) to the negative plate. That is, positive charge would naturally move in the direction of the electric field that had been created by the arrangement of the two oppositely charged plates. As a positive charge leaves the upper plate, the plate would become less positively charged as illustrated in the animation at the right. As a positive charge reaches the negative plate, that plate would become less negatively charged. Over the course of time, the amount of positive and negative charge on the two plates would slowly diminish. Since the electric field depends upon the amount of charge present on the object creating the electric field, the electric field created by the two plates would gradually diminish in strength over the course of time. Eventually, the electric field between the plates would become so small that there would be no observable movement of charge between the two plates. The plates would ultimately lose their charge and reach the same electric potential. In the absence of an electric potential difference, there will be no charge flow.

The above illustration comes close to demonstrating the meaning of an electric circuit. However, to be a true circuit, charges must continually flow through a complete loop, returning to their original position and cycling through again. If there were a means of moving positive charge from the negative plate back up onto the positive plate, then the movement of positive charge downward through the charge pipe (i.e., the wire) would occur continuously. In such a case, a circuit or loop would be established.

A common lab activity that illustrates the necessity of a complete loop utilizes a battery pack (a collection of D cells), a light bulb, and some connecting wires. The activity involves observing the effect of connecting and disconnecting a wire in a simple arrangement of the battery pack, light bulbs and wires. When all connections are made to the battery pack, the light bulb lights. In fact, the lighting of the bulb occurs immediately after the final connection is made. There is no perceivable time delay between when the last connection is made and when the light bulb is perceived to light up.

There's Something Happening in Those Wires

Part 1

The fact that the light bulb lights and remains lit is evidence that charge is flowing through the light bulb filament and that an **electric circuit** has been established. A circuit is simply a closed loop through which charges can continuously move. To demonstrate that charges are not only moving through the light bulb filament but also through the wires connecting the battery pack and the light bulb, a variation on the above activity is made. A compass is placed beneath the wire at any location such that its needle is placed in alignment with the wire. Once the final connection is made to the battery pack, the light bulb lights and the compass needle deflects. The needle serves as a detector of moving charges within the wire. When it deflects, charges are moving through the wire. And if the wire is disconnected at the battery pack, the light bulb is no longer lit and the compass needle returns to its original orientation. When the light bulb lights, charge is moving through the electrochemical cells of the battery, the wires and the light bulb filaments; the compass needle detects the movement of this charge. It can be said that there is a **current** - a flow of charge within the circuit.

There's Something Happening in Those Wires

Part 2

The electric circuit demonstrated by the combination of battery, light bulb and wires consists of two distinct parts: the internal circuit and the external circuit. The part of the circuit containing electrochemical cells of the battery is the internal circuit. The part of the circuit where charge is moving outside the battery pack through the wires and the light bulb is the external circuit. In Lesson 2, we will focus on the movement of charge through the external circuit. In the next part of Lesson 2 we will explore the requirements that must be met in order to have charge flowing through the external circuit.

#2

The Physics Classroom » Physics Tutorial » Current Electricity » Requirements of a Circuit

Current Electricity - Lesson 2 - Electric Current

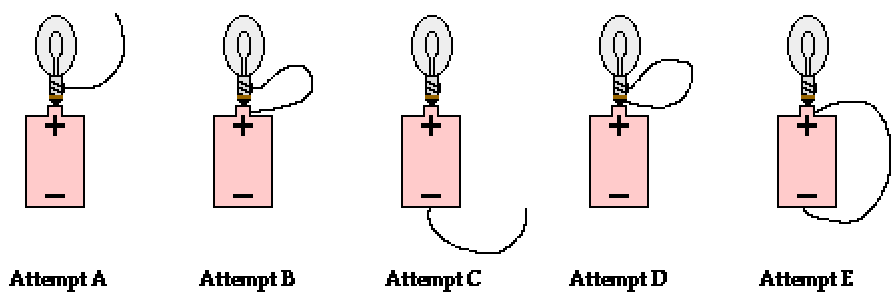
Requirements of a Circuit

- What is an Electric Circuit?
- Requirements of a Circuit
- Electric Current
- Power: Putting Charges to Work
- Common Misconceptions Regarding Electric Circuits

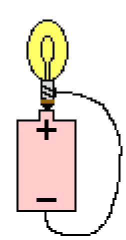
Suppose that you were given a small light bulb, an electrochemical cell and a bare copper wire and were asked to find the four different arrangements of the three items that would result in the formation of an electric circuit that would light the bulb. What four arrangements would result in the successful lighting of the bulb? And more importantly, what does each of the four arrangements have in common that would lead us into an understanding of the two requirements of an electric circuit?

The activity itself is a worthwhile activity and if not performed before, one ought to try it before reading further. Like many lab activities, there is power in the actual engagement in the activity that cannot be replaced by simply reading about it. When this activity is performed in the physics classroom, there are numerous observations that can be made by watching a class full of students eager to find the four arrangements. The following arrangements are often tried and do not result in the lighting of the bulb.

Unsuccessful Attempts at Lighting the Light Bulb



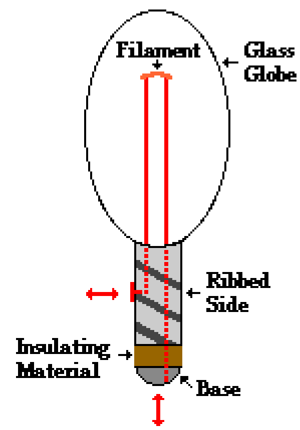
After a few minutes of trying, several healthy chuckles, and an occasional exclamation of how hot the wire is getting, a couple of students become successful at lighting the bulb. Unlike the above attempts, the first successful attempt is characterized by the production of a complete conducting loop from the positive terminal to the negative terminal, with both the battery and the light bulb being part of the loop. As shown in the diagram at the right, the base of the light bulb connects to the positive terminal of the cell and the wire extends from the ribbed sides of the light bulb down to the negative terminal of the cell. A complete conducting loop is made with the light bulb being part of the loop. A circuit exists and charge flows along the complete conducting path, lighting the bulb in the process. Compare the arrangement of the cell, bulb and wire at the right to the unsuccessful arrangements shown above. In attempt A, the wire does not loop back to the negative terminal of the cell. In attempt B, the wire does form a loop but not back to the negative terminal of the cell. In attempt C, there is no complete loop at all. Attempt D resembles attempt B in that there is a loop but not from the positive terminal to the negative terminal. And



in attempt E, there is a loop and it does go from positive terminal to negative terminal; this is a circuit but the light bulb is not included as part of it. CAUTION: Attempt E will cause your fingers to get hot as you hold the bare wire and charge begins to flow at a high rate between the positive and negative terminals.

Light Bulb Anatomy

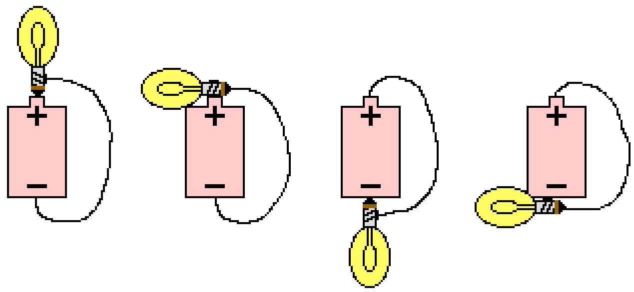
Once one group of students successfully lights the bulb, many other lab groups quickly follow suit. But then the question emerges as to what other ways that the cell, bulb and bare wire can be arranged in such a manner as to light the bulb. Often a short light bulb anatomy lesson prompts the lab groups into a quick discovery of one or more of the remaining arrangements.



A light bulb is a relatively simple device consisting of a filament resting upon or somehow attached to two wires. The wires and the filament are conducting materials that allow charge to flow through them. One wire is connected to the ribbed sides of the light bulbs. The other wire is connected to the bottom base of the light bulb. The ribbed edge and the bottom base are separated by an insulating material that prevents the direct flow of charge between the bottom base and the ribbed edge. The only pathway by which charge can make it from the ribbed edge to the bottom base or vice versa is the pathway that includes the wires and the filament. Charge can either enter the ribbed edge, make the pathway through the filament and exit out the bottom base; or it can enter the bottom base, make the pathway through the filament and exit out the ribbed edge. As such, there are two possible entry points and two corresponding exit points.

The successful means of lighting the bulb as shown above involved placing the bottom base of the bulb on the positive terminal and connecting the ribbed edge to the negative terminal using a wire. Any charge that enters the light bulb at the bottom base exits the bulb at the location where the wire makes contact with the ribbed edge. Yet the bottom base does not have to be the part of the bulb that touches the positive terminal. The bulb will light just as easily if the ribbed edge is placed on top of the positive terminal and the bottom base is connected to the negative terminal using a wire. The final two arrangements that lead to a lit light bulb involve placing the bulb at the negative terminal of the cell, either by making contact to it with the ribbed edge or with the bottom base. A wire must then connect the other part of the bulb to the positive terminal of the cell.

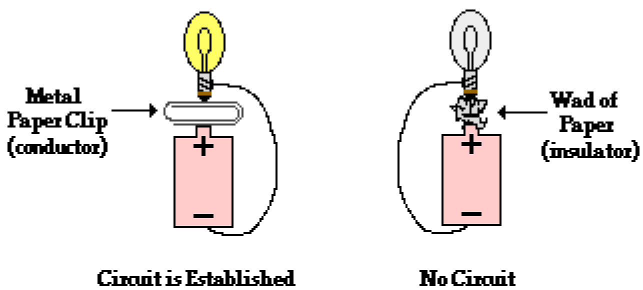
Successful Attempts at Lighting the Light Bulb



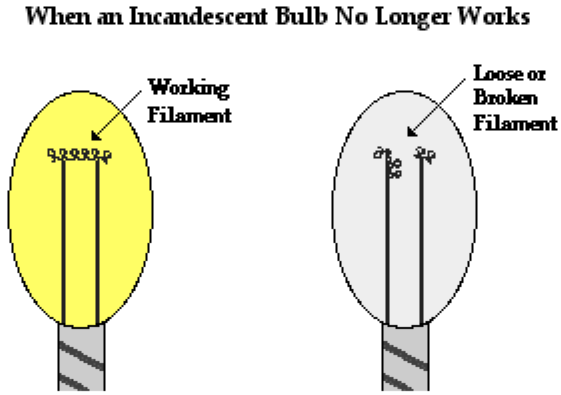
The Requirement of a Closed Conducting Path

There are two requirements that must be met to establish an electric circuit. The first is clearly demonstrated by the above activity. There must be a closed conducting path that extends from the positive terminal to the negative terminal. It is not enough that there is simply a closed conducting loop; the loop itself must extend from the positive terminal to the negative terminal of the electrochemical cell. An electric circuit is like a water circuit at a water park. The flow of charge through wires is similar to the flow of water through the pipes and along the slides at a water park. If a pipe gets plugged or broken such that water cannot make the complete path through the *circuit*, then the flow of water will soon cease. In an electric circuit, all connections must be made and made by conducting materials capable of *carrying* charge. As the cell, bulb and wire experiment continues, some students explore the capability of various materials to carry a charge by inserting them in their circuit. Metallic materials are conductors and can be inserted into the circuit to successfully light the bulb. On the other hand, paper and plastic materials are typically insulators and their insertion within the circuit will hinder the flow of charge to such a degree that the current ceases and the bulb no longer lights. There must be a closed conducting loop from the positive to the negative terminal in order to establish a circuit and to have a current.

The Importance of a Closed Conducting Loop

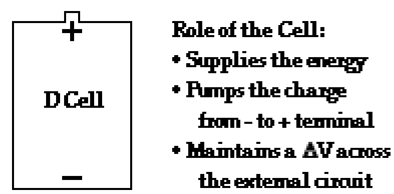


With an understanding of this first requirement of an electric circuit, it becomes clear what is happening when an incandescent light bulb in a table lamp or floor lamp no longer works. Over time, a light bulb filament becomes weak and brittle can often break or simply become loose. When this occurs, the circuit is *opened* and a closed conducting loop no longer exists. Without a closed conducting loop, there can be no circuit, no charge flow and no lit bulb. Next time you find a broken bulb in a lamp, safely remove it and inspect the filament. Often times, shaking the removed bulb will cause a rattle; the filament has likely fallen off the supporting posts that it normally rests upon to the bottom of the glass globe. When shook, you will hear the rattle of the filament hitting the glass globe.

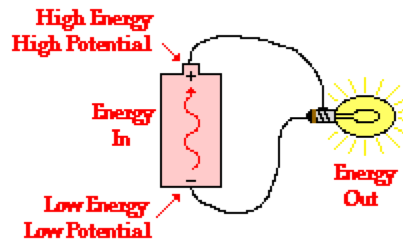


The Requirement of an Energy Supply

The second requirement of an electric circuit that is common in each of the successful attempts demonstrated above is that there must be an electric potential differenceacross the two *ends* of the circuit. This is most commonly established by the use of an electrochemical cell, a pack of cells (i.e., a battery) or some other energy source. It is essential that there is some source of energy capable of increasing the electric potential energy of a charge as it moves from the low energy terminal to the high energy terminal.As discussed in Lesson 1, it takes energy to move a positive test charge against the electric field. As applied to electric circuits, the movement of a positive test charge through the cell from the low energy terminal to the high energy terminal is a movement against the electric field. This movement of charge demands that work be done on it in order to *lift it up* to the higher energy terminal. An electrochemical cell serves the useful role of supplying the energy to do work on the charge in order to*pump it* or move it through the cell from the negative to the positive terminal. By doing so, the cell establishes an electric potential difference across the two ends of the electric circuit. (The concept of an electric potential difference and its application to electric circuits was discussed in detail in Lesson 1.)



In household circuits, the energy is supplied by a local utility company that is responsible for making sure that the *hot* and the *neutral* plates within the circuit panel box of your home always have an electric potential difference of about 110 Volts to 120 Volts (in the United States). In typical lab activities, an electrochemical cell or group of cells (i.e., a battery) is used to establish an electric potential difference across the two ends of the external circuit of about 1.5 Volts (a single cell) or 4.5 Volts (three cells in a pack). Analogies are often made between an electric circuit and the water circuit at a water park or a roller coaster ride at an amusement park. In all three cases, there is something that is moving through a complete loop - that is, through a circuit. And in all three cases, it is essential that the circuit include a section where energy is put into the water, the coaster car or the charge in order to move it *uphill* against its natural direction of motion from a low potential energy to a high potential energy. A water park ride has a water pump that pumps the water from ground level to the top of the slide. A roller coaster ride has a motor-driven chain that carries the train of coaster cars from ground level to the top of the first drop. And an electric circuit has an electrochemical cell, battery (group of cells) or some other energy supply that moves the charge from ground level (the negative terminal) to the positive terminal. By constantly supplying the energy to move the charge from the low energy, low potential terminal to the high energy, high potential terminal, and a continuous flow of charge can be maintained.



By establishing this difference in electric potential, charge is able to flow downhill through the external circuit. This motion of the charge is natural and does not require energy. Like the movement of water at a water park or a roller coaster car at an amusement park, the downhill motion is natural and occurs without the need for energy from an external source. It is the difference in potential - whether gravitational potential or electric potential - that causes the water, the coaster car and the charge to move. This potential difference requires the input of energy from an external source. In the case of an electric circuit, one of the two requirements to establish an electric circuit is an energy source.

A Difference in Potential Causes a Fluid to Flow

Water won't flow if the two ends of the pipe are at the same potential.

If the two ends of the pipe are at different potentials, then water will flow.

In conclusion, there are two requirements that must be met in order to establish an electric circuit. The requirements are

1. There must be an energy supply capable doing work on charge to move it from a low energy location to a high energy location and thus establish an electric potential difference across the two ends of the external circuit.
2. There must be a closed conducting loop in the external circuit that stretches from the high potential, positive terminal to the low potential, negative terminal.

Check Your Understanding

1. If an electric circuit could be compared to a water circuit at a water park, then the ...

... battery would be analogous to the _____.
... positive terminal of the battery would be analogous to the _____.

... current would be analogous to the _____.

... charge would be analogous to the _____.

... electric potential difference would be analogous to the _____.

Choices:

A. water pressure | B. gallons of water flowing down slide per minute

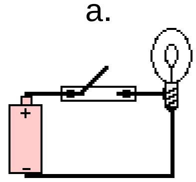
C. water | D. bottom of the slide

E. water pump | F. top of the slide

See Answer

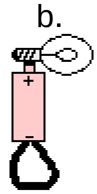
2. Utilize your understanding of the requirements of an electric circuit to state whether charge would flow through the following arrangements of cells, bulbs, wires and switches. If there is no charge flow, then explain why not.

a.



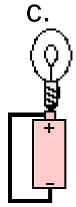
Charge Flow: Yes or No?
Explanation:

b.



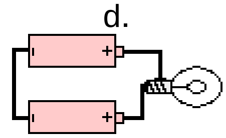
Charge Flow: Yes or No?
Explanation:

c.



Charge Flow: Yes or No?
Explanation:

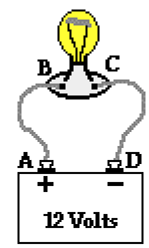
d.



Charge Flow: Yes or No?
Explanation:

See Answer

3. The diagram at the right shows a light bulb connected to a 12-V car battery. The + and - terminals are shown.



a. As a + charge moves through the battery from D to A, it ________ (gains, loses) potential energy and ________ (gains, loses) electric potential. The point of highest energy within a battery is the ______ (+, -) terminal.
b. As a + charge moves through the external circuit from A to D, it ________ (gains, loses) potential energy and ________ (gains, loses) electric potential. The point of highest energy within the external circuit is closest to the ______ (+, -) terminal.

c. Use >, <, and = signs to compare the electric potential (V) at the four points of the circuit.

V_A ___ V_B ___ V_C ___ V_D

See Answer

4. In the movie *Tango and Cash*, Kurt Russell and Sylvester Stallone escape from a prison by jumping off the top of a tall wall through the air and onto a high-voltage power line. Before the jump, Stallone objects to the idea, telling Russell "We're going to fry." Russell responds with "You didn't take high school Physics did you. As long as you're only touching one wire and you're feet aren't touching the ground, you don't get electrocuted." Is this a correct statement?

See Answer

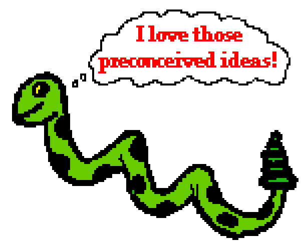
#3

Current Electricity - Lesson 2 - Electric Current

Common Misconceptions Regarding Electric Circuits

- What is an Electric Circuit?
- Requirements of a Circuit
- Electric Current
- Power: Putting Charges to Work
- Common Misconceptions Regarding Electric Circuits

In these first two lessons of the Circuits unit of The Physics Classroom, an effort has been made to present a model of how and why electric charge flows within an electric circuit. Terms have been defined and rules and principles presented and discussed. The goal has been to help students of physics to construct an accurate mental model of the world of current electricity. This goal is often impeded by the presence of preconceived ideas regarding the nature of charge flow and the role of a battery in a circuit. In many instances, these preconceived notions about charge flow and batteries are incorrect ideas and are completely inconsistent with the model presented here.



Like all misconceptions in physics, they must be directly confronted in order to successfully build an accurate mental model of the physical world.

What Do You Believe?

To begin the exploration of these misconceptions, take a moment to respond the following five true-false statements. Then click the Check Answers button to view the correct answers.

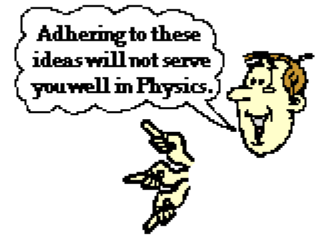
Statement	True or False?
a. When an electrochemical cell no longer works, it is out of charge and must be recharged before it can be used again.	T or F
b. An electrochemical cell can be a source of charge in a circuit. The charge that flows through the circuit originates in the cell.	T or F
c. Charge becomes used up as it flows through a circuit. The amount of charge that exits a light bulb is less than the amount that enters the light bulb.	T or F
d. Charge flows through circuits at very high speeds. This explains why the light bulb turns on immediately after the wall switch is flipped.	T or F
e. The local electrical utility company supplies millions and millions of electrons to our homes everyday.	T or F

See Answer

Batteries Are Not Rechargeable

Batteries are not rechargeable. This statement ought to get some people's attention. The belief that an electrochemical cell is rechargeable may be the starting point of a logically developed collection of misconceptions that are completely inconsistent with the model of circuits presented in this unit. Let's suppose for a moment that an electrochemical cell is rechargeable; and let's suppose that when we say they are *rechargeable*, we mean that we can place the cell in a small machine and replace or replenish the charge that it has lost through use in a circuit. If an electrochemical cell is rechargeable and this is what we mean by rechargeable, then what logical consequences would this have on our understanding of circuits?

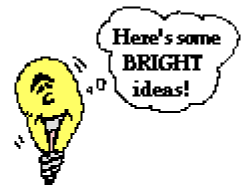
First, if an electrochemical cell is rechargeable, then it must be the source of charge within an electric circuit. Obviously, if a cell must have its charge replenished or resupplied, then it must do so because its role is to supply the charge needed to operate an electric circuit. It would be reasonable to believe that the charge that flows through a circuit to operate a flashlight bulb must originate in the flashlight battery compartment. And perhaps it would be reasonable to believe that the charge that flows out of the cells and into the bulb becomes consumed or used up in such a manner that it does not flow out of the bulb in as much quantity as it flows into the bulb. The amount of charge exiting the bulb is less than that that enters the bulb. After all, one may think, electricity is used up by a circuit; perhaps what is being used up is the charge that is supplied by the electrochemical cells. And when the flashlight bulb no longer works, the cells inside must have lost all its charge and must be placed in this little recharging machine and be recharged.



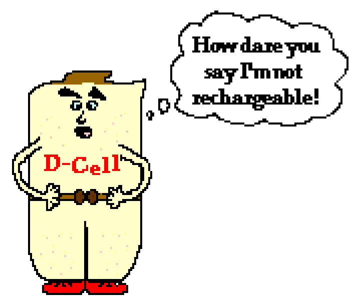
The above paragraph represents a perfectly logical extension (though entirely inaccurate) of the belief that batteries are rechargeable. If you really do believe that an electrochemical cell is rechargeable, then you likely answered True to the first three statements of the True-False quiz at the opening of thispage. But the collection of misconceptions usually does not end with the above paragraph. The reasoning continues. If one believes that an electrochemical cell is the source of charge in a flashlight circuit, then one should also believe that charge must move through the wires of a circuit at a very fast speed. After all, one can clearly observe that the bulb lights immediately after the switch on the flashlight is turned to ON. There is no noticeable time delay between when the switch is flipped and when the light bulb lights. Thus, it is reasonable to believe that if charge is being supplied by the cells in the battery compartment, then it must travel through the 2 cm of wire from the battery to the light bulb in less than a millisecond. Whatever time it does take, it cannot be much since a time delay is never observed. The reasoning may continue as follows: a home is not powered by a battery, but rather by an electrical utility company. Instead of using electrochemical cells as the source of charge in a home, the *electricity* is supplied by the utility company. One could then easily imagine that the utility company must supply a countless number of electrons to homes each day in order to operate all the appliances that are used. These electrons travel at nearly the speed of light from the fuse box or electrical panel to the appliance when an appliance is turned on. This reasoning would explain why a light bulb lights immediately after the light switch is flipped to the ON position.

Getting the Right Mental Model

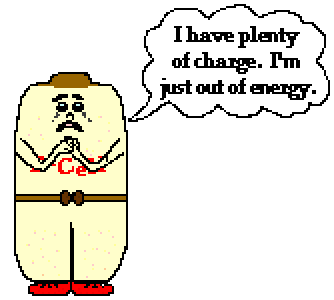
Again, the above two paragraphs represent a logical extension of the belief that an electrochemical cell is the source of charge in a circuit and that they must have their charged resupplied or replenished when they no longer work. This logic would lead a student of physics to answer True to all five statements of the True-False quiz at the beginning of this page. The problem with the reasoning above is that it leads to completely wrong conclusions. While the reasoning may be logical, the conclusions that it leads to are completely false due to its entirely incorrect initial premise - that batteries are rechargeable. It is important to realize that the mental model developed by such reasoning patterns is completely inconsistent with the model presented in Lessons 1 and 2 of this unit. Consider the following highlights discussed already in this unit and compare them to the conclusions drawn in the above paragraphs.



- An electrochemical cell supplies the energy needed to move a charge from a low potential location to a high potential location. See Lesson 1, Part c.
- The charge that flows through a circuit originates in the wires of the circuit. The charge carriers in wires are simply the electrons possessed by the atoms that make up the wires. See Lesson 2, Part c.
- Charge moves abnormally slowly - on average, about 1 meter in an hour - through a circuit. Yet as soon as a switched is turned to ON, charge located everywhere within the circuit begins to move. See Lesson 2, Part c.
- The rate at which charge flows is everywhere the same within an electric circuit. The rate at which charge flows into a light bulb is the same as the rate at which charge flows out of a light bulb. See Lesson 2, Part c.
- An electrical appliance such as a light bulb transforms the electrical energy of moving charge into other forms of energy such as light energy and thermal energy. Thus, the amount of electrical energy possessed by a charge as it exits an appliance is less than it possessed when it entered the appliance. See Lesson 1, Part c.

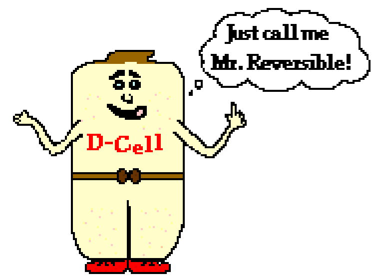


If an electrochemical cell is not rechargeable, then why do stores sell rechargeable cells for a higher cost? What kind of rip-off is that? The fact is that electrochemical cells that are referred to as rechargeable can be bought in stores. And these batteries can be placed in small machines that are called rechargers. And the process of doing so can extend the life of the battery. So as far as the consumer is concerned, it really isn't a rip-off at all. But as far as the physics teacher and physics student is concerned, it is a major offense because batteries should never be referred to as rechargeable.



Electric circuits are all about energy, not charge. When a battery no longer works, it is out of energy. A battery (or single cell) operates by packing a collection of reactive chemicals inside. These chemicals undergo an oxidation-reduction reaction that produces energy. This energy-producing reaction is capable of pumping the charge through the battery from low energy terminal to high energy terminal and establishing the electric potential difference across the external circuit. And when a battery no longer works, it is because the chemicals have been consumed to the point that the ability of the battery to move the charge between terminals has been severely diminished. When a battery no longer works, it is because the conversion of reactants to products have occurred to the extent that the energy-producing reaction is no longer able to do its job of pumping charge.

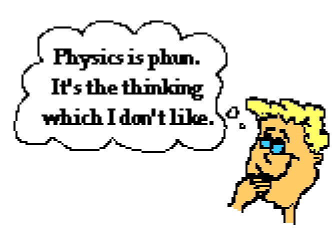
Some batteries are said to be rechargeable because this problem of the consumption of chemical reactants can be easily fixed. Such so-called rechargeable batteries rely upon a reversible reaction. The reaction can be run in the reverse direction, turning the chemical products back into chemical reactants within the cell. Since the usual reaction which powers the circuit is an exothermic reaction (a fancy chemistry name for energy-producing), the reverse reaction is an endothermic reaction which requires energy in order to work. By placing the cell into a so-called recharger, the energy of a household electrical circuit can be used to drive the reaction in the reverse direction and transform the chemical products back into chemical reactants. This reverse process requires energy; it is the recharger which supplies the energy. With reactants replenished, the cell can now be used again to power the electric circuit. A true understanding of this process would lead one to refer to such cells as reversible or re-energizable; and the machines that are used to reverse the reaction would be properly referred to as re-energizers.



Electric circuits are all about energy, not charge. The charge is simply the medium which moves the energy from location to location. The batteries or other energy source does work upon the charge to supply it with energy and place it at a high electric potential. Charge at high electric potential will spontaneously begin its very slow migration towards the low potential terminal of the cell. Charge everywhere within the circuit moves together, like soldiers marching in step. As an individual charge moves through circuit elements such as light bulbs, its electrical energy is transformed into other forms of energy such as light energy and thermal energy. With many, many charges moving through the light bulb at the same time, there is a significant transformation of electrical energy to light energy to cause the light bulb filament to noticeably glow. Upon passage through a light bulb filament, an individual charge is less energized and at a lower electric potential. The charge completes its slow migration back to the low potential terminal where the electrochemical cell does work upon the charge again to move it back up to high electric potential. Once at high potential, the charge can begin its loop again through the external circuit.

As a student of physics, grasping the conceptual meaning of ideas is not always easy. It certainly is not a mere matter of memorizing information for future retrieval. Grasping the meaning of ideas demands the exertion of mental exercising. A student of physics must do some processing work. When it comes to understanding the model of charge flow through circuits, a student should take the time to ask:

- What do I believe?
- Is what I believe sensible and logical or simply a set of ideas which I acquired without a lot of thinking about it?



- Does what I believe explain the world which I observe?
- Are there any inconsistencies in my thought processes? Does belief A logically contradict belief B?
- Are there sensible and logical alternative beliefs that better explain the world which I observe?

Taking the time to think about these questions is one of the keys to dispelling incorrect misconceptions of the physical world and arriving with more accurate mental models.

In the next Lesson of this unit of The Physics Classroom, we will explore the cause for why energy is lost within the wires of the external circuit.