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Science Unit: *Concepts in Electricity*

Lesson 3: *Simple Series Circuits*

Summary: In this lesson, students build their own **simple series circuit** that lights a bulb. They then predict what will happen to the brightness of their bulb in a circuit containing a greater number of elements in series, and test their prediction.

School Year: 2013/2014

Developed for: Lord Selkirk Elementary School, Vancouver School District

Developed by: James Day (scientist); Marie-Christine Michel and Karina Houle (teachers)

Grade level: Presented to grade 6; appropriate for grades 5 – 7 with age appropriate modifications

Duration of lesson: 1 hour and 05 minutes

Notes: This lesson is a modification of Lesson 2: Series and Parallel Circuits: Electricity with Applications Unit

It is preferable to use power adapters instead of batteries.

Batteries are not recommended because they can explode when shorted, are expensive and have a short life. Power adapters, on the other hand, are safer, last for years, contain circuits that protect them when shorted and cost much less per year of use. The typical 6-V battery used in schools costs \$10 and lasts 1-2 years. A power adapter costs \$20 - \$30 but lasts for many years.

Safety precaution:

If using batteries, be careful not to short the terminals of the battery as it will damage the battery and there is a danger of explosion. In other words, do not connect the terminals of the battery directly with a low resistance element such as a wire or any piece of metal.

Note that voltages less than 24 V are considered safe. Power supplies should be used that have outputs less than 24 V and have current limiting to prevent blowing fuses in the event that outputs are shorted.

Objectives:

Students will be able to:

1. Learn how electricity is used in circuits to do work.
2. Identify a series circuit.
3. Create a series circuit that lights a bulb.
4. Discover how the voltage potential drop across a series circuit element.

Background Information

Electric charge is a fundamental property of matter (just as mass is). Two of the three basic particles that make up an atom — namely, protons and electrons — are the carriers of electric charge. There are two types of charge: positive and negative. Protons have positive charge, electrons have negative charge.



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Electric current refers to the flow of the electric charge carried by electrons as they jump from atom to atom. Electric current is a very familiar concept: When you turn on a light switch, electric current flows from the switch through the wire to the light, and the room is instantly illuminated. Electric current flows more easily in some types of atoms than in others. Atoms that let current flow easily are called conductors, whereas atoms that don't let current flow easily are called insulators.

An electric circuit is a closed loop made of conductors and other electrical elements through which electric current can flow. For example, a very simple electrical circuit consists of three elements: a battery, a lamp, and an electrical wire that connects the two.

Vocabulary

Series circuit: A circuit in which the components are connected one after the other in a loop.

Materials

- power supplies or batteries
- battery holders
- wires
- light bulb holders
- light bulbs
- knife switches

In the Classroom

Introductory Discussion

1. The concept of electricity is both familiar and mysterious. We all know what electricity is, or at least have a rough idea, based on practical experience. We are very familiar with the electricity that flows through wires. That electricity comes from power plants that burn coal, catch the wind, or harness nuclear reactions. It travels from the power plants to our houses in big cables hung high in the air or buried in the ground. Once it gets to our houses, it travels through wires through the walls until it gets to electrical outlets. From there, we plug in power cords to get the electricity into the electrical devices we depend on every day. We know that electricity isn't free. We know that electricity can be stored in batteries. When the batteries die, all their electricity is gone. We know that some kinds of batteries are rechargeable, which means that when they've been drained of all their electricity, more electricity can be put back into them by plugging them into a charger, which transfers electricity from an electrical outlet into the battery. We know that electricity can be measured in volts. Household electricity is 120 volts (abbreviated 120 V). Flashlight batteries are 1.5 volts. Car batteries are 12 volts. We also know that electricity can be measured in watts. Incandescent light bulbs are typically 60, 75, or 100 watts. Compact fluorescent lights (CFLs) have somewhat smaller wattage ratings. Microwave ovens and hair dryers are 1,000 or 1,200 watts. We also may know that there's a third way to measure electricity, called amps. A typical household electrical outlet is 15 amps (abbreviated 15 A). And finally, we know that electricity can be very dangerous.
2. Short description of other items to discuss or review.
 - What is a circuit? Electrical current powered by an electrical source such as a battery or power supply travels from one of the two terminals of the source, through one or more circuit elements and back to the power source through the second terminal. The circuit element could be wires, lamps, heating elements, or any number of elements that conduct electricity. The simplest circuit would form a single continuous loop (called a series circuit) from one source to the other, but more complex arrangements are possible.
 - Can you think of any circuits in this classroom? Lights, computers, PA system, projectors, cell phones, DVD players, TV, etc...



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- How does a light bulb work? It is important that the students understand how current flows through a light bulb and to know why that causes a light bulb to glow.
3. Briefly describe science experiment/activity.
 - Students will gain experience constructing a basic series circuit.
 - Students will be presented with a question for which they must create and test a hypothesis. Each group will be given a different question to test. At the end of the activity, students will present their results to the rest of the class.
 4. Briefly describe the processes of science that the students will focus on (prediction/hypothesis, observations, recording results, conclusions.)
 5. Briefly describe safety guidelines.
 - If using batteries: Be careful not to short the battery terminals as it will damage the battery and there is a danger of explosion. In other words, do not connect the terminals of the battery directly with a low resistance element such as a wire or any piece of metal.

Science Activity/Experiment

Activity Title: Building and testing series circuits.

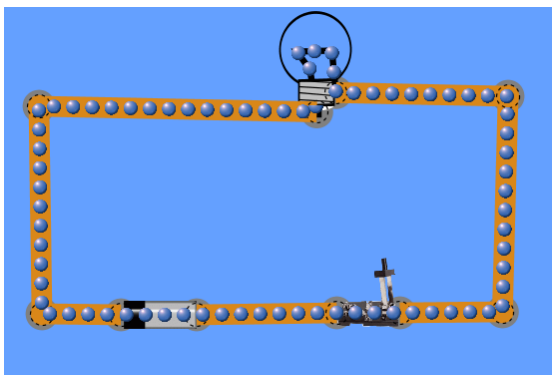
Purpose of Activity: To gain experience building simple series circuits; to test student models of how electricity flows (i.e., hypothesis testing).

Prediction or Hypothesis: Before students make their prediction (or hypothesis), it helps if they start with a question, or make observations and then ask a question. They will use their prior knowledge from building a simple series circuit (the PhET pre-homework and step 1) to predict what they think will happen when presented with a series circuit containing a greater number of circuit elements. They will record their prediction based on the following question: What will happen when...? (See below, starting at 3.a., for the variety of questions that a group might be given).

Methods and Instructions:

Set-up prior to experiment: Little circuit kits must be put together so that each group can work with the same type and number of circuit elements (wires, battery boxes and batteries OR power supplies, light bulb holders, light bulbs, etc.) Students will work in groups of two.

1. Working in small groups, students will construct a simple series circuit to light a single light bulb with a battery, as shown in the PhET picture below.

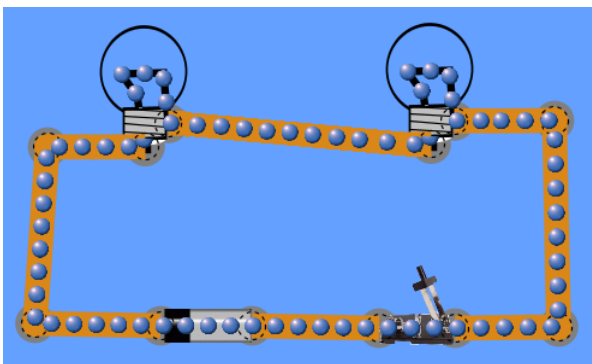




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2. Students sketch their circuit into their science notebooks.
3. Groups will then be given one of the following questions. Students will make and record their hypothesis in their science notebooks.
 - a. What will happen to the brightness of your bulb if you add a second battery to your series circuit?
 - b. What will happen to the brightness of your bulbs if you add a second bulb to your series circuit? (As shown in the figure below.)



- c. What will happen to the brightness of your bulb if you add a second battery and a second bulb to your series circuit?
4. Once students have recorded their hypothesis, they will be provided with the necessary circuit elements to test their hypothesis. Students will record their observation in their science notebooks and explicitly write whether or not their initial hypothesis was correct or not. Be sure to remind students that it is unimportant whether or not their initial hypothesis was correct; what is important is that their hypothesis was tested and that they now have a better understanding of how circuits work. It's always better to know more now than you did before (which sometimes means correcting mistakes in your thinking).
5. All students will then be presented with a more complicated series circuit. If the brightness of a single bulb in series with a single battery is "1", how bright will the second bulb be in a series circuit that contains four batteries and six bulbs? Have some students share their hypotheses with the class. Using the DC Circuit Construction PhET, displayed on a SMARTBOARD, build the circuit in question and test the hypotheses as a group. Time permitting, other circuits can be tested (or re-tested, from the questions covered earlier).

Closure Discussion

1. Did the circuits behave as you originally expected?
2. What other types of circuits can you imagine? (This discussion should be steered toward parallel circuits, in preparation for the next SRP lesson.)

References

- <http://www.dummies.com/how-to/content/electronics-basics-fundamentals-of-electricity.html>
<http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html#c1>
<http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc>



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Extension of Lesson Plan

1. Use different circuit elements to determine which materials are good conductors and which are poor conductors (i.e., good insulators) of electricity. Materials could include: coins, pencils, paper clips, erasers, nails and screws, paper, cutlery, etc.
2. Use a digital multimeter so that students can measure voltage drops across the bulb and other circuit elements.

Helpful Analogical Diagrams

DC Circuit Water Analogy

This is an active graphic. Click any part of it for further details.

Water Circuit:

- Volume flowrate: e.g., cm³/sec
- High pressure: 50 lb/in² ≈ 50 lb/in²
- Low pressure: 0 lb/in² ≈ 0 lb/in²
- Resistance: R
- Flow rate: F
- Components: Pump, Reservoir
- Law: Poiseuille's Law
- Equation: $F = \frac{\Delta P}{R}$

Electrical Circuit:

- Charge flowrate = current = $\frac{\text{coulombs}}{\text{second}} = \text{amperes}$
- High voltage: 12 volts ≈ 12 volts
- Low voltage: 0 volts ≈ 0 volts
- Resistance: R
- Current: I
- Components: Battery, Ground
- Law: Ohm's Law
- Equation: $I = \frac{\Delta V}{R}$

In a direct current (DC) electrical circuit, the voltage (V in volts) is an expression of the available energy per unit charge which drives the electric current (I in amperes) around a closed circuit. Increasing the resistance (R in ohms) will proportionately decrease the current which may be driven through the circuit by the voltage.

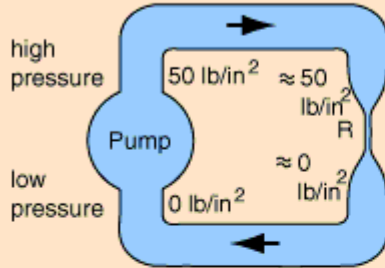
Each quantity and each operational relationship in a battery-operated DC circuit has a direct analog in the water circuit. The nature of the analogies can help develop an understanding of the quantities in basic electric circuits. In the water circuit, the pressure P drives the water around the closed loop of pipe at a certain volume flowrate F. If the resistance to flow R is increased, then the volume flowrate decreases proportionately. You may click any component or any relationship to explore the details of the analogy with a DC electric circuit.



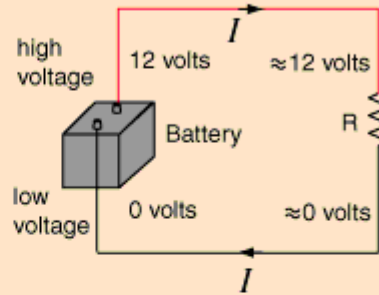
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Voltage Law and Pressure

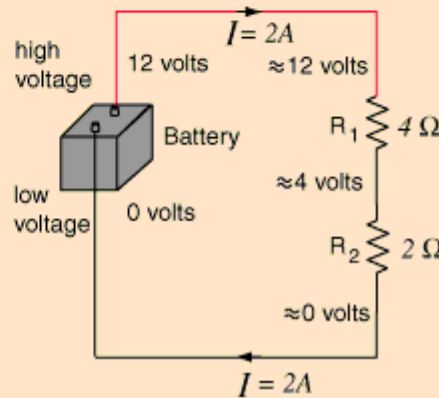
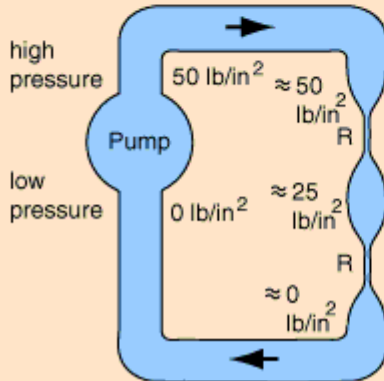
A net zero change in voltage or pressure around any closed path is a consequence of conservation of energy.



There cannot be any net pressure change on any closed loop path. Any pressure increase produced by the pump must be followed by a pressure drop back to the original pressure as it re-enters the pump.



The net voltage change around any closed loop path must be zero. Any voltage rise produced by the battery must be followed by a voltage drop to bring it back to the original voltage.



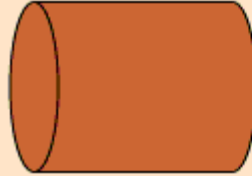


Current-Flowrate Analogy

Volume
flowrate in
liters/min,
 cm^3/sec ,
 m^3/sec , etc.



A large pipe offers very little [resistance](#) to flow, as shown by [Poiseuille's law](#).



A wire offers very little [resistance](#) to charge flow according to [Ohm's law](#).

Electric current
flow in
 $\text{coulombs}/\text{sec}$
= amperes.

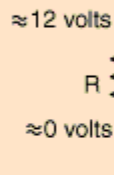
Connecting a battery to an appliance through a wire is like using a large pipe for water flow. Very little voltage drop occurs along the wire because of its small resistance. You can operate most appliances at the end of an extension cord without noticeable effects on performance.



Resistance to Flow

The [resistance to flow](#) represented by a severe constriction in a water pipe is analogous to the [resistance to electric current](#) represented by a common electric "resistor".

The resistance of a constriction in a large pipe is so great that essentially all the pressure drop will appear across the resistance.



The resistance of a copper wire is so small that essentially all the voltage drop will appear across the resistor (or an appliance).

The severe constriction will have more resistance than the remainder of the pipe system. Likewise a resistor in an electric circuit will generally have much more resistance than the wire of the circuit. If the single elements represented are the only resistances in the circuit, then essentially all the pressure or voltage will drop across these single elements. The fact that essentially all the voltage drop appears across a resistor or an ordinary electrical appliance makes possible the operation of such appliances from an extension cord, or the operation of several appliances in parallel on a single circuit in your home.



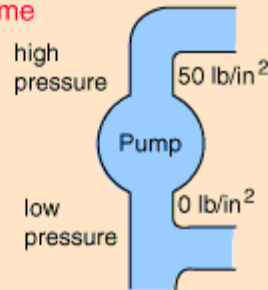
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Voltage-Pressure Analogy

A battery is analogous to a pump in a water circuit. A pump takes in water at low pressure and does work on it, ejecting it at high pressure. A battery takes in charge at low voltage, does work on it and ejects it at high voltage.

$$\text{pressure} = \frac{\text{energy}}{\text{volume}}$$

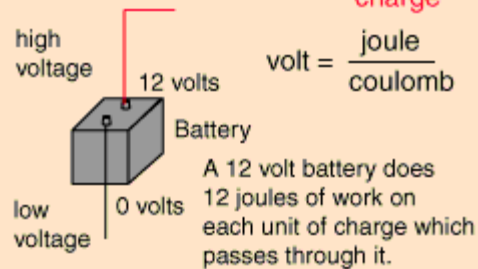
$$\begin{aligned} \text{pressure} &= \frac{F}{A} \\ \frac{F}{A} &= \frac{F d}{A d} = \frac{W}{V} \\ &= \frac{\text{energy}}{\text{volume}} = \frac{\text{joule}}{\text{m}^3} \end{aligned}$$



A closed faucet has pressure behind it, but no flow.
(resistance $\rightarrow \infty$)

$$\text{voltage} = \frac{\text{energy}}{\text{charge}}$$

$$\text{volt} = \frac{\text{joule}}{\text{coulomb}}$$



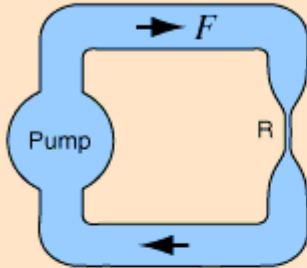
A receptacle has voltage behind it, but no current if nothing is plugged in.
(resistance $\rightarrow \infty$)



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Current Law and Flowrate

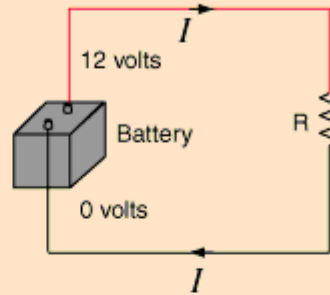
volume
flowrate e.g., cm^3/sec



With continuous circulation around the pipe system, the volume flowrate must be the same at any cross-section of the pipe system.

Conservation of liquid

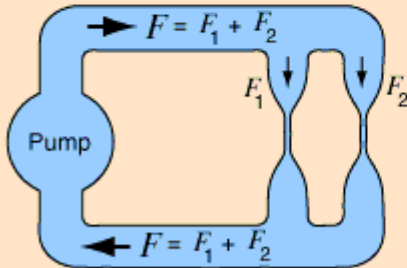
charge
flowrate = current = $\frac{\text{coulombs}}{\text{second}} = \text{amperes}$



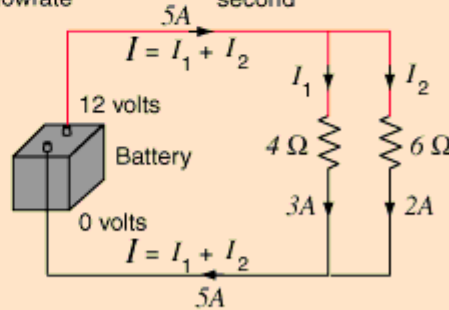
The electric current is the charge flowrate and it must be the same at any cross-section of the circuit. This is a general principle called the current law.

Conservation of charge

volume
flowrate e.g., cm^3/sec



charge
flowrate = current = $\frac{\text{coulombs}}{\text{second}} = \text{amperes}$



For any circuit, fluid or electric, which has multiple branches and parallel elements, the flowrate through any cross-section must be the same. This is sometimes called the principle of continuity.



Electrical Circuits **Pre-lesson Homework**

Introduction:

In this activity you will investigate the physical science of electrical circuits. You will see how electrical current behaves in a parallel vs. series arrangement and what the relative brightness of bulbs in these circuits.

1. Go to the website: <http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc>
2. Click the “Run Now!” button. You may get a warning that this type of file can harm your computer, but this file is fine. Keep the file and run the application. You may need to get some help from your parents.

Free Exploration:

1. While playing with the simulation, keep the ‘Lifelike’ option selected under the “Visual’ column.
2. Use the ‘Tools’ column, select a “Voltmeter” (to measure voltage) and an “Ammeter” (to measure current).
3. Explore the simulation freely – drag and drop elements (batteries, wires, and so on) from the right and drop them into the open area on the left. Try whatever you want!
 - a. Build your own circuit (a path so that electrons can return to where they began).
 - b. Use the voltmeter to measure the voltage across any section of your circuit. For example, put the voltmeter near the battery and place the red tab at one end and the black at the other.
 - c. Use the ammeter (as a part of your circuit – treat like a section of wire!) to measure the current flowing along the path at that point.
 - d. By right-clicking on an element, you can change its values. For example, play with the resistance and voltage of the battery. Notice how this changes the readings on the voltmeter and ammeter.

HINT: You can wipe everything clean by hitting the “Reset All” button.

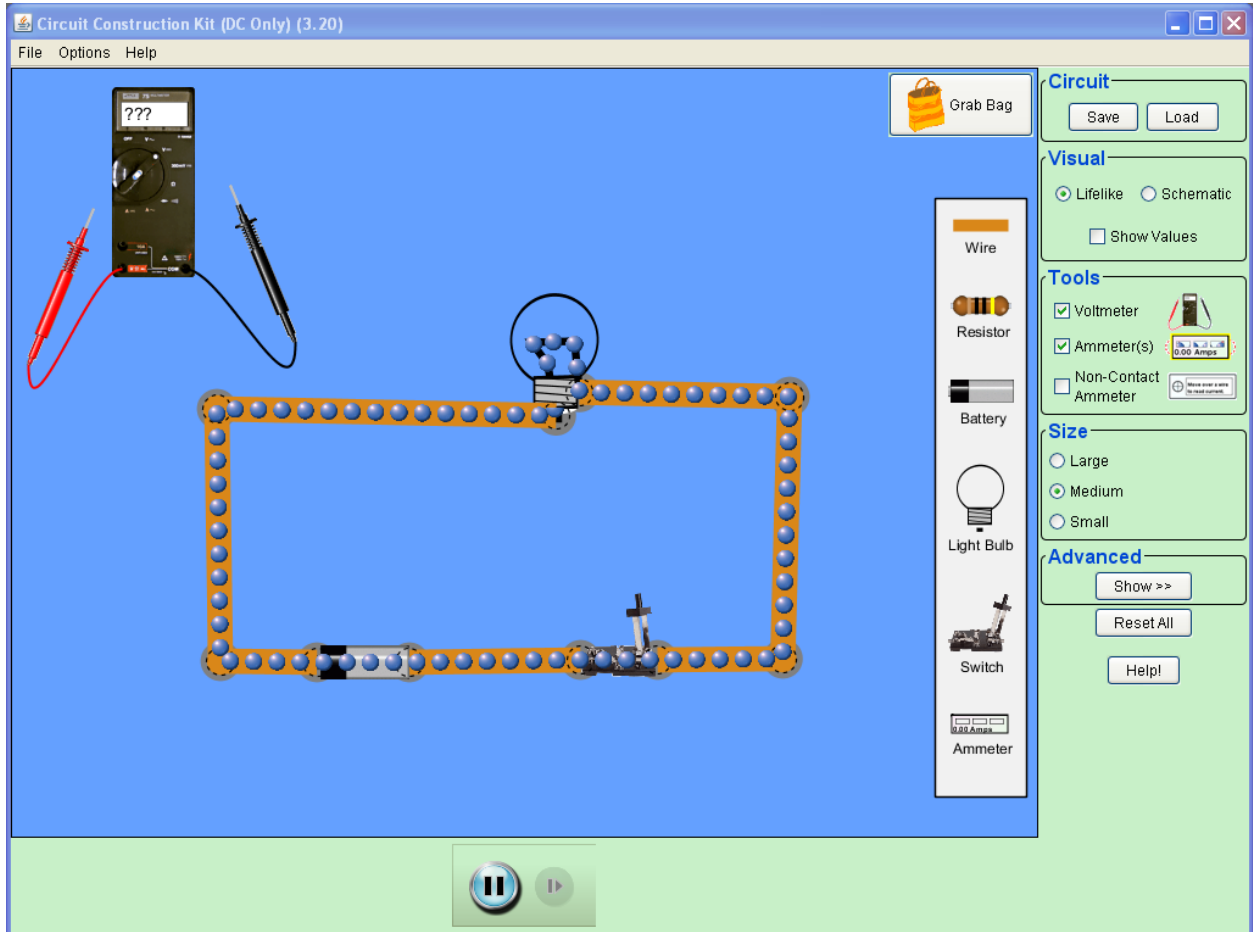
Application:

1. Hit the “Reset All” button.
2. Create the circuit shown below.



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3. Answer the following questions.
 - a. What happens to the electrons (the blue dots) when the switch is closed?
 - b. What happens to the light bulb when the switch is closed?
 - c. Using the voltmeter, what is the voltage across the battery?
 - d. Using the voltmeter, what is the voltage across the light bulb?
 - e. Right-click on the battery, and change its voltage from 9.0V to 15.0V.
What happens to the electrons when you make this change? What happens to the light bulb when you make this change?