PHYS 1755 Electric Circuits Sim: Building Models Name:______________________

Object: To develop a mental model of electricity by doing inquiry-based experiments.

Preparation: The PhET simulation "Circuit Construction Kit: DC" from the University of Colorado is how we'll learn about simple circuits. The simulation is written in HTML5 and should run in any modern web browser. Go to this URL:
`https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc`.

Procedure and Results: Drag circuit elements from the carousel on the left into the play area. Connect them together by overlaying the dashed circles. Clicking on the connections allows you to cut them. Delete circuit elements by clicking on them and then selecting the trash can. You are encouraged to play freely—in a simulation you can't hurt anything (neither the equipment nor you!).

Introductory Exercises Select the "Intro" button/tab to begin. Unclick the "show current" box.

1. First figure out how to use one battery, one bulb, and *one* wire to make the bulb light up.

2. Find three variations of this circuit (for a total of four slightly different circuits) that also light the bulb. (This is more instructive in real life because some people don't realize there are two attachments for a bulb and charges go in one contact point and out the other; but this is obvious in the simulation.)

3. Add one more wire to make the circuit cleaner and easier to observe. What things can you change to make the the bulb brighter? (Click on the bulb and battery in turn.)

Current Click the "show current" box. Current I is merely the orderly movement of electric charges. The SI unit is the ampere which is defined as a coulomb of charge passing by in the wire every second: A = C/s. We like to imagine positive charges moving, which is the direction we define conventional current, but in normal metal wires the charges that move are actually *negative* electrons moving in the opposite direction. You can choose "Conventional" current with red arrows or "Electrons" which are blue circles moving the other direction. Try each and see which you prefer.

1. With the one-bulb, one-battery, two-wires circuit drag an Ammeter from the palate on the right into the play area. You can position the cross-hairs to find the value of the current at

any point in the circuit. What do you notice about the current in the different circuit elements (battery, bulb, wires)?

2. What can you do to change the current? (See procedure 3 above, plus one more thing you can do to the battery.)

3. Too much current through a battery can ruin it. Figure out how to light the battery on fire.

Voltage Potential difference ΔV, often called voltage, is related to the strength of the force pushing the charges around the circuit. The SI unit of voltage is the volt. The voltage of a battery is determined by its chemistry; typical, non-rechargeable D-, C-, AA-, and AAA-cells are all 1.5 V.

1. Click the reset button in the lower right and set up a one-bulb circuit with *two* batteries end to end. Then try *three* batteries end to end. We say these end-to-end batteries are "in series." How is the ammeter reading affected? How is the brightness of the bulb affected?

2. Guess/predict a rule for the voltage of a given set of batteries in series.

3. Verify your predicted rule by putting two batteries in series but make them different voltages (by clicking on at least one of the batteries and changing the value). Drag a Voltmeter from the palate on the right and attach one of the leads to each end the set/group of batteries. Then doubly verify your rule by switching the polarity of one of the batteries.

4. Given your rule, speculate about the internal make-up of a real-life 9-V battery. Examining a 12-V car battery may give you an idea.

5. How does the voltage across the bulb compare to the voltage across the series-combination of batteries?

6. Figure out how to connect two or three batteries "in parallel" (side by side) rather than in series. How do the brightness of and the ammeter readings in the bulb compare to the one-battery circuit?

7. Guess/predict a rule for the voltage of a given set of identical batteries in parallel.

Resistance Resistance R impedes the movement of charges in the circuit. In the carousel you have resistors whose job is to do this. Resistors dissipate thermal energy when there is current in them. The bulbs are merely resistors that get hot enough to glow; for this reason, bulbs can function as visible current indicators if you don't have an ammeter (although their own resistance changes the current in the circuit). The SI unit of resistance is the ohm with symbol Ω.

1. Guess/predict a rule for the equivalent resistance of a given set of resistors in series.

2. Check your predicted rule by putting two or three resistors in series with a bulb and see what that does to the brightness of the bulb. Verify with an ammeter the effect of adding resistors in series. Doubly verify your rule by changing the resistance of one or more of the resistors. Triply verify by changing the resistance of the light bulb—it is just a resistor that glows.

3. What does the ammeter say about the current in all the resistors and the bulb in series?

4. What does the voltmeter say about the voltage across each *different* resistor in series?

5. Guess/predict a rule for the equivalent resistance of a given set of resistors in parallel.

6. Connect two or three resistors in parallel and connect that combination in series with a bulb and a battery. How does the brightness of the bulb change as you change the resistance of the resistors or add more resistors in parallel?

7. What does the ammeter say about the current in each *different* resistor in parallel?

8. What does the voltmeter say about the voltage across each of the resistors in parallel?

Conductors and Insulators If an object has low resistance we call it a conductor and if it has high resistance an insulator. There is a wide range of resistances; many objects are in between the extreme categories. Metals are usually good conductors because they have many electrons that are free to move; that's why wires are usually made of metal. But other things can conduct too.

1. The second and third panels in the carousel have many household items. Determine which are conductors and which are insulators. Were there any surprises? Were all conductors equally conductive?

2. Why is the pencil sharpened on both ends?

3. Based on the simulation and further research, are human bodies conductors? Why should you be careful around high voltages?

4. Which of the conductors can you light on fire in the simulation? Why?

5. Pay special attention to the fuse. It has a conducting state and an insulating state. Why? What causes it to switch states? (If you "blow" a fuse, just get a new one from the carousel.)

6. Figure out the purpose of fuses in real life by putting one in series with a conductor you managed to light on fire. Explain.

Ohm's Law For many conductors, there is a very simple mathematical relationship between current in the conductor, the voltage across the conductor, and the resistance of the conductor.

1. Using your above results and any further investigations you may need, ascertain how the voltage across and resistance of a conductor determine the current in the conductor. (Your calculations will be simpler if you turn on the Values check-box in the upper right pane.) Write this relationship as a very simple mathematical equation. This is called Ohm's law.

2. If a graph of current vs. voltage is linear we say the conductor is "ohmic," in which case the slope of the line is the reciprocal of the resistance. Are the bulb filaments in this simulation ohmic? (Bulb filaments in real life are not strictly ohmic because the resistance increases as current increases and the temperature increases.)

3. The simulation does not provide an ohmmeter to measure resistance. This is unimportant for individual resistors because you can click on a resistor to find its resistance. But an ohmmeter would help you verify your rule for the equivalent resistance of a group of resistors in parallel (procedure 5 in the Resistance section above). Since you have no ohmmeter, use Ohm's law to verify your rule for resistors in parallel.

4. Many people harbor the misconception that a battery is a source of constant current. That is not the case. What is a battery's job in life? What determines the current in a circuit?

5. The batteries in this simulation are not like real batteries in that the simulation batteries have an adjustable voltage. In this sense they are acting more like an adjustable DC (Direct Current) power supply. What do you suppose the voltage is like in an AC (Alternating Current) power supply?

Advanced Exercises Select the "Lab" button/tab at the bottom. This gives you access to a new second panel in the carousel with high-voltage batteries, and high-resistance bulbs and resistors, as well as some new settings on the right.

1. We model ideal wires as having zero resistance but real wires do have some resistance. (There are in real life cool things called superconductors that have zero resistance!) Change the Wire Resistivity setting and find out how the resistance of wires varies with length. This is a reason we are not encouraged to use lots of long extension cords in our houses.

2. We model ideal batteries as having no internal resistance but real batteries have some internal resistance. Measure the voltage across a battery and across the bulb in an operating circuit both when it has no internal resistance and when it has high internal resistance. What happens to the brightness of the bulb as the internal resistance of the battery increases?

3. The simulation's Lab tab gives you a new ammeter which must be placed in series in a circuit (whereas voltmeters are put in parallel with the circuit element you wish to measure the potential difference across). This is how the ammeters in our real, physical lab work. Fiddle around with the new ammeter and the new circuit elements in the second panel of the carousel until you learn something new. What did you learn?

4. Select the stick figure icon next to the battery icon in the lower right of the screen to see the

"schematic" symbols that electrical engineers use to draw circuits. Repeat a couple of the earlier procedures with the schematic symbols turned on.

Further Explorations: If this simulation was interesting, fun, and not quite enough to satisfy you, please see these other related PhET simulations (some of which require java):
`https://phet.colorado.edu/en/simulation/legacy/battery-voltage`
`https://phet.colorado.edu/en/simulation/resistance-in-a-wire`
`https://phet.colorado.edu/en/simulation/legacy/battery-resistor-circuit`
`https://phet.colorado.edu/en/simulation/ohms-law`
`https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac`
`https://phet.colorado.edu/en/simulation/legacy/capacitor-lab` (would teach some ideas from the CASTLE kits)

Conclusions: What was your prior experience and comfort level with electricity? What did you learn from the simulation? Was there anything you would have liked to try that wasn't available in the simulation? How did this simulation relate to topics covered in the lecture course?