A MODEL FOR CIRCUITS PART 1: CURRENT AND RESISTANCE

In this tutorial, we construct a model for electric current that we can use to predict and explain the behavior of simple electric circuits.

I. Complete circuits

A. Obtain a battery, a light bulb, and a single piece of wire. Connect these in a variety of ways. Sketch each arrangement below.

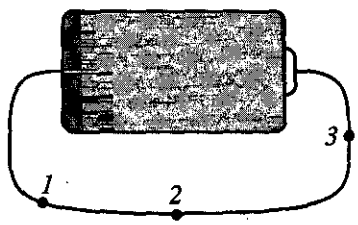
Arrangements that *do* light the bulb	Arrangements that *do not* light the bulb

You should have found at least four different arrangements that light the bulb. How are these arrangements similar? How do they differ from arrangements in which the bulb does not light?

State the requirements that must be met in order for the bulb to light.

B. A student has briefly connected a wire across the terminals of a battery until the wire feels warm. The student finds that the wire seems to be equally warm at points *1*, *2*, and *3*.

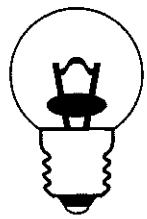
Based on this observation, what might you conclude is happening in the wire at one place compared to another?



C. Light a bulb usin g a battery and a single wire. Observe and record the behavior (*i.e.*, brightness) of the bulb when objects made out of various materials are inserted into the circuit. (Try materials such as paper, coins, pencil lead, eraser, your finger, *etc.*)

What is similar about most of the objects that let the bulb light?

D. Carefully examine a bulb. Two wires extend from the filament of the bulb into the base. You probably cannot see into the base, however, you should be able to make a good guess as to where the wires are attached. Describe where the wires attach. Explain based on your observations in parts A–C.



On the basis of the observations that we have made, we will make the following assumptions:

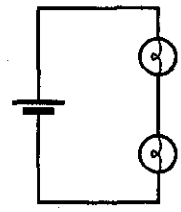
1. A flow exists in a complete circuit from one terminal of the battery, through the rest of the circuit, back to the other terminal of the battery, through the battery and back around the circuit. We will call this flow *electric current.*

2. For identical bulbs, bulb brightness can be used as an indicator of the amount of current through that bulb: the brighter the bulb, the greater the current.

Starting with these assumptions, we will develop a model that we can use to account for the behavior of simple circuits. The construction of a scientific model is a step-by-step process in which we specify only the minimum number of attributes that are needed to account for the phenomena under consideration.

II. Bulbs in series

Set up a two-bulb circuit with identical bulbs connected one after the other as shown. Bulbs connected in this way are said to be connected in *series*.



A. Compare the brightness of the two bulbs with each other. (Pay attention only to large differences in brightness. You may notice minor differences if two "identical" bulbs are, in fact, not quite identical.)

Use the assumptions we have made in developing our model for electric current to answer the following questions:

1. Is current "used up" in the first bulb, or is the current the same through both bulbs?

2. Do you think that switching the order of the bulbs might make a difference? Check your answer.

3. On the basis of your observations *alone,* can you tell the direction of the flow through the circuit?

B. Compare the brightness of each of the bulbs in the two-bulb series circuit with that of a bulb in a single-bulb circuit.

Use the assumptions we have made in developing our model for electric current to answer the following questions:

1. How does the current through a bulb in a single-bulb circuit compare with the current through the same bulb when it is connected in series with a second bulb? Explain.

2. What does your answer to question 1 imply about how the current through the *battery* in a single-bulb circuit compares to the current through the *battery* in a two-bulb series circuit? Explain.

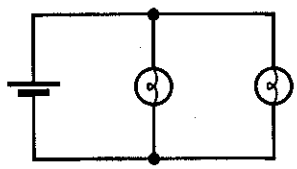
C. We may think of a bulb as presenting an obstacle, or *resistance,* to the current in the circuit.

1. Thinking of the bulb in this way, would adding more bulbs in series cause the total obstacle to the flow, or *total resistance,* to increase, decrease, or stay the same as before?

2. Formulate a rule for predicting how the current through the battery would change (*i.e.,* whether it would *increase, decrease,* or *remain the same*) if the number of bulbs connected in series were increased or decreased.

III. Bulbs in parallel

Set up a two-bulb circuit with identical bulbs so that their terminals are connected together as shown. Bulbs connected together in this way are said to be connected in *parallel.*



A. Compare the brightness of the bulbs in this circuit.

1. What can you conclude from your observation about the amount of current through each bulb?

2. Describe the current in the entire circuit. Base your answer on your observations. In particular, how does the current through the battery seem to divide and recombine at the junctions of the two parallel branches?

B. Is the brightness of each bulb in the two-bulb parallel circuit *greater than, less than,* or *equal to* that of a bulb in a single-bulb circuit?

How does the amount of current through a *battery* connected to a single bulb compare to the current through a *battery* connected to a two-bulb parallel circuit? Explain based on your observations.

C. Formulate a rule for predicting how the current through the battery would change *(i.e.,* whether it would *increase, decrease,* or *remain the same)* if the number of bulbs connected in parallel were increased or decreased. Base your answer on your observation of the behavior of the two-bulb parallel circuit and the model for current.

What can you infer about the total resistance of a circuit as the number of parallel branches is increased or decreased?

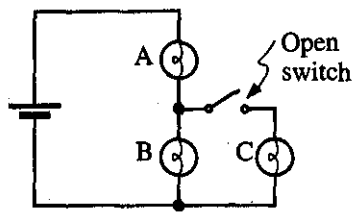
D. Does the amount of current through a battery seem to depend on the number of bulbs in the circuit and how they are connected?

E. Unscrew one of the bulbs in the two-bulb parallel circuit. Does this change significantly affect the current through the branch that contains the other bulb?

A characteristic of an *ideal* battery is that the branches connected directly across it are independent of one another.

IV. Limitations: The need to extend the model

A. The circuit at right contains three identical bulbs and an ideal battery. Assume that the resistance of the switch, when closed, is negligible. Use the model we have developed to:



- predict the relative brightness of the bulbs in the circuit with the switch closed. Explain.

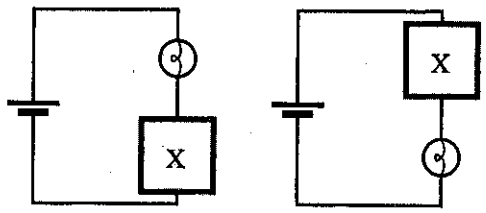
- predict how the brightness of bulb A changes when the switch is opened. Explain.

B. Show that a simple application of the model for current that we have developed thus far is inadequate for determining how the brightness of bulb B changes when the switch is opened.

A MODEL FOR CIRCUITS PART 2: POTENTIAL DIFFERENCE

I. Current and resistance

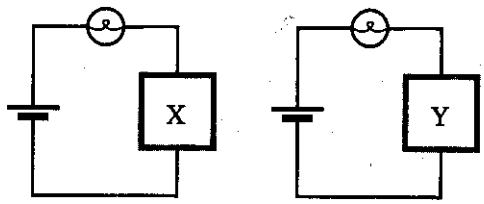
A. The circuits at right contain identical batteries, bulbs and unknown identical elements labeled X.



How do the bulbs compare in brightness? Explain.

In each circuit, how does the current through the bulb compare to the current through element X? Explain.

B. The circuits at right contain identical batteries and bulbs. The boxes labeled X and Y represent different unknown elements. (Assume there are no batteries in either box.)



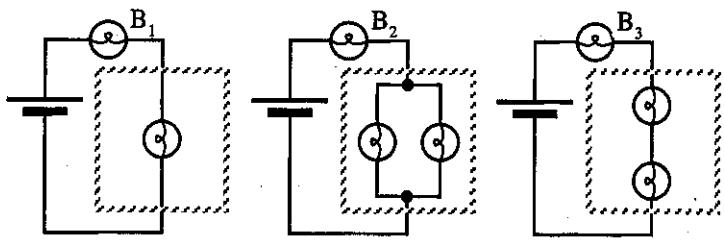
It is observed that the bulb on the left is brighter than the bulb on the right.

1. Based on this observation, how does the resistance of element X compare to that of element Y? Explain.

2. In each circuit, how does the current through the bulb compare to the current through the unknown element?

3. In each circuit, how does the current through the bulb compare to the current through the battery?

C. Predict the relative brightness of bulbs B_1, B_2, and B_3 in the circuits shown. (A dashed box has been drawn around the network of circuit elements that is in series with each of these bulbs.)



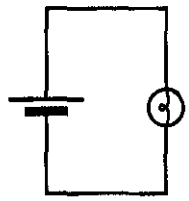
What does your prediction imply about the relative currents through the *batteries?* Explain.

Have a tutorial instructor show you these circuits so that you can check your answers. Resolve any conflicts between your answers and your observations.

II. Potential difference

For the remaining circuits in this tutorial use the battery holder with two batteries connected in series. The two-battery combination will be treated as a single circuit element.

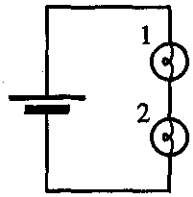
A. Set up the circuit with a single bulb and the battery combination as shown. Connect each probe of the voltmeter to a different terminal of the battery holder to measure the potential difference across the battery. Make a similar potential difference measurement across the bulb.



How does the potential difference across the bulb compare to the potential difference across the battery?

V_{Bat}	V_{Bulb}

B. Set up the circuit containing two bulbs in series as shown.



Rank from largest to smallest the currents through bulb 1, bulb 2, and the bulb in the single bulb circuit from part A ($i_{Bulb\ 1}$, $i_{Bulb\ 2}$, i_{single}). Explain.

Measure the potential difference across each element in the circuit.

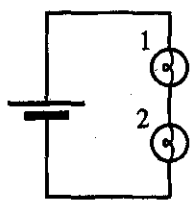
V_{Bat}	$V_{Bulb\ 1}$	$V_{Bulb\ 2}$

1. How does the potential difference across the battery in this circuit compare to the potential difference across the battery in the single-bulb circuit? (See part A.)

2. Rank the potential differences across bulb 1, bulb 2, and the bulb in the single-bulb circuit from part A.

3. How does the potential difference ranking compare to the brightness ranking of the bulbs?

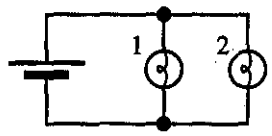
C. Predict what the voltmeter would read if it were connected to measure the potential difference across the network of bulb 1 and bulb 2 together. Explain.



Test your prediction.

How does the potential difference across the network of bulbs compare to the potential difference across the battery?

D. Set up the circuit with two bulbs in parallel as shown.



Rank the currents through bulb 1, bulb 2, and the bulb in the single bulb circuit from part A. Explain.

How does the current through bulb 1 compare to the current through the battery? Explain.

Measure the potential difference across each circuit element.

V_{Bat}	$V_{Bulb\ 1}$	$V_{Bulb\ 2}$

1. How does the potential difference across the battery in this circuit compare to the potential difference across the battery in the single-bulb circuit?

2. Rank the potential difference across bulb 1, bulb 2, and the bulb in the single bulb circuit from part A.

3. How does the ranking by potential difference compare to the ranking by brightness?

E. Answer the following questions based on the measurements you have made so far.

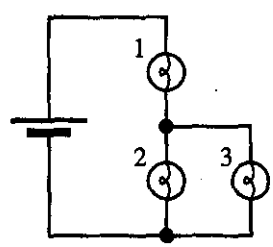
1. Does the *current through the battery* depend on the circuit to which it is connected? Explain.

2. Does the *potential difference across the battery* depend on the circuit to which it is connected? Explain.

III. Extending the model

Our model for electric circuits includes the idea that, for identical bulbs, the brightness of a bulb is an indicator of the current through the bulb. Based on our observations in this tutorial, we can extend the model to include the idea that, for circuits containing identical bulbs, the brightness of a bulb is also an indicator of the potential difference across the bulb.

A. Set up the circuit with three bulbs as shown and observe their brightness.

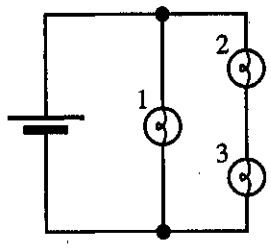


Before making the voltmeter measurements, predict the ranking of the potential difference across the battery and each bulb (V_{Bat}, $V_{Bulb\ 1}$, $V_{Bulb\ 2}$, and $V_{Bulb\ 3}$). Explain your prediction.

Measure the potential difference across each element in the circuit. If your measurements are not consistent with your ranking above, resolve the inconsistencies.

V_{Bat}	$V_{Bulb\ 1}$	$V_{Bulb\ 2}$	$V_{Bulb\ 3}$

B. Before setting up the circuit shown at right:



- Predict the ranking of the currents through the battery and each bulb (i_{Bat}, $i_{Bulb\ 1}$, $i_{Bulb\ 2}$, and $i_{Bulb\ 3}$). Explain.

- Predict the voltmeter measurements across each of the elements in the circuit shown. Explain.

Prediction:

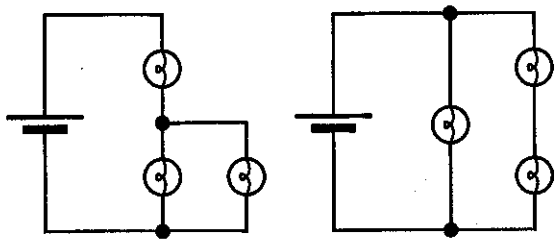
V_{Bat}	$V_{Bulb\ 1}$	$V_{Bulb\ 2}$	$V_{Bulb\ 3}$

Set up the circuit and check your predictions. If your observations and measurements are not consistent with your predictions, resolve the inconsistencies.

Measurement:

V_{Bat}	$V_{Bulb\ 1}$	$V_{Bulb\ 2}$	$V_{Bulb\ 3}$

C. Both circuits at right have more than one path for the current. Sketch all possible current loops on the diagrams. (A "current loop" is *a single path* of conductors that connects one side of the battery to the other.)



For each of the current loops you have drawn, calculate the sum of the potential differences across the bulbs in that loop. (Use the measurements you made above.)

How do the sums of the potential differences across the bulbs in each loop compare to the potential difference across the battery?

➪ Check your answer with a tutorial instructor.