LAB UNIT: CIRCUITS

This lab unit on circuits is appropriate for introductory high school physics (algebra based) for juniors and seniors. All of the labs can be adapted to be individual student investigations or teacher-led demos. Time will most likely dictate how a particular teacher carries out each lab activity.

Prior to beginning this unit, it is assumed students have already completed a unit on energy and a unit on static electricity. Concepts from these units that students need to know are: *charge, energy, conservation of energy, conservation of charge, types of energy, joules,* and *coulombs*.

LAB 1: Characteristics of Circuits

In these activities, students will determine:

- that a circuit must be a closed loop
- that the loop must be made of conducting materials
- how a light bulb is constructed inside

This lab is a guided inquiry worksheet and is assessed on effort and completeness (check, check-plus, check-minus, zero).

WORKSHEET 1: Characteristics of Circuits

LAB 2: Charge Flow in Circuits

In these activities, students will determine that:

- the current in a circuit can be qualitatively measured using the deflection of a compass
- the direction of current can be determined by the deflection of a compass
- the magnitude of current in a series circuit is the same in all wires
- the current splits at junctions (The Junction Rule: current in = current out)
- the current is in one direction around the loop

This lab is a guided inquiry worksheet and is assessed on effort and completeness (check, check-plus, check-minus, zero).

WORKSHEET 2: Charge Flow in Circuits

LAB 3: Resistance

In these activities students will determine:

- how the resistance of a conductor increases with its length
- how the resistance of a conductor decreases with its cross sectional area
- how the resistance of a conductor depends on the conducting material
- that resistors in series become more resistive (resistances add)
- that resistors in parallel become more conductive (conductances add)
- that the equivalent resistance of a circuit is the single resistor that yield the same current as a network of resistors when connected to the same voltage source.

This lab is a guided inquiry worksheet and is assessed on effort and completeness (check, check-plus, check-minus, zero).

WORKSHEET 3: Resistance

LAB 4: Charge Energy in Circuits
In this lab, students will use a circuit simulation to determine:

- voltage (energy per charge) gained at the battery equals voltage dropped around the circuit
- The Loop Rule: V_battery = V1 + V2 + V3 + ...

This lab is a guided inquiry worksheet and is assessed on effort and completeness (check, check-plus, check-minus, zero).

WORKSHEET 4: Charge Energy in Circuits

LAB 5: Ohm's Law
In this lab, students will use a circuit simulation to determine:

- Ohm's Law in the form of I = V/R for individual circuit elements and the whole circuit.
- Verification of the Loop Rule and Junction Rule for a complex circuit.

This lab is a guided inquiry worksheet and is assessed on effort and completeness (check, check-plus, check-minus, zero).

WORKSHEET 5: Ohm's Law

LAB 6: Circuit Design Lab
In this lab, students will design their own lab procedure to determine:

- The resistance of 3 unknown resistors.
- The equivalent resistance when the 3 resistors are connected in series (two ways).
- The equivalent resistance when the 3 resistors are connected in parallel (two ways).

This lab is a formal experimental design lab (Application Experiment). It is assessed using the Scientific Abilities rubric.

LAB 7: Light Bulb Resistance Design Lab
In this lab, students will design their own lab procedure to determine:

- The qualitative relationship between a light bulb's brightness and its resistance.

This lab is a formal experimental design lab (Observation Experiment). It is assessed using the Scientific Abilities rubric.

UNIT EXAM

CREDITS:
Some of the material here has been reproduced and/or modified from other sources. I attempt to give credit to my best recollection. Any omissions are completely my fault. If the reader knows of any corrections or additions, please email fpn1@cornell.edu so I may make the appropriate changes. Thanks!

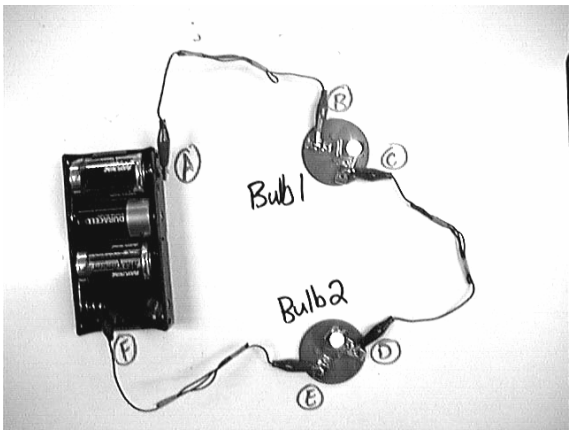
MODELING WORKSHOP PROJECT (http://modeling.asu.edu)
Labs 1A-C, 2A-D, 3B-C; Worksheets 1 and 2 (originally based on CASTLE curriculum)

MARK SCHOBER (http://modelingphysics.org)
Worksheets 1, 2, 3, 4

THE PHYSICS CLASSROOM (http://www.glenbrook.k12.il.us/gbssci/Phys/Class/BBoard.html)
Worksheet 3

RUTGERS PHYSICS ASTRONOMY EDUCATION RESEARCH GROUP (http://paer.rutgers.edu/scientificabilities/)
Scientific Abilities Rubrics for Labs 6 and 7

LAB 1A: Circuit Characteristics



What will happen to bulbs 1 and 2 when you disconnect the wires at various points?

Predictions:

Point	Bulb 1 Lit / Unlit	Bulb 2 Lit / Unlit
A		
B		
C		
D		
E		
F		

Observations:

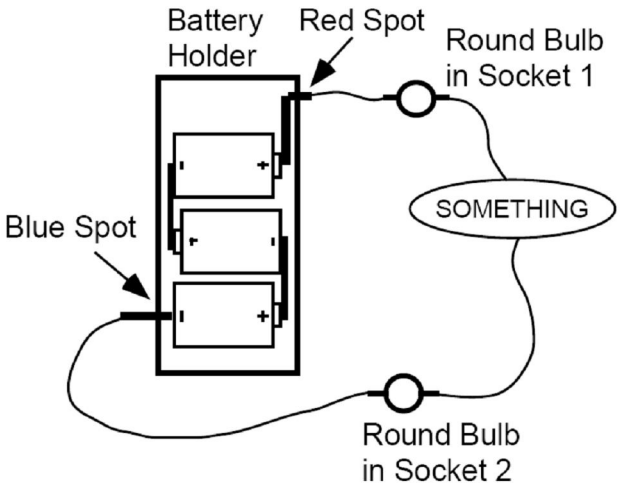
Point	Bulb 1 Lit / Unlit	Bulb 2 Lit / Unlit
A		
B		
C		
D		
E		
F		

Briefly explain your reasoning for point predictions B, D, and E.

Conclusion:
(Your answer to the focus question in the "V" above.)

Consensus:

LAB 1B: Circuit Characteristics



What type of objects, when inserted into the loop, will allow the two test bulbs to light?

Predictions:

Object	Light? (Y or N)
Foil	
Cardboard	
Paperclip	
Shoestring	
Wax paper	
Chalk	
Pencil wood	
Pencil lead	
Eraser	

Observations:

Object	Light? (Y or N)
Foil	
Cardboard	
Paperclip	
Shoestring	
Wax paper	
Chalk	
Pencil wood	
Pencil lead	
Eraser	

Conclusion:

Consensus:

LAB 1C: Circuit Characteristics

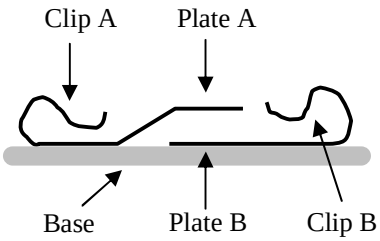


Fig 1. Socket – side view

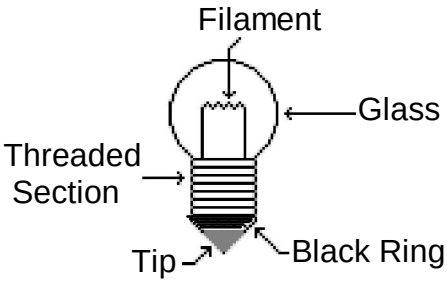


Fig 2. Diagram of a bulb

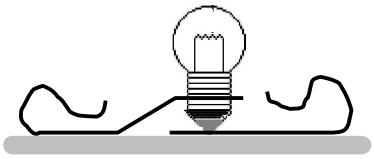


Fig 3. Bulb in socket

(1) Which parts of a socket and bulb are conductors and which are insulators?
(2) What is the conducting path through the bulb?

Predictions:

Test Objects	Closed Loop?
Socket parts:	
1) Clip A & Clip B	
2) Clip A & Plate A	
3) Plate A & Plate B	
4) Plate A & Base	
5) Clip A & Base	
Parts of the bulb:	
6) Tip of bulb	
7) Thread part	
8) Glass	
9) Black ring	
10) Thread & Tip	

Observations:

Test Objects	Closed Loop?
Socket parts:	
1) Clip A & Clip B	
2) Clip A & Plate A	
3) Plate A & Plate B	
4) Plate A & Base	
5) Clip A & Base	
Parts of the bulb:	
6) Tip of bulb	
7) Thread part	
8) Glass	
9) Black ring	
10) Thread & Tip	

Conclusions:

(1)

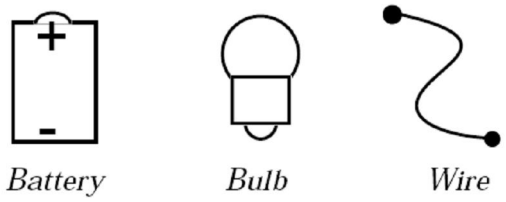
(2)

Consensus:

(1)

(2)

LAB 1D: Circuit Characteristics



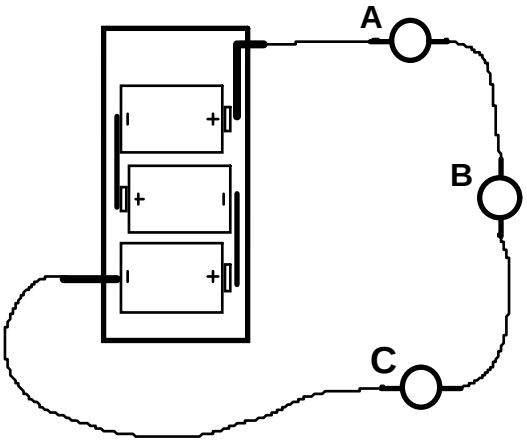
Use the battery and wire(s) to light the light bulb. In the boxes below, draw 2 different configurations which light the bulb with **two** wires, and 2 different configurations which light the bulb with **one** wire.

What similarities do you see in the configurations that successfully light the bulb?

2 WIRE SUCCESS **Be sure to clearly trace the closed-loop path**	**2 WIRE SUCCESS** **Be sure to clearly trace the closed-loop path**
1 WIRE SUCCESS **Be sure to clearly trace the closed-loop path**	**1 WIRE SUCCESS** **Be sure to clearly trace the closed-loop path**

WORKSHEET 1: Circuit Characteristics

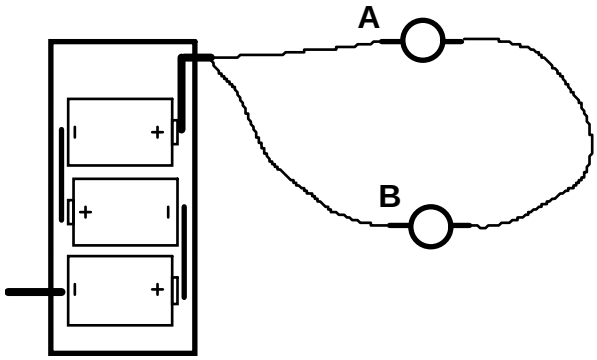
1. In the following circuit, which bulb lights first? _____



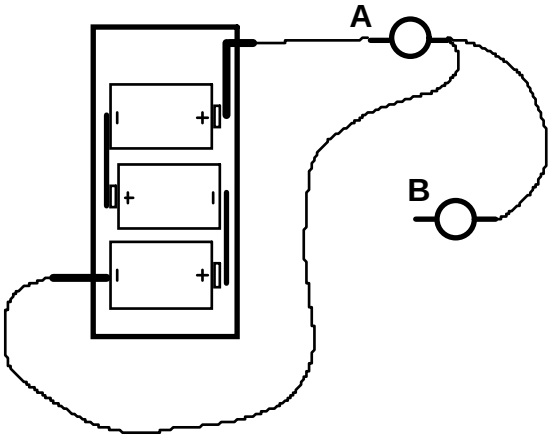
(A) Bulb A
(B) Bulb B
(C) Bulb C
(D) They all light at the same time.
(E) Bulbs A and C light first, then B lights.

Explain your answer:

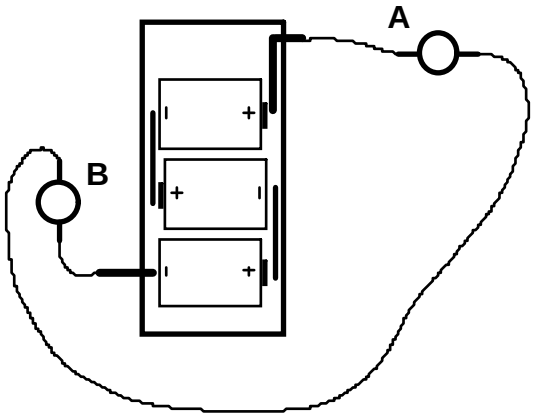
2. Study the three loops shown below. For each loop, state which of the bulbs, if any, will light.



I. _____



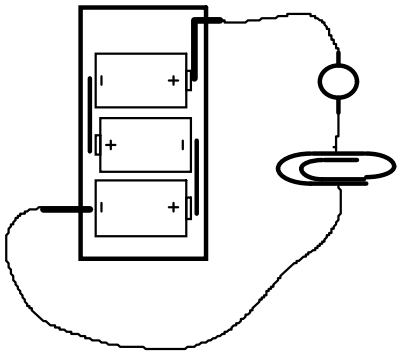
II. _____



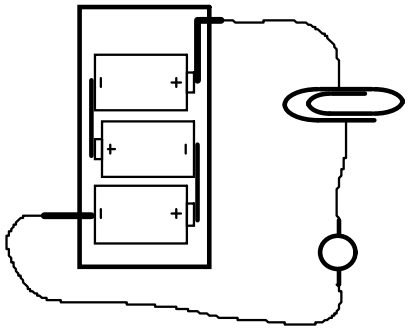
III. _____

3. Study the two circuits below in which a paper clip has been inserted between wires in a circuit.

Circuit A



Circuit B



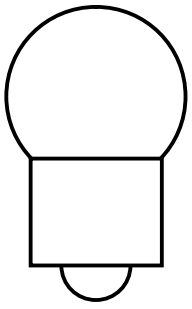
Which of the following statements are true? _____

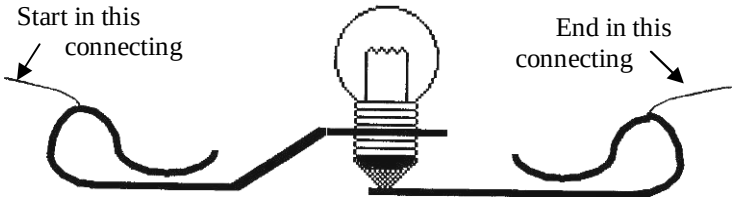
(A) The bulb will light more brightly in Circuit A.
(B) The bulb will light more brightly in Circuit B.
(C) The bulb will be the same brightness in either case.
(D) The bulb will not light.

Explain:

4. We have observed in several activities that as soon as a very small gap is produced anywhere in the circuit, the bulbs go out. Would you classify air as a conductor or an insulator? Explain.

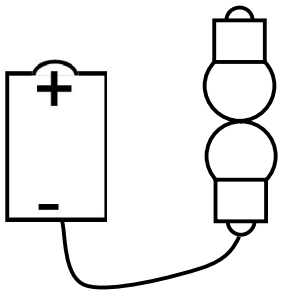
5. (a) On the left diagram, draw in the light bulb filament and show where/how it is attached.
(b) On the right diagram, draw the continuous conducting path through the bulb and socket.





For each of the following circuits, explain which, if any, of the bulbs will light. If the bulbs don't light, change the circuit so that they will. Draw in the filament and show the continuous conducting path through the entire circuit.

6.



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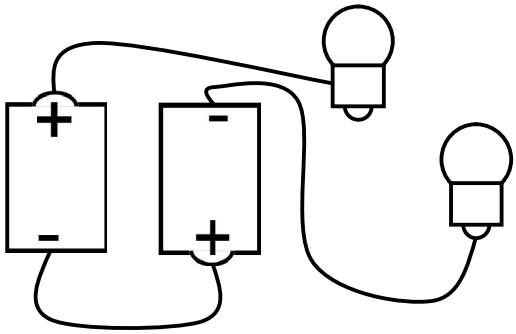

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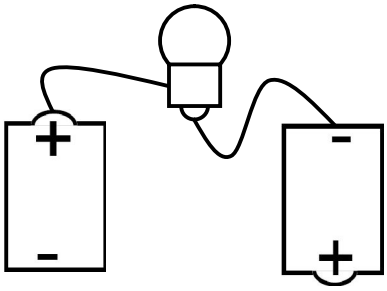

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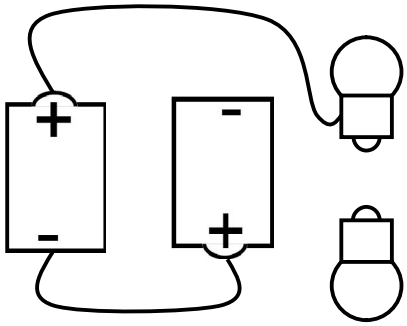
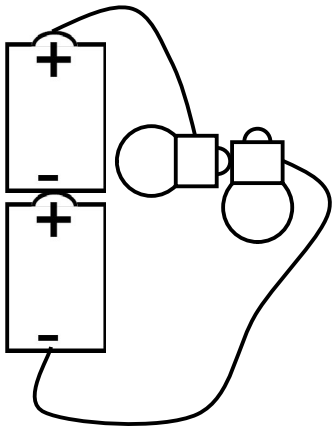


10. Explain why all of the bulbs go out if one bulb in the circuits you drew above burns out.

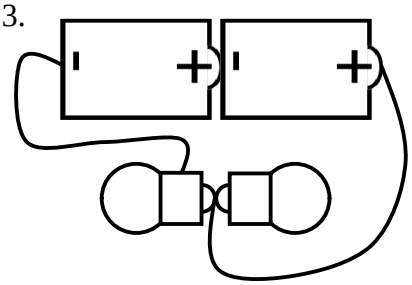
11. Write in your own words a definition of the word <u>circuit</u> which anyone could use to determine if a given set of connections is or is not a circuit.

For each of the following circuits, draw a continuous conducting path (if possible) through the circuits AND show which bulbs will be lit with light rays**. DO NOT ADD ANY WIRES!**

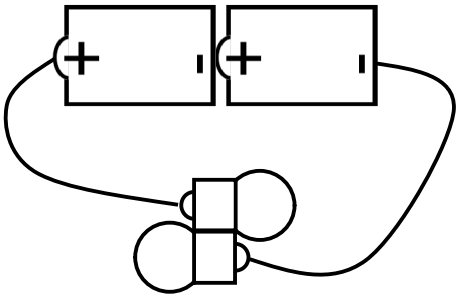
12.



13.



14.



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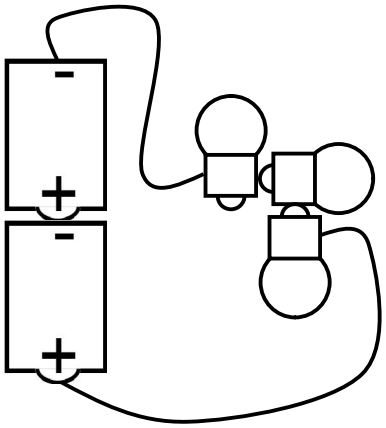

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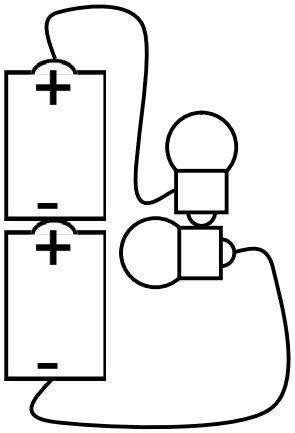
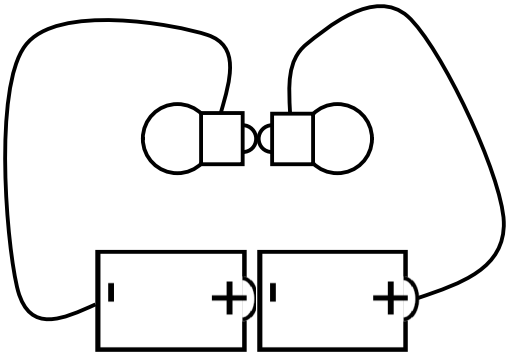
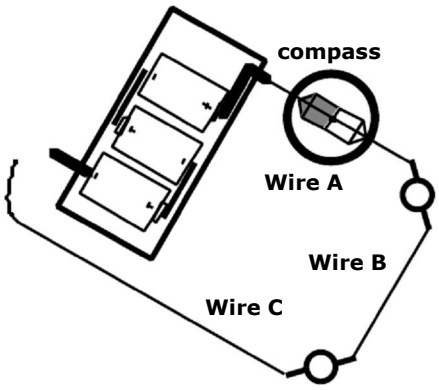


17.



LAB 2A: Charge Flow in Circuits



What does a compass tell you about what is happening in the wires?

Predictions:

Predict the relative strength of electrical activity in each wire. (e.g. A = B, B < C)

Predict the direction and amount of compass deflection for each wire in the diagram above.

Observations:

Describe the relative strength of electrical activity in each wire as indicated by the compass.

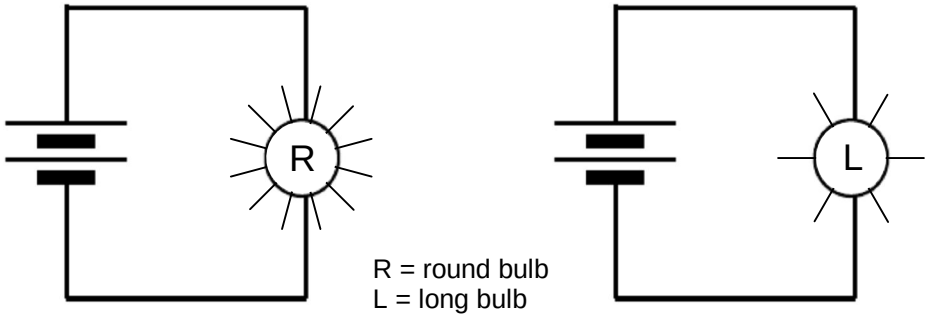
Describe the direction and amount of compass deflection for each wire.

What would be the effect of reversing the battery pack on the compass deflection?

Describe the direction and amount of compass deflection for each wire when the battery pack is reversed.

Conclusion:	*Consensus:*

LAB 2B: Charge Flow in Circuits



How does bulb brightness relate to compass deflection and charge flow?

Predictions:

1. How does the bulb brightness compare?

2. How do the compass deflections compare?

3. Which circuit has a greater charge flow?

Observations:

1. How does the bulb brightness compare?

2. How do the compass deflections compare?

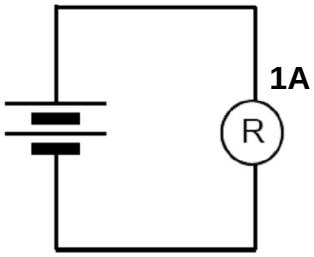
3. Which circuit has a greater charge flow?

Briefly explain your reasoning for questions 1-3:.

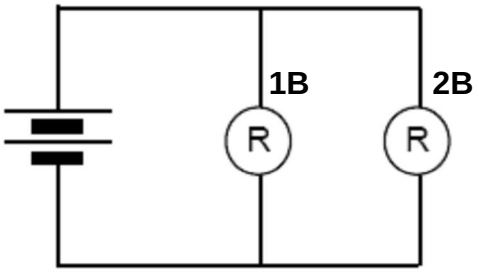
Conclusion:

Consensus:

LAB 2C: Charge Flow in Circuits



R = round bulb



(1) How is charge flow affected by adding a branch to the circuit?
(2) Does charge get used up or lost in branches?

Predictions:

Bulbs	Brighter?	Deflection?
1A vs. 1B		
1A vs. 2B		
1B vs. 2B		

Observations:

Bulbs	Brighter?	Deflection?
1A vs. 1B		
1A vs. 2B		
1B vs. 2B		

Conclusion:

(1)

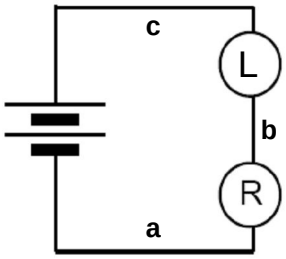
(2)

Consensus:

(1)

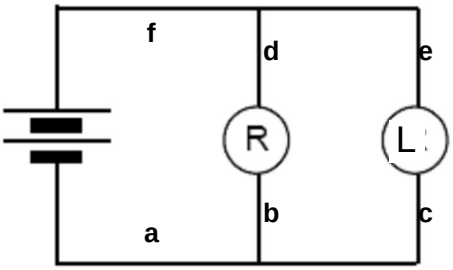
(2)

LAB 2D: Charge Flow in Circuits



Bulbs in SERIES

R = round bulb
L = long bulb



Bulbs in PARALLEL

(1) How does charge flow in a series circuit?
(2) How does charge flow in a parallel circuit?
(3) Does charge get used up or lost?

Predictions:

1. Which circuit contains the brightest bulbs?

2. For the SERIES circuit, rank the charge flow in wires **a-c** from least to greatest.

3. For the PARALLEL circuit, rank the charge flow in wires **a-f** from least to greatest.

Observations:

1. Which circuit contains the brightest bulbs?

2. For the SERIES circuit, rank the charge flow in wires **a-c** from least to greatest.

3. For the PARALLEL circuit, rank the charge flow in wires **a-f** from least to greatest.

Conclusions:

Consensus:

WORKSHEET 2: Charge Flow in Circuits

1. Describe evidence which indicates that bulbs light only when something is happening in the wires.

2. Indicate whether each of the following statements is **True** or **False**. Then state evidence which either supports or contradicts each statement.

   (a) _____ Light bulbs are non-directional devices. (Whichever way they are connected in the circuit, they behave the same way, even if you turn them around.)

   Evidence:

   (b) _____ The battery determines the direction of flow of charge in a circuit.

   Evidence:

   (c) _____ A compass can be used to find the exact direction that charge flows in a circuit.

   Evidence:

   (d) _____ Charge moves out of each end of the battery into the loop.

   Evidence:

   (e) _____ A compass can be used to find the relative amount of charge flow in a circuit.

   Evidence:

3. The sphere of a Van de Graaff generator had a charge of 84 nanocoulombs. When connected to the ground, it was discharged in 24 milliseconds. What was the average discharge current?

4. The current through a light bulb in a flashlight is 0.75 ampere.
   (a) How much charge passes through the filament
      i) in 20 seconds?

      ii) in 5 minutes?

      iii) in 2 hours?

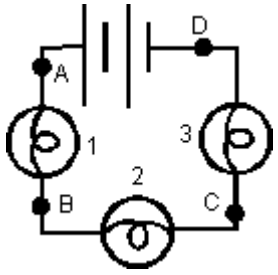
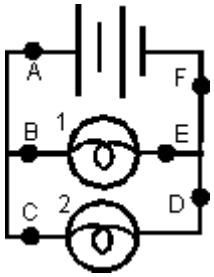
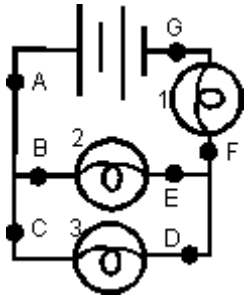
   (b) How many electrons enter the filament every second? How many electrons exit the filament every second?

   (c) Where do the electrons entering the filament come from? Where do they go after exiting?

   (d) How long should the flashlight stay on so that 3 coulombs of electrons pass through the filament?

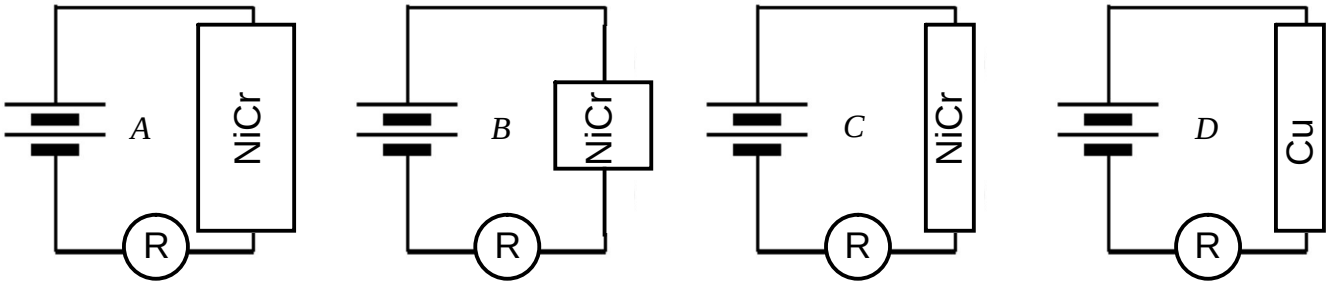
5. Describe an experiment (like you did in lab) that shows that charge is not used up in a circuit.

6. For each circuit, rank the flow of charge at the lettered points and rank the brightness of the numbered bulbs. (For example: A = B > C = D > E)

a)	b)	c)
		
Flow ranking:	Flow ranking:	Flow ranking:
Brightness ranking:	Brightness ranking:	Brightness ranking:

LAB 3A: Resistance

R = round bulb



What characteristics determine a wire's resistance to charge flow?

Predictions:

1. Compare circuits A and B. How does the decreasing the length of a wire affect the brightness of the bulb?

2. Compare circuits A and C. How does the decreasing the width of a wire affect the brightness of the bulb?

3. Compare circuits C and D. How does the changing the type of material affect the brightness of the bulb?

Observations:

1. Compare circuits A and B. How does the decreasing the length of a wire affect the brightness of the bulb?

2. Compare circuits A and C. How does the decreasing the width of a wire affect the brightness of the bulb?

3. Compare circuits C and D. How does the changing the type of material affect the brightness of the bulb?

Use an ohmmeter to measure the resistance of the wires. (Resistance is measured in units called ohms.)

A: long, wide, nichrome wire: _____ ohms

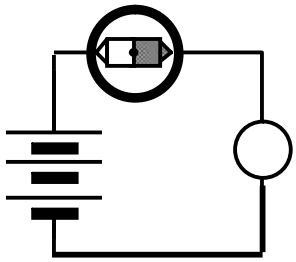
B: ½ length, wide, nichrome wire: _____ ohms

C: long, ½ width, nichrome wire: _____ ohms

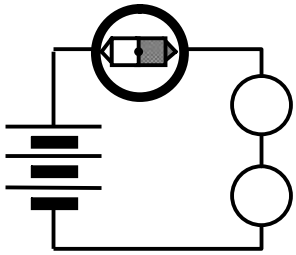
D: long, ½ width, copper wire: _____ ohms

What mathematical patterns do you see in the data?

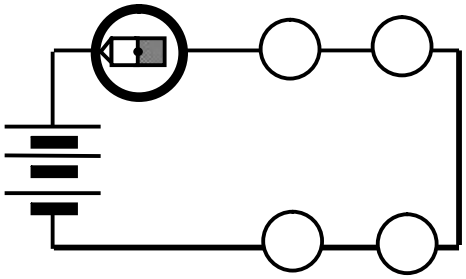
LAB 3B: Resistance



Circuit A



Circuit B



Circuit C

How does the number of bulbs in series affect the overall resistance to charge flow?

Predictions:

1. Which circuit contains the brightest bulb(s)?
2. Which circuit contains the dimmest bulb(s)?
3. Which circuit has the greater compass deflection?
4. Which circuit has the least compass deflection?

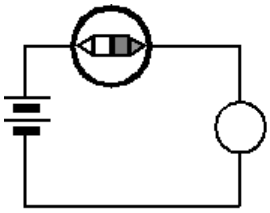
Observations:

1. Which circuit contains the brightest bulb(s)?
2. Which circuit contains the dimmest bulb(s)?
3. Which circuit has the greater compass deflection?
4. Which circuit has the least compass deflection?

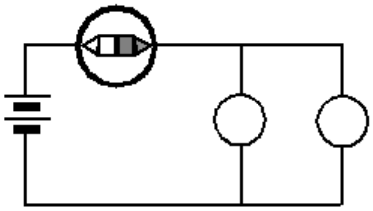
Conclusions:

Consensus:

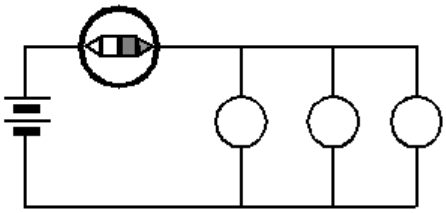
LAB 3C: Resistance



Circuit A



Circuit B



Circuit C

How does the number of bulbs in parallel affect the overall resistance to charge flow?

Predictions:

1. Which circuit contains the brightest bulb(s)?

2. Which circuit contains the dimmest bulb(s)?

3. Which circuit has the greater compass deflection?

4. Which circuit has the least compass deflection?

Observations:

1. Which circuit contains the brightest bulb(s)?

2. Which circuit contains the dimmest bulb(s)?

3. Which circuit has the greater compass deflection?

4. Which circuit has the least compass deflection?

Conclusions:

(1)

(2)

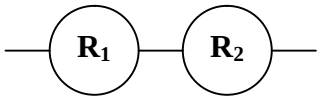
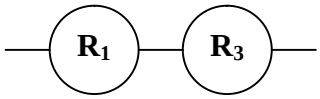
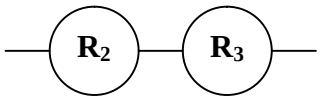
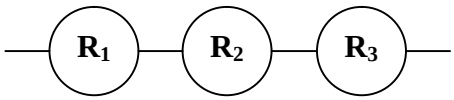
Consensus:

(1)

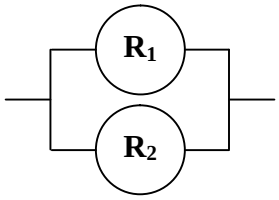
(2)

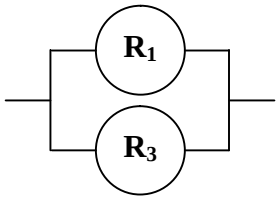
LAB 3D: Resistance

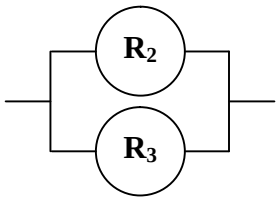
Obtain 3 rheostats and set them to different resistances. Measure the resistance of each one individually using the ohmmeter. Then use the wires to connect them in the configurations shown. Use the ohmmeter again to measure the resistance of the combination. Then calculate the conductances of each resistor and of the combination. Remember, **C** = 1/R and is measured in mhos.

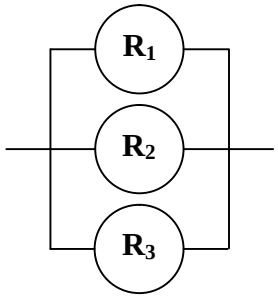
RESISTORS IN SERIES	**Resistances (measured)**	**Conductances (calculated)**
	R_1 =	G_1 =
	R_2 =	G_2 =
	R_{eq} =	G_{eq} =
	R_1 =	G_1 =
	R_3 =	G_3 =
	R_{eq} =	G_{eq} =
	R_2 =	G_2 =
	R_3 =	G_3 =
	R_{eq} =	G_{eq} =
	R_1 =	G_1 =
	R_2 =	G_2 =
	R_3 =	G_3 =
	R_{eq} =	G_{eq} =

What mathematical pattern do you see when resistors are combined in series?

RESISTORS IN PARALLEL	Resistances (measured)	Conductances (calculated)
	R_1 = R_2 =	G_1 = G_2 =
	R_{eq} =	G_{eq} =

	R_1 = R_3 =	G_1 = G_3 =
	R_{eq} =	G_{eq} =

	R_2 = R_3 =	G_2 = G_3 =
	R_{eq} =	G_{eq} =

	R_1 = R_2 = R_3 =	G_1 = G_2 = G_3 =
	R_{eq} =	G_{eq} =

What mathematical pattern do you see when resistors are combined in parallel?

LAB 3E: Resistance

→ Google "PhET" and find the Circuit Construction Kit (DC only).

PART ONE: Series Circuits

1. (a) Construct a **series** circuit with **2 light bulbs** and **2 batteries**. Be sure the batteries are touching + to − (i.e., black to silver). On the right-hand menu, click "Show values" to get the resistance of each bulb. Also on the right, check "Non-Contact Ammeter." This device will tell you the charge flow (current) in a wire. In the table, record the resistances and the currents as indicated.

Bulb	Current	Resistance
1		
2		
Total	(current in battery)	

Schematic Diagram

(b) Write a mathematical formula which relates the total current (the current through the battery) to the current in the two light bulbs.

2. (a) If you could replace the two light bulbs with just one that would create the **same** total current, what would be the resistance of that bulb? Test it by building a second circuit. Change the resistance of the bulb by right-clicking on the bulb and choosing "Change resistance." Record the values for the resistance and current in the table.

Bulb	Current	Resistance
R_{eq}		

Schematic Diagram

(b) This single resistance is called the *equivalent resistance*. How does the equivalent resistance bulb compare to the original two bulbs? Write an equation showing this relationship.

3. (a) Add a third light bulb in **series** to the circuit. Record the measurements as indicated.

Bulb	Current	Resistance
1		
2		
3		
Total	(current in battery)	(equivalent resistance)

Schematic Diagram

Compare this 3-bulb circuit to the 2-bulb circuit you made previously.

(b) By adding the 3rd bulb, the current in the other 2 bulbs has _____, and the total current in the circuit has _____.

(c) By adding the 3rd bulb, the brightness of the other 2 bulbs has _____.

(d) By adding the 3rd bulb, the resistance of the other two bulbs has _____, and the total resistance of the circuit has _____.

4. (a) Now **quadruple** the resistance of the 1st light bulb by right-clicking on the bulb and choosing "Change resistance." Record the measurements as indicated.

Bulb	Current	Resistance
1		
2		
3		
Total	(current in battery)	(equivalent resistance)

Schematic Diagram

Compare this new 3-bulb circuit to the 3-bulb circuit you previously made.

(b) The current through the high resistance bulb has _____, and the current through the other 2 bulbs has _____, and the total current of the circuit has _____.

(c) The brightness of the high resistance bulb has _____, and the brightness of the other 2 bulbs has _____.

(d) The total resistance of the circuit has _____.

PART TWO: Parallel Circuits

5. (a) Construct a **parallel** circuit with **2 light bulbs** and **1 battery**. On the right-hand menu, click "Show values" to get the resistance of each bulb. Also on the right, check "Non-Contact Ammeter." This device will tell you the charge flow (current) in a wire. In the table, record the resistances and the currents as indicated.

Bulb	Current	Resistance
1		
2		
Total	**(current in battery)**	

Schematic Diagram

(b) Write a mathematical formula which relates the total current (the current through the battery) to the current in the two light bulbs.

6. (a) If you could replace the two light bulbs with just one that would create the **same** total current, what would be the resistance of that bulb? Test it by building a second circuit. Change the resistance of the bulb by right-clicking on the bulb and choosing "Change resistance." Record the values for the resistance and current in the table.

Bulb	Current	Resistance
$\mathbf{R_{eq}}$		

Schematic Diagram

(b) This single resistance is called the *equivalent resistance*. How does the equivalent resistance bulb compare to the original two bulbs? Write an equation showing this relationship.

7. (a) Add a third light bulb in **parallel** to the circuit. Record the measurements as indicated.

Bulb	Current	Resistance
1		
2		
3		
Total	(current in battery)	(equivalent resistance)

Schematic Diagram

Compare this 3-bulb circuit to the 2-bulb circuit you made previously.

(e) By adding the 3rd bulb, the current in the other 2 bulbs has _____, and the total current in the circuit has _____.

(f) By adding the 3rd bulb, the brightness of the other 2 bulbs has _____.

(g) By adding the 3rd bulb, the resistance of the other two bulbs has _____, and the total resistance of the circuit has _____.

8. (a) Now **quadruple** the resistance of the 1st light bulb by right-clicking on the bulb and choosing "Change resistance." Record the measurements as indicated.

Bulb	Current	Resistance
1		
2		
3		
Total	(current in battery)	(equivalent resistance)

Schematic Diagram

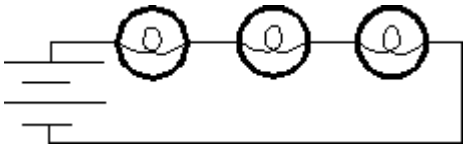
Compare this new 3-bulb circuit to the 3-bulb circuit you previously made.

(b) The current through the high resistance bulb has _____, and the current through the other 2 bulbs has _____, and the total current of the circuit has _____.

(c) The brightness of the high resistance bulb has _____, and the brightness of the other 2 bulbs has _____.

(d) The resistance of the other two bulbs has _____, and the total resistance of the circuit has _____.

WORKSHEET 3: Resistance



1. In a series circuit there is just one loop.

a) How is the charge flow out of the battery (and back into it) affected by adding more bulbs in series?

b) How does the charge flow through each bulb compare?

c) How does the brightness of each bulb compare to the brightness of a bulb in a single-bulb circuit,?

d) How does adding more bulbs in series affect their brightness?

e) How is electric current related to the resistance of the circuit?

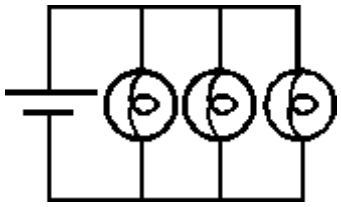
f) If the resistance of a circuit is tripled, by what factor does the current change?

g) If the resistance of a circuit is reduced to one-quarter of its original value, by what factor does the current change?

h)Does adding resistors in series increase or decrease the overall resistance of a circuit?

i) In series circuits, bulbs can be thought of as "obstacles to flow". Explain how the number of obstacles in a series circuit is related to the resistance of the circuit.

2. In a parallel circuit, there is more than one loop.



a) How is the charge flow out of the battery (and back into it) affected by adding additional pathways?

b) How does the charge flow through a single bulb compare to the flow of charge through the battery?

c) How does the sum of the charge flow through the three bulbs compare to the flow of charge through the battery?

d) How does the brightness of each bulb compare to the brightness of a bulb in a single-bulb circuit,?

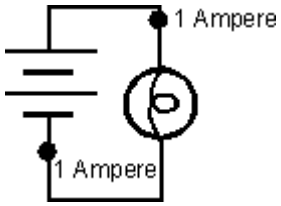
e) How is the resistance of a circuit affected by adding additional pathways?

f) If a one loop circuit is changed by adding two more identical loops, by what factor does the current through the battery change?

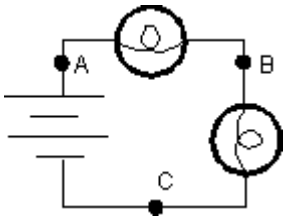
g) Does adding resistors in parallel increase or decrease the overall resistance of a circuit?

h) 4. In parallel circuits, adding more branches adds additional pathways. Explain how the number of pathways in a parallel circuit is related the resistance of the circuit.

3. In this reference circuit, the charge flow is 1 Ampere. What will be the flow at the marked points in each of the following circuits? Assume that the batteries and bulbs have the same properties as those in the reference circuit.



a)



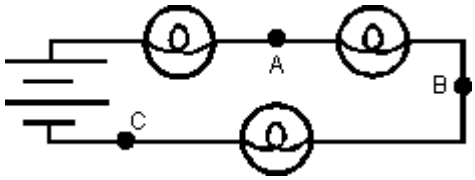
Hint: How does the resistance compare to the example circuit? How is resistance related to current?

A=

B=

C=

b)

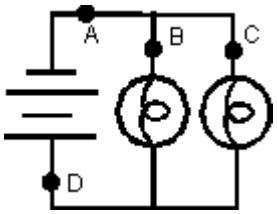


A=

B=

C=

c)



Hint: Does changing one branch affect the another? Answer B and C first.

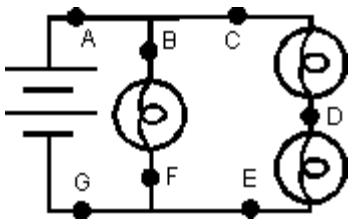
A=

B=

C=

D=

d)



A=

B=

C=

D=

E=

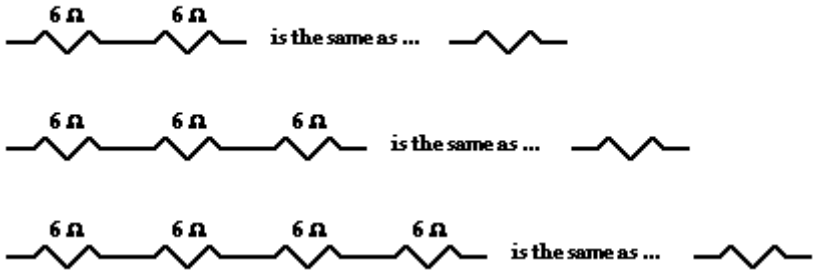
F=

G=

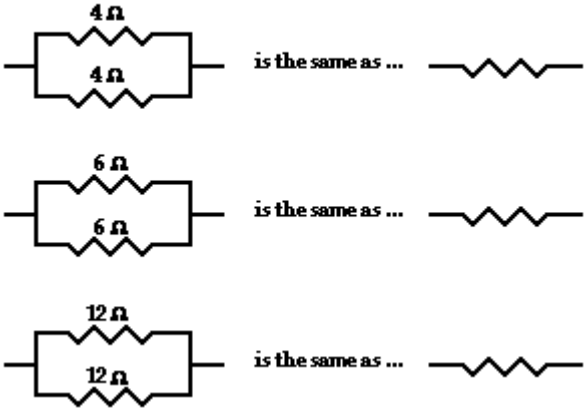
4. Determine the resistance of a 1-mile length of 12-gauge copper wire. Given: 1 mile = 1609 meters, 12-gauge = diameter of 0.2117 cm, and resistivity of copper = 1.7×10^{-8} Ω-m.

5. Two wires - A and B - with circular cross-sections have identical lengths and are made of the same material. Yet, wire A has four times the resistance of wire B. How many times greater is the diameter of wire B than wire A?

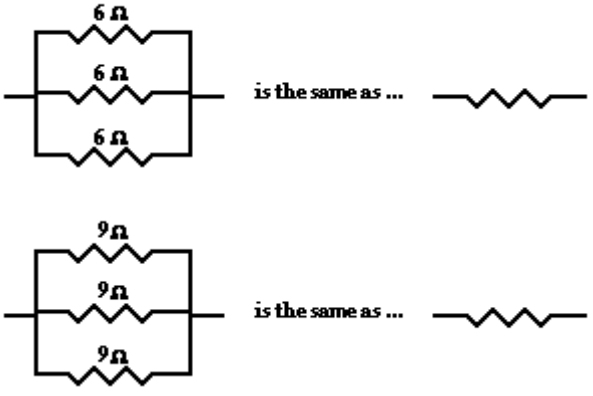
6. **Equivalent Resistance**



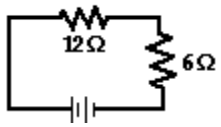
7. **Equivalent Resistance**



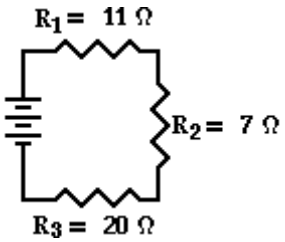
8. **Equivalent Resistance**



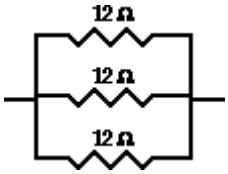
9.



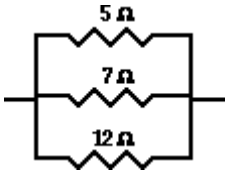
10.



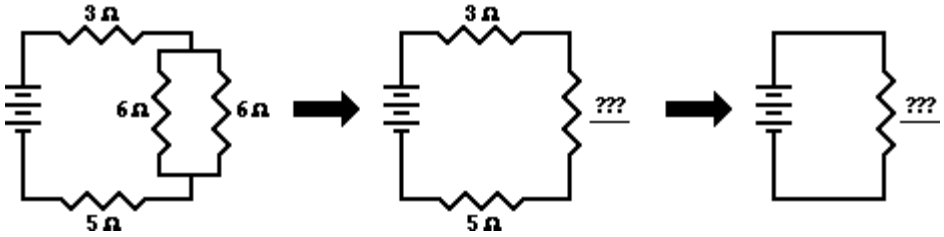
11.



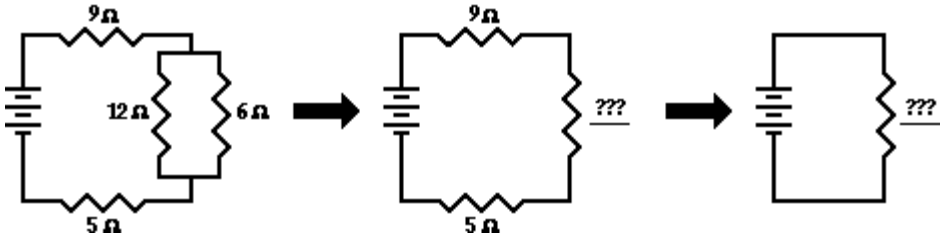
12.



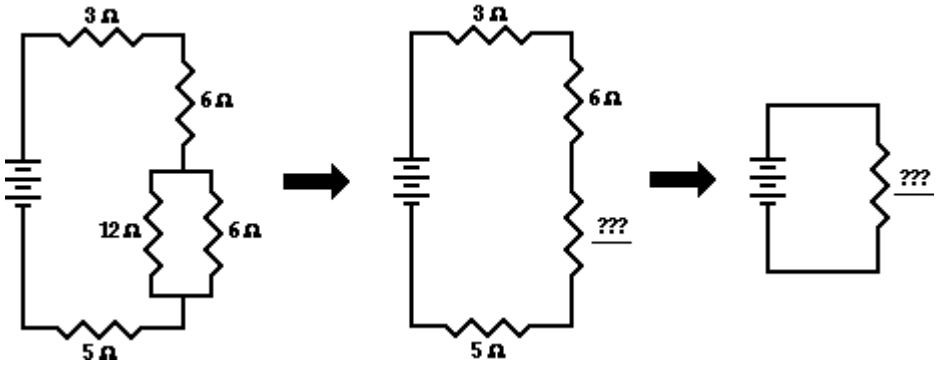
13.



14.



15.

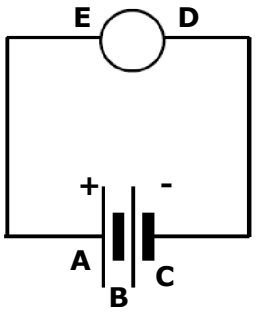


LAB 4: Charge Energy iIn Circuits

→ Google PhET and go to the DC Circuit construction kit.

- The charge energy model says **each charge carries energy.**
- The purpose of this lab is to better understand **how the energy of each charge changes** as it passes through a circuit.
- You will use a device called a **voltmeter** (check the toolbox) to measure energy per charge in various parts of the circuit.
- **1.6×10^{-19} joule per electron = 1 joule per coulomb = 1 volt**

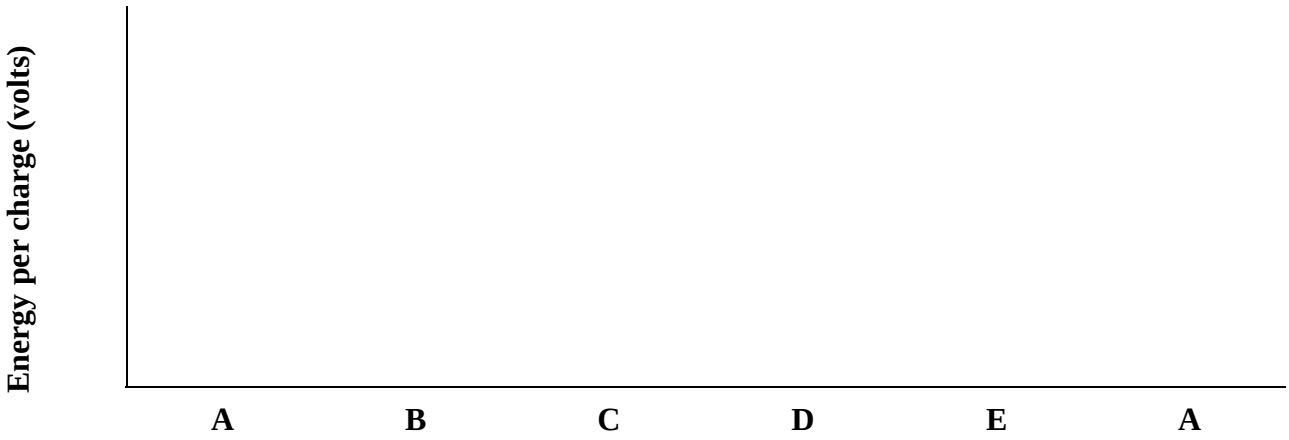
PART ONE
Set up the following circuit (2 batteries and 1 bulb):



Using a voltmeter is simple. With the circuit connected, **<u>keep the red lead touching the positive terminal of the first battery (A)</u> and move the black lead to different points in the circuit**. When set up this way, the voltmeter reading tells you the energy per charge at the location of the black lead.

Measure and record the energy per charge at the following locations:
A. _____ volts where the electrons enter the positive terminal of the first battery
B. _____ volts where the electrons leave the first battery and enter the second one
C. _____ volts where the electrons leave the second battery
D. _____ volts where the electrons enter the light bulb
E. _____ volts where the electrons leave the light bulb

Make a graph showing the energy per charge at each point in the circuit. Connect with straight lines. Make an appropriate numerical scale on the y-axis



Based on your data:

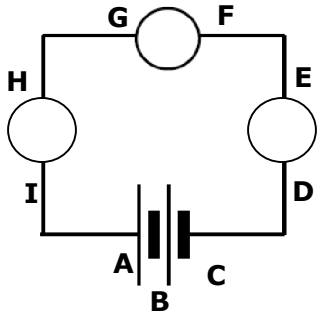
Electrons gain energy in the [battery | bulb | wires]

Electrons lose energy in the [battery | bulb | wires]

Electron energy remains constant in the [battery | bulb | wires]

PART TWO

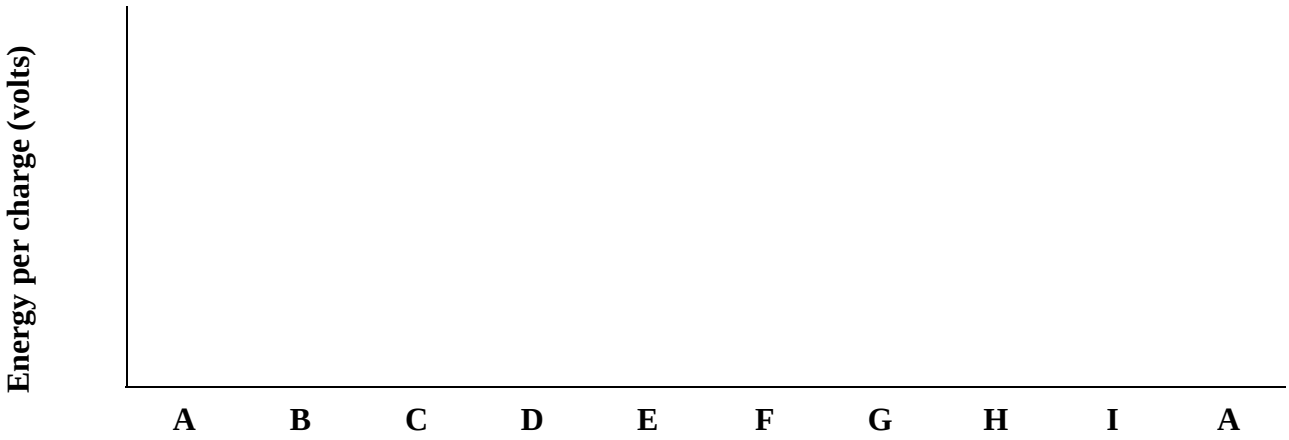
Now add two more bulbs in series:



Measure and record the energy per charge at the following locations:

A. _____ volts where the electrons enter the positive terminal of the first battery
B. _____ volts where the electrons leave the first battery and enter the second one
C. _____ volts where the electrons leave the second battery
D. _____ volts where the electrons enter light bulb 1
E. _____ volts where the electrons leave light bulb 1
F. _____ volts where the electrons enter light bulb 2
G. _____ volts where the electrons leave light bulb 2
H. _____ volts where the electrons enter light bulb 3
I. _____ volts where the electrons leave light bulb 3

Make a graph showing the energy per charge at each point in the circuit. Connect with straight lines. Make an appropriate numerical scale on the y-axis

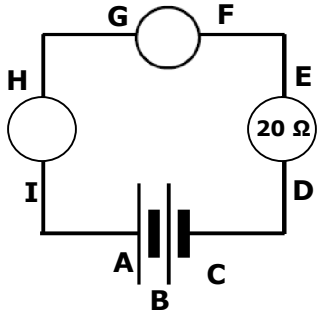


How does the electron energy lost in one bulb in this circuit compare to the bulb in previous one?

How does the **total** electron energy lost in all 3 bulbs compare to the **total** energy gained in the batteries?

PART THREE

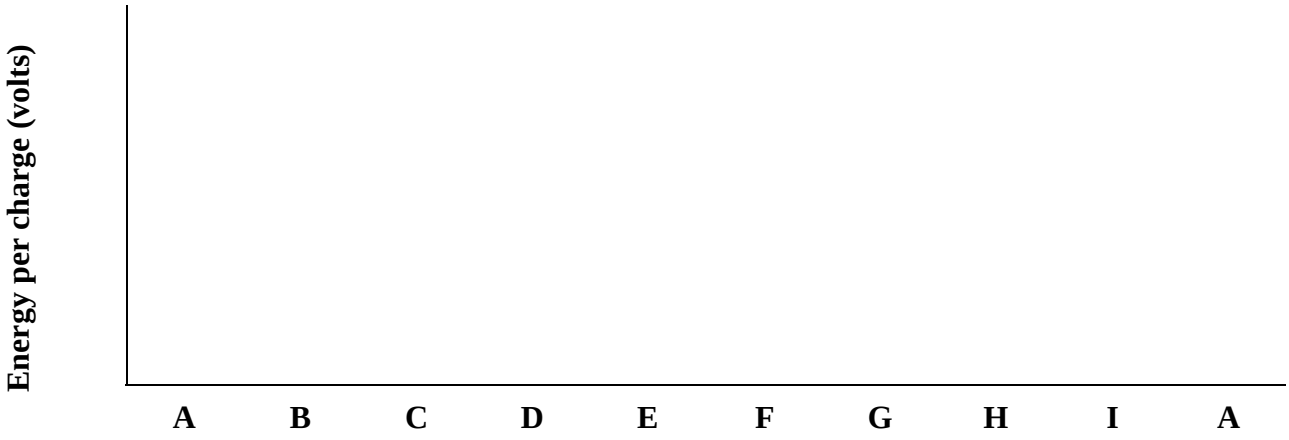
Now DOUBLE the resistance of the first bulb:



Measure and record the energy per charge at the following locations:

A. _____ volts where the electrons enter the positive terminal of the first battery
B. _____ volts where the electrons leave the first battery and enter the second one
C. _____ volts where the electrons leave the second battery
D. _____ volts where the electrons enter light bulb 1 (20 ohms)
E. _____ volts where the electrons leave light bulb 1 (20 ohms)
F. _____ volts where the electrons enter light bulb 2
G. _____ volts where the electrons leave light bulb 2
H. _____ volts where the electrons enter light bulb 3
I. _____ volts where the electrons leave light bulb 3

Make a graph showing the energy per charge at each point in the circuit. Connect with straight lines. Make an appropriate numerical scale on the y-axis

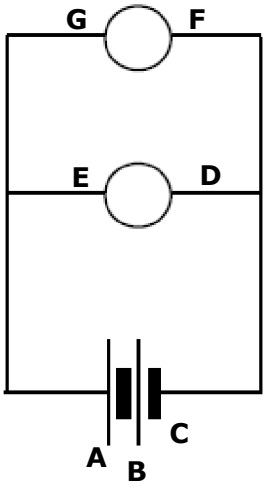


How does the electron energy lost in 20 ohm bulb compare to a 10 ohm bulb?

How does the brightness of the 20 ohm bulb compare to the brightness of a 10 ohm bulb?

How does the **total** electron energy lost in all 3 bulbs compare to the **total** energy gained in the batteries?

PART FOUR
Now connect two 10 ohm bulbs in parallel.



Measure and record the energy per charge at the following locations:
A. _____ volts where the electrons enter the positive terminal of the first battery
B. _____ volts where the electrons leave the first battery and enter the second one
C. _____ volts where the electrons leave the second battery
D. _____ volts where the electrons enter light bulb 1
E. _____ volts where the electrons leave light bulb 1
F. _____ volts where the electrons enter light bulb 2
G. _____ volts where the electrons leave light bulb 2

Compare the electron energy lost in the two bulbs:

Compare the electron energy lost in a single bulb to the electron energy gained at the battery:

These results might not make sense to you. Look at it this way:

In the 3 bulb series circuit, how many light bulbs does a single electron visit in its journey around the circuit?

In the 2 bulb parallel circuit, how many light bulbs does a single electron visit in its journey around the circuit?

Use this to explain your results:

WORKSHEET 4: Charge Energy in Circuits

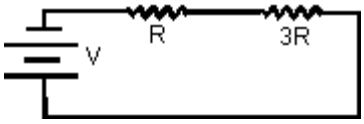
1. AA batteries have a voltage of 1.5 volts.
   (a) Give an interpretation for the number 1.5 in this case.

   (b) How much energy is depleted in the battery when 0.5 A of current pass through it in 1 hour?

   (c) If the battery dies after 24 hours, how much total energy did the battery contain?

   (d) If 2 A of current had been passing through the battery, how long would the battery last?

2. Consider the following circuit:

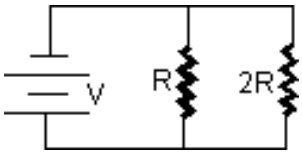


   (a) For a battery with voltage **V**, what will be the voltage drop across each resistor?

   (b) Explain which resistor would get hotter in terms of *charge flow* **and** *energy per charge.* (Or if they were bulbs, which would be brighter and why.)

   (c) Is there a relationship between resistance and voltage drop in a series circuit? If so, state it.

3. Consider the following circuit:

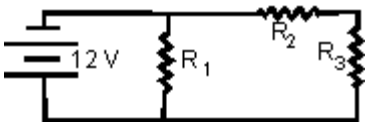


   (a) For a battery with voltage **V**, what will be the voltage drop across each resistor?

   (b) Explain which resistor would get hotter in terms of *charge flow* **and** *energy per charge.* (Or if they were bulbs, which would be brighter and why.)

   (c) How does the voltage drop across each branch in a parallel circuit compare?

4. Consider the following circuit with three identical resistors:

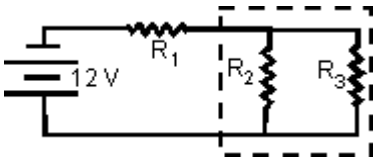


(a) Rank the resistors according to the flow of charge through them.

(b) How does the voltage drop across R_1 compare to the **sum** of the voltage drops across R_2 and R_3?

(c) What will be the voltage drop across each resistor?

5. Consider the following circuit with three identical resistors:



(a) Rank the resistors according to the flow of charge through them.

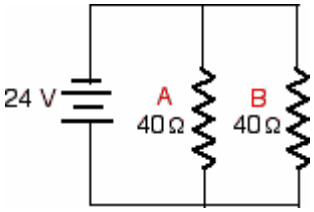
(b) Imagine the resistors in the dashed box were a single resistor. How would its total resistance compare to the resistance of R_1?

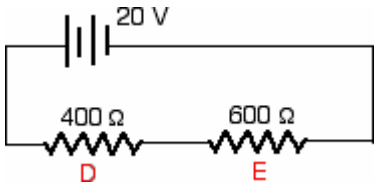
(c) Redraw the circuit as a series circuit consisting of two resistors and label their relative resistances.

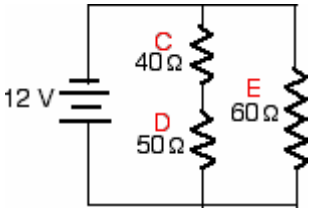
(d) Based on your answer to parts **b** and **c**, will it take more energy per charge to get the charges through R_1 or the dashed box?

(e) What will be the voltage drop across resistors R_1, R_2, and R_3?

6. Determine the voltage drop across each resistor:



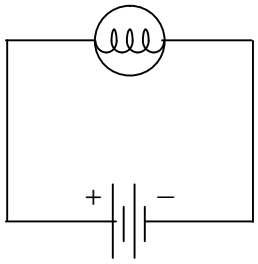




LAB 5: Ohm's Law

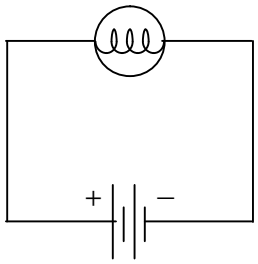
→ Google "PhET" and find the Circuit Construction Kit (DC only).

EXPERIMENT 1: Vary the resistance of a light bulb and measure the resulting current.



	Voltage Before V_o	Voltage After V_f	Voltage Drop $\|\Delta V\|$	Resistance R	Current I
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					

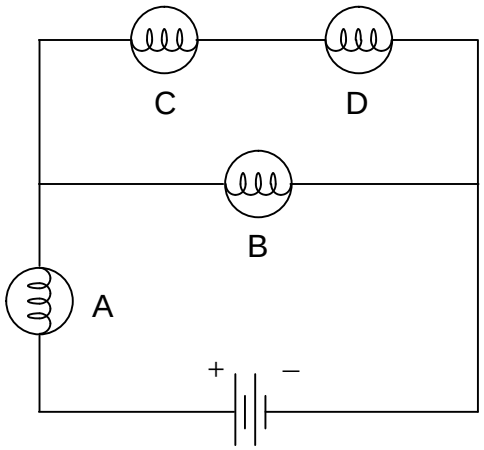
EXPERIMENT 2: Vary the voltage drop across a light bulb and measure the resulting current.



	Voltage Before V_o	Voltage After V_f	Voltage Drop $\|\Delta V\|$	Resistance R	Current I
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					

Based on your data from Experiments 1 and 2, determine the equation that relates current to both resistance and voltage drop. This relationship is called Ohm's Law.

EXPERIMENT 3: Circuit Analysis



	$\|\Delta V\|$	R	I	P
A				
B				
C				
D				
T				

1. MEASURE the voltage and current for each bulb. Now look at the data. Does Ohm's Law work for each individual bulb (A thru D)? For the circuit as a whole (T)?

2. What are the possible loops an electron could travel in it journey around the circuit? Show whether or not the Loop Rule works for each loop. (i.e., $|\Delta V_{battery}| = \Sigma\, |\Delta V_{bulbs}|$) Is energy conserved?

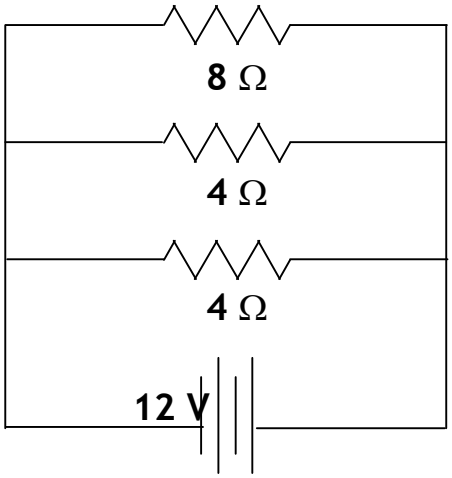
3. Where are the junctions in the circuit where current is branching and/or merging? Show whether or not the Junction Rule work for each junction. (i.e., $\Sigma\, I_{in} = \Sigma\, I_{out}$) Is charge conserved?

4. Calculate the total resistance of the circuit in two ways…
   (a) Use Ohm's Law:
   (b) Determine the equivalent resistance:
   (careful, this is a combination circuit!)

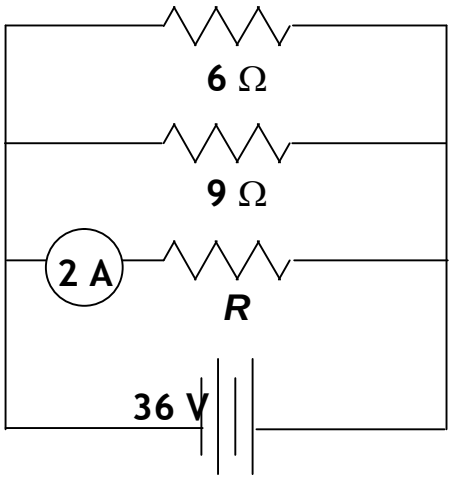
5. Calculate the power for each bulb. How is bulb brightness related to power?

WORKSHEET 5: Ohm's Law

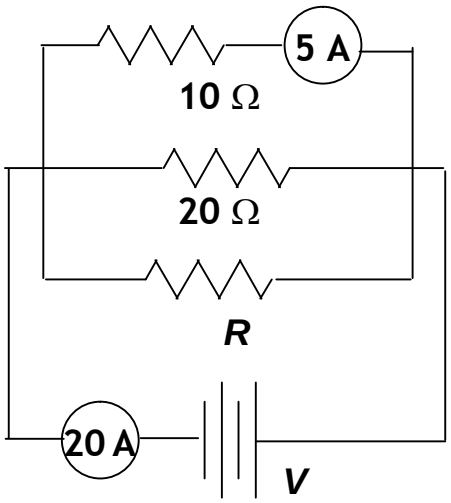
Complete the voltage/current/resistant table for each circuit given.



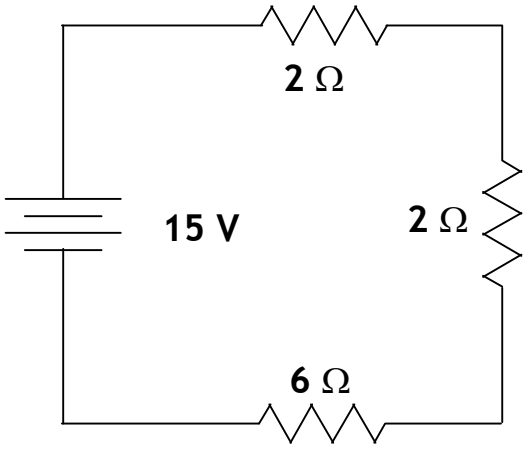
	|ΔV|	I	R
1			
2			
3			
T			



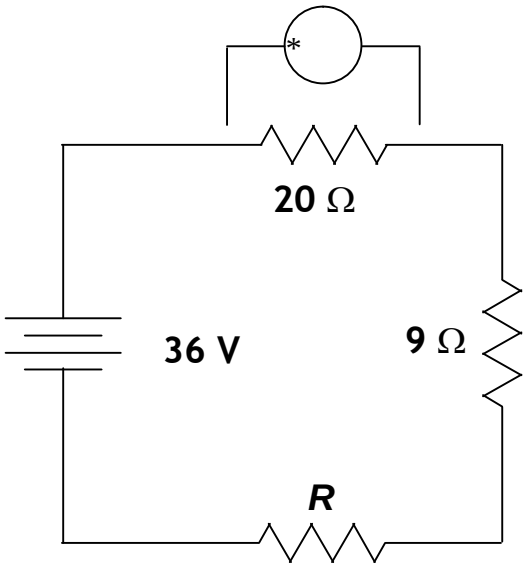
	|ΔV|	I	R
1			
2			
3			
T			



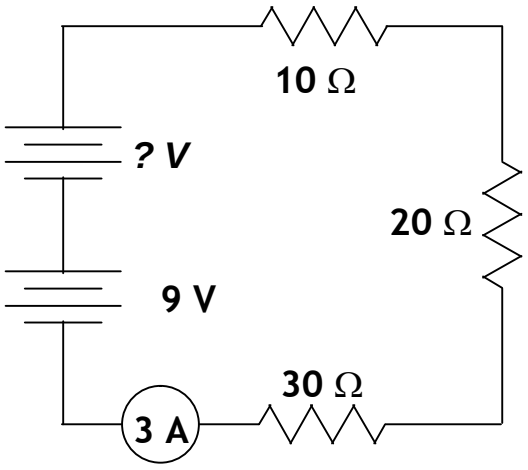
	|ΔV|	I	R
1			
2			
3			
T			



	$\lvert\Delta V\rvert$	I	R
1			
2			
3			
T			



	$\lvert\Delta V\rvert$	I	R
1			
2			
3			
T			



	$\lvert\Delta V\rvert$	I	R
1			
2			
3			
T			

LAB 6: Circuit Design Lab

PROBLEM 1: Design two independent experiments to determine the equivalent resistance of 3 unknown resistors when they are combined in SERIES.

PROBLEM 2: Design two independent experiments to determine the equivalent resistance of 3 unknown resistors when they are combined in PARALLEL.

You have access to a DC voltage supply, wires, an ammeter, and a voltmeter.
You may NOT use the ohmmeter.

For EACH problem, write the following in your notebook:

LAB DESIGN

(a) ___ Describe your experimental design with both a labeled diagram and a verbal description.
(b) ___ Identify the physics quantities you will measure and describe how you will measure each.
(c) ___ Devise the mathematical procedure you will need in order to solve the problem.
(d) ___ List the assumptions you made about the objects, interactions, and/or processes.

MEASURED DATA

(e) ___ Perform the experiment and record your measurements in an appropriate manner.

DATA ANALYSIS

(f) ___ Calculate the resistances, based on your procedure and measurements.

CONCLUSION

(g) ___ Compare the two outcomes by computing the percent difference:

$$\%\ difference = \frac{difference\ between\ value\ A\ and\ value\ B}{average\ of\ \ value\ A\ and\ value\ B} \times 100$$

___ Discuss possible reasons for any discrepancies.

Your work will be evaluated based on the rubric on the reverse side.

Scientific Abilities Rubric (Lab 6: Circuit Design Lab)

Scientific Ability	Adequate	Needs some improvement	Inadequate	Missing
(a1) Is able to design a reliable experiment that solves the problem	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to a reliable solution.	The experiment attempts to solve the problem, but due to the nature of the design the data will not lead to a reliable solution.	The experiment does not solve the problem.
(a2) Is able to communicate the details of an experimental procedure clearly and completely	Diagrams and/or experimental procedure are clear and complete.	Diagrams and/or experimental procedure are present but with minor omissions or vague details.	Diagrams are present but unclear and/or experimental procedure is present but important details are missing.	Diagrams are missing and/or experimental procedure is missing or extremely vague.
(b) Is able to use available equipment to make measurements	All of the chosen measurements can be made and all details about how they are done are provided and clear.	All of the chosen measurements can be made, but the details about how they are done are vague or incomplete.	All of the chosen measurements can be made, but no details are given about how it is done.	At least one of the chosen measurements cannot be made with the available equipment.
(c) Is able to choose a productive mathematical procedure for solving the experimental problem	Mathematical procedure is fully consistent with the design. All the quantities are calculated correctly. Final answer is meaningful.	Correct and complete mathematical procedure is described but an error is made in the calculations.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.
(d) Is able to identify the assumptions made in using the mathematical procedure	All assumptions are correctly identified.	Most assumptions are correctly identified.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	No attempt is made to identify any assumptions.
(e) Is able to record and represent data in a meaningful way	All important data are present, organized, and recorded clearly.	All important data are present, but recorded in a way that requires some effort to comprehend.	Some important data are absent or incomprehensible.	Data are either absent or incomprehensible.
(f) Is able to analyze data appropriately	The analysis is appropriate, complete, and correct.	The analysis is appropriate but it contains minor errors or omissions.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	No attempt is made to analyze the data.
(g) Is able to evaluate the results by means of an independent method	A second independent method is used to evaluate the results. The discrepancy between the results of the two methods, and possible reasons are discussed. A percentage difference is calculated.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. However, there is little or no discussion about the differences in the results due to the two methods.	No attempt is made to evaluate the consistency of the result using an independent method.

LAB 7: Light Bulb Design Lab

PROBLEM:
Design an experiment to determine if the brightness of a light bulb affects its resistance.

You have access to a DC voltage supply, a rheostat, wires, an ammeter, and a voltmeter.
You may NOT use the ohmmeter.

For EACH problem, write the following in your notebook:

LAB DESIGN

(a) ___ Describe your experimental design with both a labeled diagram and a verbal description.
(b) ___ Identify the physics quantities you will measure and describe how you will measure each.
(c) ___ Devise the mathematical procedure you will need in order to solve the problem.
(d) ___ List the assumptions you made about the objects, interactions, and/or processes.

MEASURED DATA

(e) ___ Perform the experiment and record your measurements in an appropriate manner.

DATA ANALYSIS

(f) ___ Calculate the resistances, based on your procedure and measurements.

CONCLUSION

(g) ___ What pattern (if any) do you see?
(h) ___ Do your results surprise you? Why? Give a possible explanation for your results.

Your work will be evaluated based on the rubric on the reverse side.

Scientific Abilities Rubric (Lab 7: Light Bulb Design Lab)

Scientific Ability	Adequate	Needs some improvement	Inadequate	Missing
(a1) Is able to design a reliable experiment that investigates the phenomenon	The experiment might yield interesting patterns relevant to the investigation of the phenomenon.	Some important aspects of the phenomenon will not be observable.	The experiment may not yield any interesting patterns.	The experiment does not investigate the phenomenon.
(a2) Is able to communicate the details of an experimental procedure clearly and completely	Diagrams and/or experimental procedure are clear and complete.	Diagrams and/or experimental procedure are present but with minor omissions or vague details.	Diagrams are present but unclear and/or experimental procedure is present but important details are missing.	Diagrams are missing and/or experimental procedure is missing or extremely vague.
(b) Is able to use available equipment to make measurements	All of the chosen measurements can be made and all details about how they are done are provided and clear.	All of the chosen measurements can be made, but the details about how they are done are vague or incomplete.	All of the chosen measurements can be made, but no details are given about how it is done.	At least one of the chosen measurements cannot be made with the available equipment.
(c) Is able to choose a productive mathematical procedure for solving the experimental problem	Mathematical procedure is fully consistent with the design. All the quantities are calculated correctly. Final answer is meaningful.	Correct and complete mathematical procedure is described but an error is made in the calculations.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.
(d) Is able to identify the assumptions made in using the mathematical procedure	All assumptions are correctly identified.	Most assumptions are correctly identified.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	No attempt is made to identify any assumptions.
(e) Is able to record and represent data in a meaningful way	All important data are present, organized, and recorded clearly.	All important data are present, but recorded in a way that requires some effort to comprehend.	Some important data are absent or incomprehensible.	Data are either absent or incomprehensible.
(f) Is able to analyze data appropriately	The analysis is appropriate, complete, and correct.	The analysis is appropriate but it contains minor errors or omissions.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	No attempt is made to analyze the data.
(g) Is able to identify a pattern in the data	The patterns represents the relevant trend in the data	The pattern has minor errors or omissions	The pattern described is irrelevant or inconsistent with the data	No attempt is made to search for a pattern
(h) Is able to devise an explanation for an observed pattern	A reasonable explanation is made.	An explanation contradicts previous knowledge or the reasoning is flawed.	An explanation is vague, not testable, or contradicts the pattern.	No attempt is made to explain the observed pattern.