Electricity III

Purpose

- To encourage the building of mental models that correspond with physical reality.
- This series of experiments examines the internal consistency of the idea of 'obstacle'. Our model of electricity will only be helped if this idea is consistent with our observations.
- To examine how obstacles combine when in series and in parallel

Equipment

- 3 rechargeable 'D' cells.
- Battery holders
- 3 rheostats. (Each rheostat uses 30 A.W.G. Kanthal A1)
- 3 #48 bulbs that are already in bulb-holders
- 1 Meter stick
- One 22 or 20 Ohm resistor
- 8 alligator-to-alligator wires
- 2 (long) banana-to-alligator wires
- 1 compass

Groups will share standard obstacles including; 3 spools of insulated wire.

Verify that you have all of the equipment listed. Notify your TA if anything is missing.

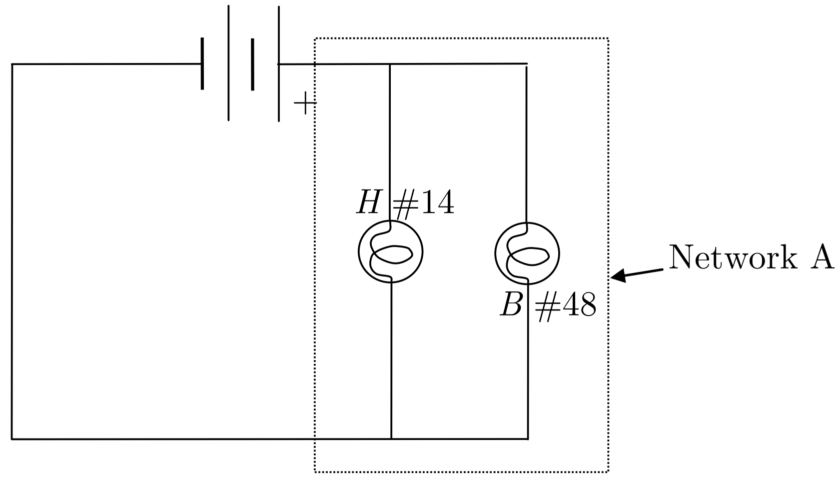
Introduction

So far, the **Model of Electricity** is**:**

1. Electricity flows in electric circuits.

    a. *If two bulbs are identical and the same flow of electricity passes through them then they will light with the same brightness (and vice versa.) The brightness of a bulb increases if flow through it increases (and vice versa)*
    b. *No flow is used up by components as it goes around the circuit*
    c. *The flow through components that are wired in series is the same*
    d. *The flow going into and coming out of a branch (made of components that are in parallel) is the same.*

At the end of electricity II, we made (but didn't test) the hypothesis that "Other factors being equal, the size of the flow increases if a component offers it a smaller obstacle (and vice versa)". At that time, we imagined that the battery responded to the obstacle presented to it by changing the size of the flow; the battery sends a large flow if the obstacle is small, but sends a smaller flow if the obstacle is large. If the circuit consists of several obstacles, then somehow the battery 'senses' the total size of the obstacle (also called 'the equivalent obstacle') and sends the circuit a flow of an appropriate size. For example, the following circuit diagram shows two bulbs in parallel with each other.



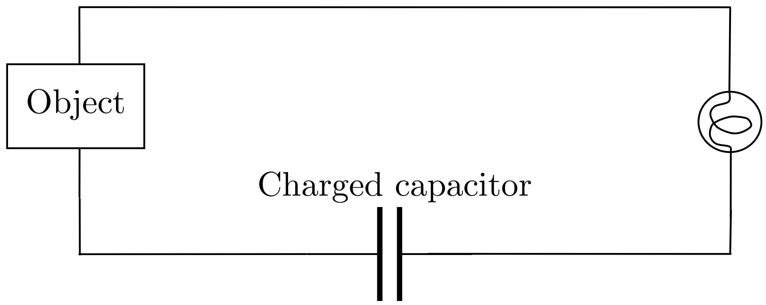
But the battery doesn't 'sense' the details of the circuit. All the battery 'senses' is that network A is connected to it. Somehow it figures out the appropriate (total) flow to send to the network so that when the flow splits up, the flow through bulb *H* and bulb *B* is 'correct' given the different obstacles that they present. The 'correct' flow will have something to do with the total obstacle that network A presents (if the hypothesis above is correct and if the idea of 'obstacle' is a useful one.)

This lab will measure the size of an obstacle (by comparing it to a length of Kanthal wire.) Once we can measure the size of an obstacle, we will figure out how to combine obstacles to find the equivalent obstacle that is 'sensed' by a battery.

This approach can only work if we can find a means of measuring the size of an obstacle. Our observations so far have not included much quantitative measurement. Perhaps that is as it should be: Physics is often presented as if it were about nothing except measurements and the use of memorized formulae. Measurement (or calculation) usually serves to add increased precision to answers that we already know. That is not to dismiss the use of measurement and calculation but to see these techniques in perspective. It is important that we have at least a rough idea of what is happening *before* we jump into precise measurements or calculation.

One possible way of measuring obstacle presented by an object would be to discharge a charged capacitor through the object and a certain bulb. We might expect that the time that a bulb glowed would be a measure of the obstacle presented. Suppose that the obstacle presented by an object is very large. A <u>capacitor is charged</u> and then is put in the following circuit;

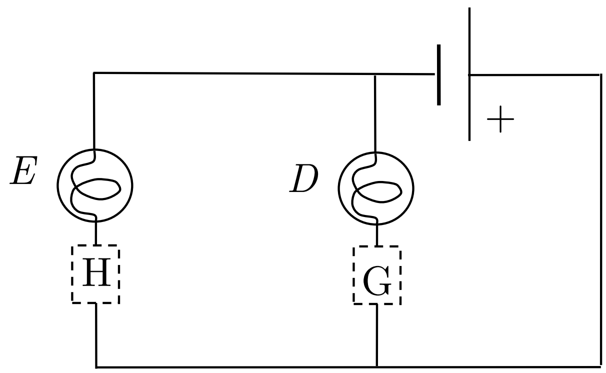
Circuit 1



Will the bulb light for the whole time that the capacitor discharges? Explain. (Hint: you might want to recall circuit 4 of electricity II.) [2] Say why this method (of measuring the size of an obstacle) isn't useful. [1]

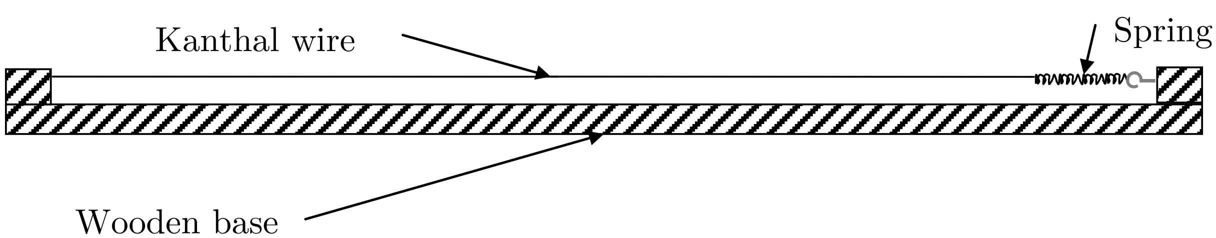
To find a better way to measure the size of an obstacle, consider the following circuit.

Circuit 2

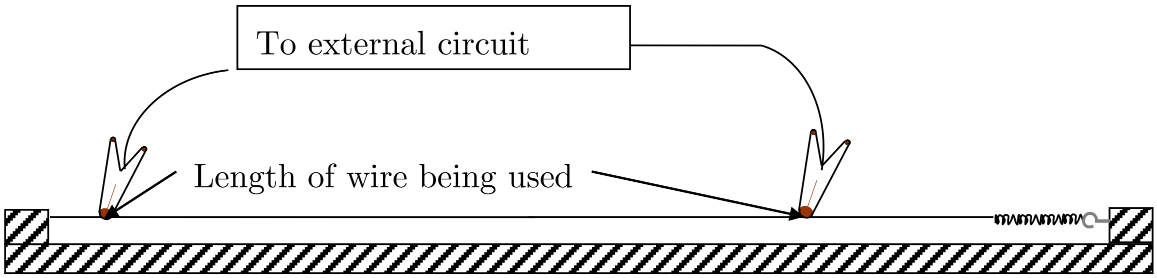


Bulbs *D* and *E* are identical. G and H are objects that conduct electricity but present obstacles to the flow. <u>Suppose that *G* presents a bigger obstacle than *H*</u>. **What do you predict about the relative brightness of bulb *D* and of bulb *E*? Explain your prediction using the ideas of 'flow' and 'obstacle'. [3]**

During the lab, you will build circuit 2. $\boxed{G}$ will be an obstacle of unknown size. Obstacle $\boxed{H}$ will be a length of Kanthal wire. (Kanthal A1 is an alloy of 72% iron, 22% chromium and 6% Aluminum.) If a certain length of Kanthal presents a certain obstacle, then longer lengths of Kanthal can be expected to present larger obstacles. An un-insulated piece of this wire is strung between supports on a piece of wood.



The wooden rheostats are as drawn in these diagrams. Both ends of the Kanthal wire are connected to an external circuit with alligator clips.



Electricity will only flow through the wire between the clips. Obstacle $\boxed{H}$ is the length of Kanthal wire that is between the clips. This device is a very simple rheostat. (You have three rheostats. The biggest of these is just a long length of Kanthal wire that is held in place by either hooks or screws.)

Some of the newer rheostats are made out of clear plastic. The smaller plastic ones allow a connection to one end of the wire by way of a banana connector. The other end is (closest to the spring) needs to be connected using an alligator clip as in the case of the wooden rheostats. For these rheostats, electricity will only flow through the wire between the clip and the end of Kanthal wire that is connected to a banana terminal. Obstacle $\boxed{G}$ is the length of Kanthal wire that is between the clip and banana terminal.

Either rheostat allows us measure the length of Kanthal wire with a meter stick.

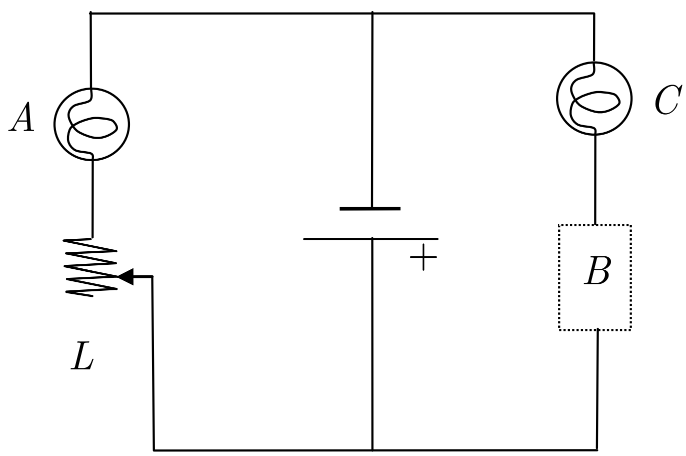
Suppose that the alligator clips are moved so that bulbs *D* and *E* have the same brightness. *(Remember that the size of obstacle H is being controlled by this length of wire.)* To answer the following question, you will need a statement from the model of electricity at the start of the Introduction. Use it to **compare the flow through bulb *D* with the flow through bulb *E*. (Instead of quoting the relevant statement from the model of electricity, just include the label; 1a, 1b or 1c in your answer.) [2]**

Use your previous answer to compare the flow through obstacle $\boxed{G}$ and obstacle $\boxed{H}$. [1] Use the hypothesis (underlined near the beginning of the introduction) to make a statement about the relative sizes of obstacles $\boxed{G}$ and $\boxed{H}$. [1]

Be very careful that you understand how circuit 2 operates. Similar circuits will appear in these labs for the next few weeks.

Suppose that we assume that the hypothesis of 'obstacle to the flow' still makes sense after we have tested it. Consider the following circuit.

Circuit 3



The two bulbs are identical. <u>Suppose that the alligator clips are moved so that the rheostat presents an obstacle of the same size as conductor B</u>. **How will the brightness of bulb *A* compare with the brightness of bulb *C*? Explain. [3]**

We'll use rheostats to build *circuits* that *measure the sizes of obstacles* during the experiment. We'll see if the hypothesis of "obstacle to the flow" continues to makes sense.

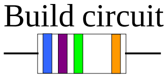
Instructions

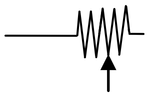
The #48 bulbs that you use have been sorted into groups of bulbs that are identical. The different groups of bulbs have been marked with different colors of paint on one side of their threaded cylinder. (You probably don't need to take the bulb out of the holder to see the mark.) The bags that bulbs are in have also been marked with the same color of paint. The accuracy of your data depends on your using a group of identical bulbs. Before you begin, check that all your bulbs have been marked with the same color. Let your TA know if they aren't. When you are finished the lab put the bulbs (and nothing else) back in their marked bag.

Building Circuits

Always have a circuit diagram in front of you when you build a circuit.

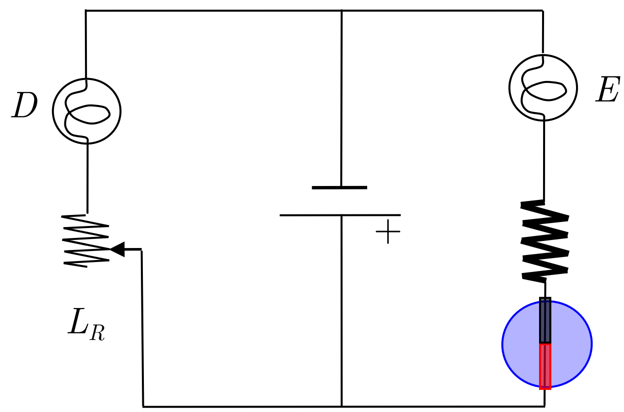
It might help if you begin to build the circuit by starting at the negative terminal of the battery. Build in loops that lead to the positive end of the battery. (Only make the connection to the positive end when you are sure that all other connections are made correctly.)

Build circuit 1 (below). In the diagram below, the symbol  stands for a carbon resistor (that looks like; ).

The symbol  stands for a rheostat. Use a short rheostat when building circuit 1.

When building this circuit, I'd think of it as being made of two loops: One loop includes the carbon resistor and the second loop includes the rheostat. When using this circuit, you might need more Kanthal. If so then you can use a long rheostat instead of the short one. Don't worry about the compass: it isn't electrically connected to anything.

Circuit 1



Adjust the length of Kanthal wire, L_R , so that both bulb *D* and bulb *E* have the same brightness. Please be careful when doing this. Sliding the alligator clip doesn't work. When the alligator clip slides most easily, it doesn't make good contact with the Kanthal wire. To get good contact, ***make sure that the jaws of the alligator clip hold the Kanthal wire. To move the clip, unclamp it, move it to a new position and then release the clip so that the jaws hold the Kanthal wire***. After making this adjustment**, what can you say about the flow of electricity through the bulb *D* relative to the flow through bulb *E*? Explain using a concept from the model of electricity. (Instead of quoting the relevant statement from the model of electricity, just include the label; 1a, 1b or 1c in your answer.) [1]**

What can you say about the size of the obstacle presented by the carbon resistor relative to the size of the obstacle presented by the rheostat? Explain. (You can use your previous answer to help with this explanation.) Mention any hypothesis that you use. [3]

In your report, draw a circuit that can be used to find the obstacle presented by a bulb. On your diagram, label the bulb that is having its obstacle measured and label any bulbs that are identical. [5]

Show your circuit diagram to your TA before proceeding.

Use one cell as the battery in circuit 1. **Copy table 1 into your report.** Use circuit 1 to **measure and record the length of Kanthal wire that is equivalent to the obstacle presented by each of the objects in the first column of table 1**. The objects in table 1 are going to take the place of the carbon resistor in circuit 1. This will allow you to compare the obstacle presented by them to the obstacle presented by a length of Kanthal wire. After measuring the size of the obstacle, *notice the deflection of the compass*.

Table 1

Object	**One cell**	**Two cells in series**	**Three cells in series**
Any spool of wire			
alligator-to-alligator cable			
# 48 bulb			
Carbon resistor			

Make a battery that consists of two cells in series. Repeat the measurement of the sizes of the obstacles that are presented by the objects listed in table 1. Use your measurements to **fill in the <u>second column</u> of table 1**. *Notice the deflection of the compass*.

Repeat using battery of three cells in series. **Fill in <u>column 3</u> of table 1.** *Notice the deflection of the compass*. **[5]**

Compare the flow through the circuit when one cell was used with the flow when two cells were used. What happened to flow when three cells were used? [1]

There is experimental uncertainty associated with every measurement. Reducing this uncertainty to zero is not the focus of building a physical Model. Your task is to look for patterns in your results despite the ever-present uncertainty in your measurements. **For which objects is the obstacle approximately constant if the number of cells is allowed to change? For which objects is the obstacle not even approximately constant as the number of cells changes? [3]**

Have your TA check this answer

Copy the following table into your report;

Table 2a

Length of Kanthal (L)	Obstacle presented by two of these lengths in series
30 cm	
40 cm	
50 cm	

Use only one cell in the following: Measure the equivalent length of the obstacle presented by two 30-cm pieces of Kanthal in series. ***Record your observations in the first row of table 2a.*** **[1]** (Use the two shorter rheostats to give you the lengths specified in table 2b. These two rheostats will take the place of the carbon resistor in circuit 1. The long rheostat is to be left in the other loop of circuit 1 as before.) ***Repeat for lengths of 40 cm and 50 cm.*** **[2]**

Suppose that two wires separately present an obstacle L. Then suppose that the two wires are put in series. **Use table 2a to write an expression for the size of the single obstacle (called L_{eq}) that is presented by the series combination of two obstacles of length L. [1]**

Copy table 2b into your report;

Table 2b

Length L_1	Length L_2	Obstacle presented by L_1 and L_2 in series
13 cm	29 cm	
31 cm	59 cm	

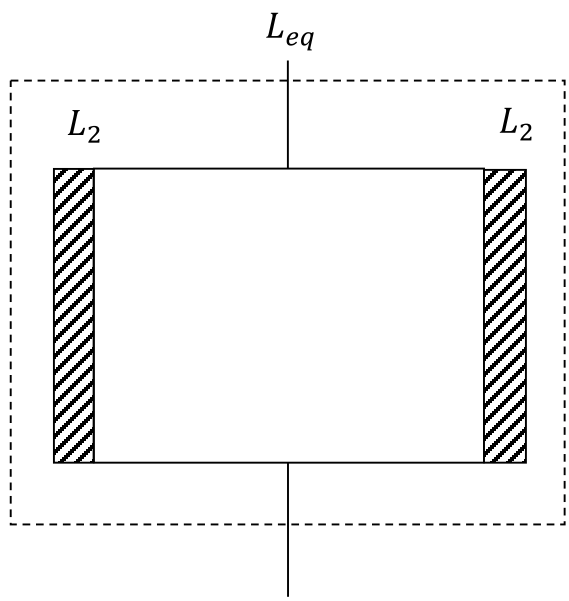
Measure the obstacle that is presented by a 13 cm piece of Kanthal in series with a 29 cm piece. ***Record your result in the first row of table 2b*****. [1]** *Repeat for a 31 cm piece and a 59 cm piece,* ***recording your result in the second row of table 2b*****. [1]** Do you notice a pattern emerging? (If not, choose another pair of non-equal lengths and measure the obstacle equivalent to this pair in series. Put the results under the last line of table 2b.) **Use table 2b to write an expression for the obstacle that is equivalent to that presented by the combination of L_1 in series with L_2. [1]**

Copy table 3a into your report;

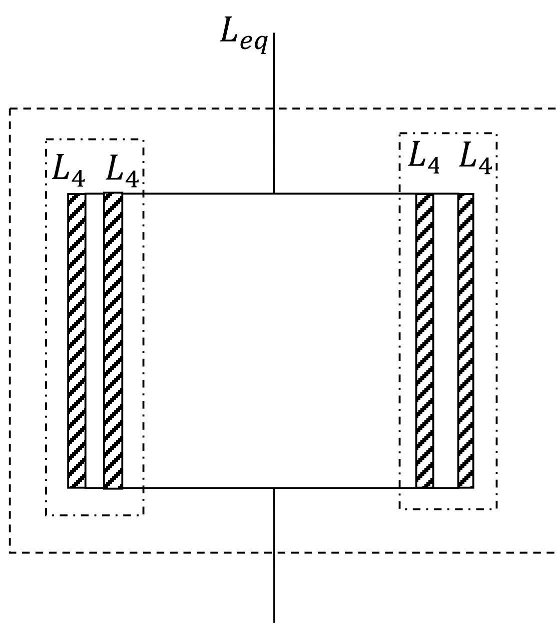
Table 3a

Length of Kanthal (L)	Obstacle presented by two of these lengths in parallel
30 cm	
40 cm	
50 cm	
60 cm	

Measure the equivalent length of the obstacle presented by two 30-cm pieces of Kanthal in parallel. ***Record the results in the first row of table 3a*****. [1]** Repeat for two lengths of 40 cm, 50 cm and 60 cm, recording the results in table 3a. **[3] Use table 3a to write an expression for an obstacle (called L_{eq}) that is equivalent to two pieces of Kanthal of length L_2 that are in parallel. [1]** (In the following diagram, the pieces of Kanthal of length L_2 are represented by narrow shaded rectangles. The dotted box is imaginary. L_{eq} is the obstacle measured by an external circuit outside the dotted box.)



Going further, imagine that each of the obstacles L_2 (in the diagram above), is actually made up of two obstacles (inside the dot-dash lines in the diagram below). Each of the four smaller obstacles has length L_4 (in parallel).



Express L_2 in terms of L_4 . Previously, you found L_{eq} **in terms of L_2. Use this to express L_{eq} in terms of L_4. Show your calculation and explain (in words) what you are doing. [2]** The expression for L_{eq} in terms of L_4 can be interpreted as an expression for the size of an obstacle L_{eq} that is presented by four identical obstacles of size L_4. What if each obstacle L_4 above was actually made up of two obstacles of size L_8. **Express L_8 in terms of L_4. Use your previous work to express L_{eq} in terms of L_8. [2]**

The discussion of the previous paragraph allows you to calculate the obstacle presented by several identical obstacles in parallel. **Write down an expression for an obstacle (called L_{eq}) that you expect to be equivalent <u>*N* pieces</u> of Kanthal <u>of length</u> *L* that are in parallel**. **[1]**

Show the patterns you have noticed to your TA.

Copy table 3b into your report;

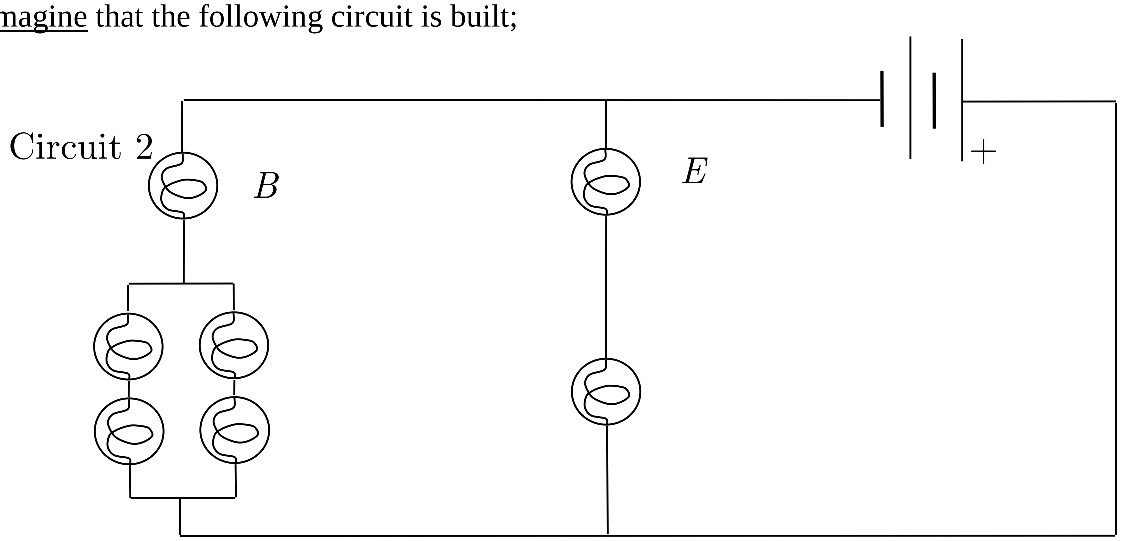
Table 3b

Length L_1	Length L_2	Obstacle presented by L_1 and L_2 in parallel
31 cm	59 cm	
47 cm	61 cm	

Use only one D-cell to measure the equivalent length of pieces of Kanthal that aren't the same length but are in parallel. ***Record the results in table 3b*. [2]**

You will need the contents of table 3b for the pre-lab for electricity IV but will be submitting table 3b to your TA. Before submitting the table, record a copy that you'll have when you are doing the prelab for electricity IV. The prelab for electricity IV has a suitable table for recording these results if you have it with you. If not, make a copy of table 3b on any convenient sheet of paper.

<u>Imagine</u> that the following circuit is built;



It is observed that bulb *B* has the same brightness as bulb *E*. Assume that the obstacle presented by each of the seven bulbs is *L* (irrespective of the flow that actually goes through them). **Explain why bulb B has the same brightness as bulb E**. **Explain your answer thoroughly. Your answer should refer to observations that you have made in this lab. [3]** (You will have to refer to the four bulbs that are in the same branch as bulb *B*, and the single bulb in the same branch as bulb *E*.) *Hint*: You have seen a similar circuit: circuit 2 of the pre-lab for this lab. Part of your explanation will need to refer to it.

Remember leave the apparatus as it was when you arrived.
Ask your TA to check your apparatus before you turn in your reports.

Shut-down the computer if it is turned on.

Take any rechargeable cells out of the battery-holders and put them in re-charger. (Make sure that you get the polarity of the battery right.) Connect your battery holders in series before you give the TA your report.

The *pre-lab for electricity IV is not short* and you might like to begin it in this lab if time allows. As always, begin the pre-lab early so that you are ready to ask questions during office hours.

The next item in this manual is an exercise on drawing graphs. The report on ‘Drawing Graphs’ is due at the beginning of Electricity IV. Please remember that this homework exercise is not a lab. It can’t be dropped or made up.

PRE-LAB

NAME:____________________________ Course & Section ______________________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

For circuit 1: Will the bulb light for the whole time that the capacitor discharges? Explain. (Hint: you might want to recall circuit 4 of electricity II.)

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____**[2]**

Say why this method (of measuring the size of an obstacle) isn't useful.

____**[1]**

For circuit 2:
Suppose that G presents a bigger obstacle to the flow than H. What do you predict about the relative brightness of bulb *D* and of bulb *E*? Explain your prediction using the ideas of 'flow' and 'obstacle'.

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____

____**[3]**

<u>Suppose that the alligator clips are moved so that bulbs *D* and *E* have the same brightness.</u>
…compare the flow through bulb *D* with the flow through bulb *E*. (Instead of quoting the relevant statement from the model of electricity, just include the label; 1a, 1b or 1c in your answer.)

____

____**[2]**

Use your previous answer to compare the flow through obstacle $\boxed{G}$ and obstacle $\boxed{H}$

____

____**[1]**

Use the hypothesis (underlined near the beginning of the introduction) to make a statement about the relative sizes of obstacles $\boxed{G}$ and $\boxed{H}$

____**[1]**

How will the brightness of bulb A compare with the brightness of bulb C? Explain.

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____

____**[3]**

REPORT

NAME:___________________________ Course & Section: __________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

For circuit 1:

… what can you say about the flow of electricity through the bulb *D* relative to the flow through bulb *E*? Explain using a concept from the model of electricity. (Instead of quoting the relevant statement from the model of electricity, just include the label; 1a, 1b or 1c in your answer.)

____**[1]**

What can you say about the size of the obstacle presented by the carbon resistor relative to the size of the obstacle presented by the rheostat? Explain. (You can use your previous answer to help with this explanation.) Mention any hypothesis that you use.

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____**[3]**

Draw a circuit that can be used to find the obstacle presented by a bulb. On your diagram, <u>label the bulb that is having its obstacle measured</u> and <u>label any bulbs that are identical</u>.

Check the previous diagram with your TA **[5]**

Lengths of Kanthal that are equivalent to the obstacle presented by the objects listed;

Table 1

Object	One cell	Two cells in series	Three cells in series
Any spool of wire			
alligator-to-alligator cable			
# 48 bulb			
Carbon resistor			

[5]

Compare the flow through the circuit when one cell was used with the flow when two cells were used. What happened to flow when three cells were used?

____**[1]**

In table 1:
For which objects is the obstacle approximately constant (if the number of cells changes)? For which objects is the obstacle not even approximately constant as the number of cells changes?

____

____

____**[3]**

Have your TA check this answer

Table 2a

Length of Kanthal (L)	Obstacle presented by two of these lengths in series
30 cm	
40 cm	
50 cm	

[3]

Use table 2a to write an expression for the size of the single obstacle (called L_{eq}) that is presented by the series combination of two obstacles of length L .

____**[1]**

Table 2b

Length L_1	Length L_2	Obstacle presented by L_1 and L_2 in series
13 cm	29 cm	
31 cm	59 cm	

[2]

Use table 2b to write an expression for the obstacle that is equivalent to that presented by the combination of L_1 in series with L_2 .

____**[1]**

Table 3a

Length of Kanthal (L)	Obstacle presented by two of these lengths in parallel
30 cm	
40 cm	
50 cm	
60 cm	

[4]

Use table 3a to write an expression for an obstacle (called L_{eq}) that is equivalent to two pieces of Kanthal of length L_2 that are in parallel.

____**[1]**

Express L_2 in terms of L_4. Previously, you found L_{eq} in terms of L_2. Use this to express L_{eq} in terms of L_4. Show your calculation and explain (in words) what you are doing.

Calculation:

[3]

Express L_8 in terms of L_4. Use your previous work to express L_{eq} in terms of L_8.

____**[2]**

Write down an expression for an obstacle (of length L_{eq}) that you expect to be equivalent <u>N pieces</u> of Kanthal <u>of length</u> L that are in parallel.

____**[1]**

Table 3b

Length L_1	Length L_2	Obstacle presented by L_1 and L_2 in parallel
31 cm	59 cm	
47 cm	61 cm	

Copy the results of table 3b into pre-lab for electricity IV **[2]**

Explain why bulb B has the same brightness as bulb E. Explain your answer thoroughly. Your answer should refer to observations that you have made in this lab.

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____**[3]**