Electricity II

Purpose

- To encourage the building of mental models that correspond with physical reality
- To use capacitors as a tool for developing ideas about DC circuits
- To make observations that show the need for a second concept in our Model of Electricity

Equipment

- 3 rechargeable 'D' cells
- 1 charger
- Battery holders
- 2 $25,000\ \mu\mathrm{F}$ capacitors
- 3 #48 bulbs that are already in bulb-holders. #48 bulbs have cylindrical globes.
- 3 *#14 bulbs* that are already in bulb-holders. #14 bulbs have *spherical globes*.
- 8 alligator-to-alligator wires
- 2 (long) banana-to-alligator wires
- 1 compass

Groups will share rolls of painter's tape. Verify that you have all of the equipment listed. Notify your TA if anything is missing.

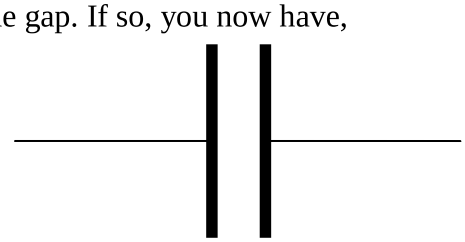
The TA needs,

- Neon bulb NE2H
- Battery
- Resistor 22kΩ (ballast)

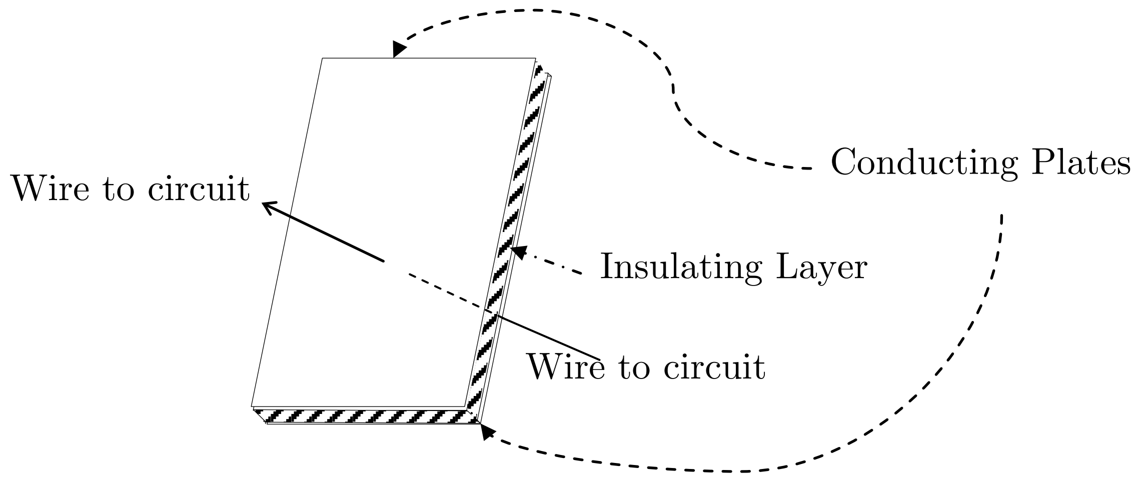
Introduction

NAME:____________________________

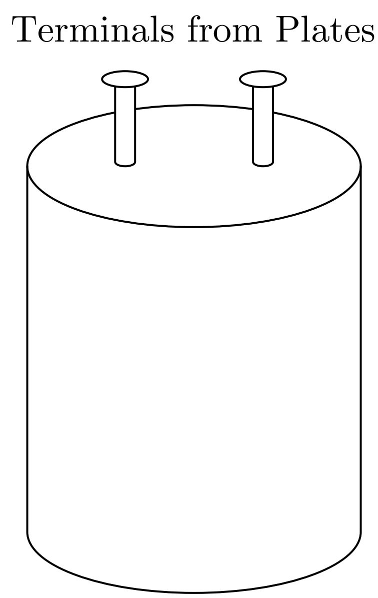
In electricity I, we saw that there was no *steady* flow of electricity if there was a break in a wire. However, interesting things happen if there is a break in the circuit and there is a large quantity of conductor near the break. The effect is very slight if we just make a cut in a piece of ordinary wire, but the effect can be seen if the wire at the break is quite thick (and the gap between the wires is small). The easiest way to do this is to connect (thin) wires to thick plates of metal and separate the plates by a small distance. Suppose that a large plate of metal is attached to each end of wire nearest the gap. If so, you now have,



(Remember that you are looking 'edge-on' at the gap so the large plates are the two vertical lines.) The capacitor plates are separated by a thin layer of insulating material. This is how a very simple capacitor is made and the previous diagram is used as the symbol for a capacitor in circuit diagrams. The gap in this symbol is much bigger than the gap in an actual capacitor. The plates of an actual capacitor are often very thin but have a large surface area. A wire is attached to each plate and these wires allow the capacitor to be connected to the rest of a circuit.



This 'sandwich' of insulating layer and plates can be rolled up and put inside a metal can.

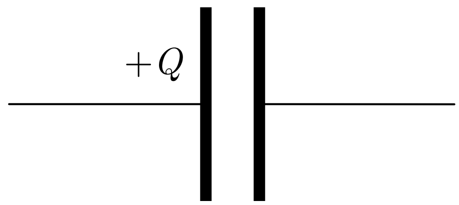


In practice, the technology used to build a capacitor will be more sophisticated. For example, the insulating material in some capacitors (called 'polar capacitors') must be connected to a battery in a specified way. However, the capacitors that we are using are non-polar so you don't have to think about which electrode needs to be connected to which terminal of the battery. ***In order to think about how capacitors work, imagine that the insulating material is a (very) thin gap of air.***

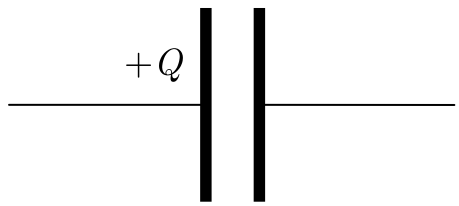
The following question is to be answered in your pre-Lab and does not require prior knowledge of capacitors. All you have to know is how a capacitor is constructed (from the

introduction to this lab). You'll also have to recall the electrostatics experiments and their results.

An electrophorus is charged (as in electrostatics II). It briefly touches one terminal of a capacitor so that a positive charge, +*Q*, is put on the plate of the capacitor that is connected to the terminal. After the electrophorus is removed, we have;

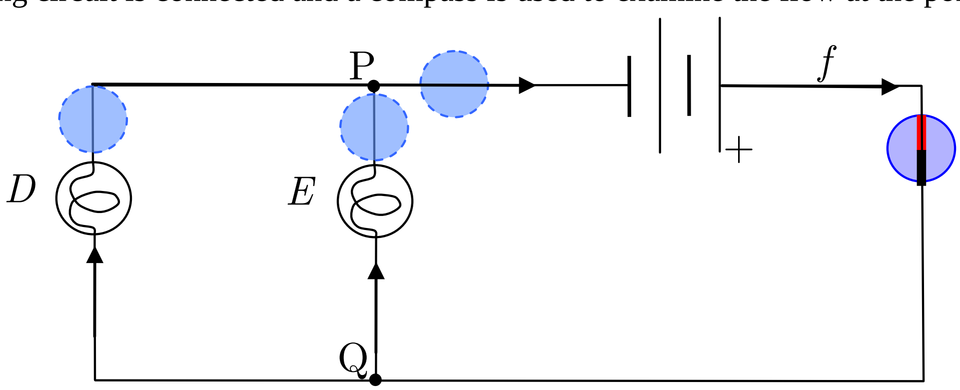


Will any changes take place at other plate (on the right of the diagram)? If so, <u>draw the charge</u> on the following diagram and <u>explain why it appears</u>. Your **explanation must include** reasons for the <u>sign</u> <u>and size</u> of any charge that appears and it must **say how these electrostatic charges originate**.



If nothing happens to the other plate then explain why not. **[3]**

The following circuit is connected and a compass is used to examine the flow at the points marked with circles.



A flow of size f leaves the positive terminal of the battery and deflects the compass needle on the right of the diagram. This flow continues to point Q. Compass needles at the positions just above bulbs D and bulb E are deflected by a smaller amount than the compass needle closest to the positive terminal of the battery. The compass needle closest to the negative terminal of the battery deflects by the same amount as the compass needle closest to the positive terminal of the battery. **What can you infer about the flow at each of the four compass positions? What is happening to the flow at points *P* and *Q*? [2]**

Instructions

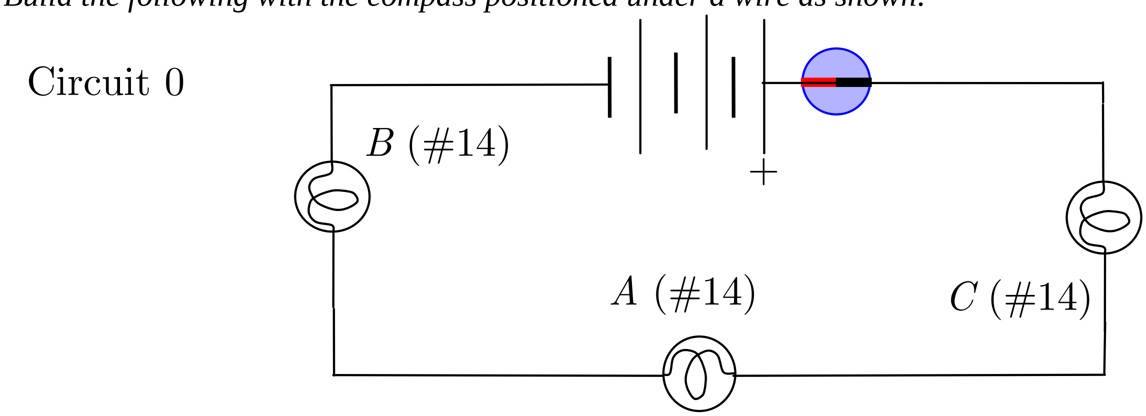
We can add statement 1 d to our model of electricity following from your TAs introduction and consideration of the second pre-lab question,

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.*

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 #48 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.*

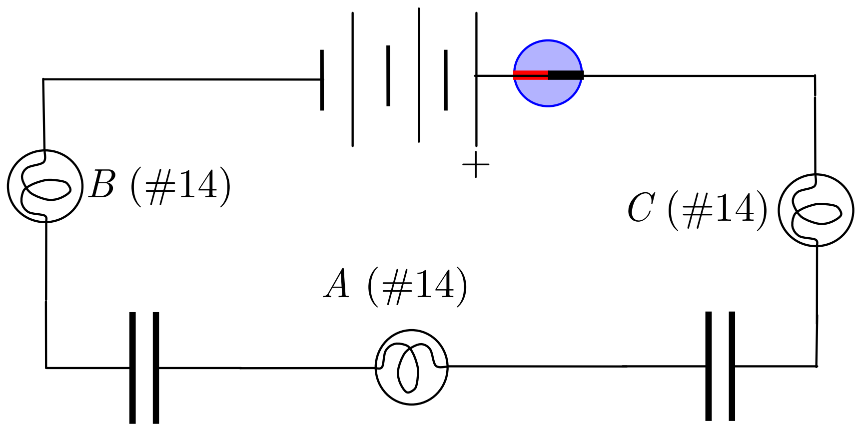
Build the following with the compass positioned under a wire as shown.



What is the sense of rotation of the compass when the circuit is completed; clockwise or counter-clockwise? [1]

Next, (without interchanging the wires that go to the battery) *include two capacitors in the circuit* to give circuit 1. After connecting up this circuit, and waiting for a moment, I'll refer to the capacitor as being charged. A later question will explore exactly what this means but for now, we'll say that a capacitor becomes charged if we connect it across a battery. I'll also refer to 'discharging the capacitor'. For now, a charged capacitor will discharge if we connect one terminal to the other (even if the connection goes through bulbs). To be fair, you'll need to discharge a capacitor for the same amount of time as was spent charging it. Adopt this as the usual way to charge & discharge a capacitor even if no bulb lights or a compass stops being deflected during either charge or discharge.

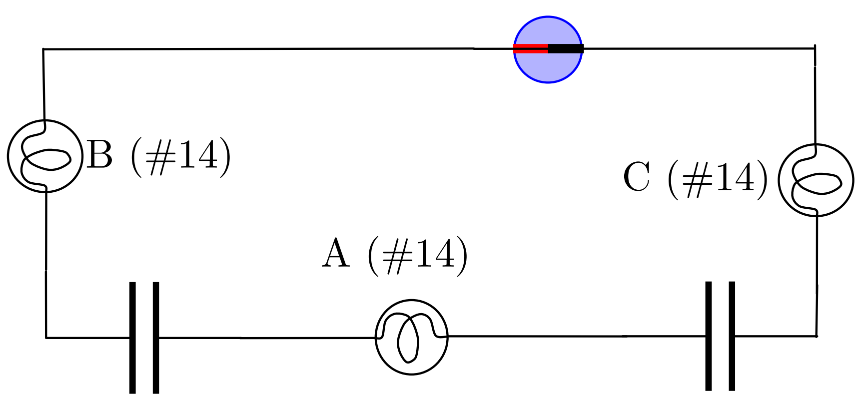
Circuit 1
(charging)



Circuit 1 is called ‘a circuit’ even though there is a break in the conducting path inside a capacitor. You’ll notice that the bulbs flicker when you connect the circuit. This is fine. (The flow must stop shortly after it began and the reason will be explored later.) **Compare the direction of the flow in circuit zero and circuit one (charging). [1]** *You should repeat this several times to make sure of your result. To return the capacitor to its initial state, break the circuit anywhere and use another piece of wire to connect the capacitor terminals. The capacitor will be ready to be used again after a short time.* [The time should be the same as the time during which the capacitor was connected to the battery.] *Better still, use the fact that the capacitors are already connected with wire: disconnect from the battery and touch the wires that were connected to the battery!* **Compare the size of the flow in circuit zero and circuit one (when the capacitors are charging). Give two observations that support your answer and explain how they support your answer. [2]**

Circuit 1 does something interesting when the capacitors either charge or discharge; all the bulbs flicker!

Circuit 1
(discharging)



All the bulbs light briefly but I’ll focus on bulb *A*. The flow that makes it light briefly can’t come directly from either terminal since it isn’t directly connected to a battery both during charging and during discharging. Let’s *make a hypothesis about the flow and see if it helps us explain our observations*. If the hypothesis helps then we’ll accept it tentatively. If it doesn’t then we’ll either modify it so that it becomes helpful or we will reject it. The *initial hypothesis is that the flow is made up of particles that don’t interact with each other* (i.e. don’t exert forces on each other). [For example, cars flow along a roadway without (hopefully!) interacting]. You will test one part of this hypothesis below.

Identify one point past which the particles can’t go (if we assume that the initial hypothesis is true). Explain why they can’t pass this point. Be as specific as you can about the location of this point. **[2]**

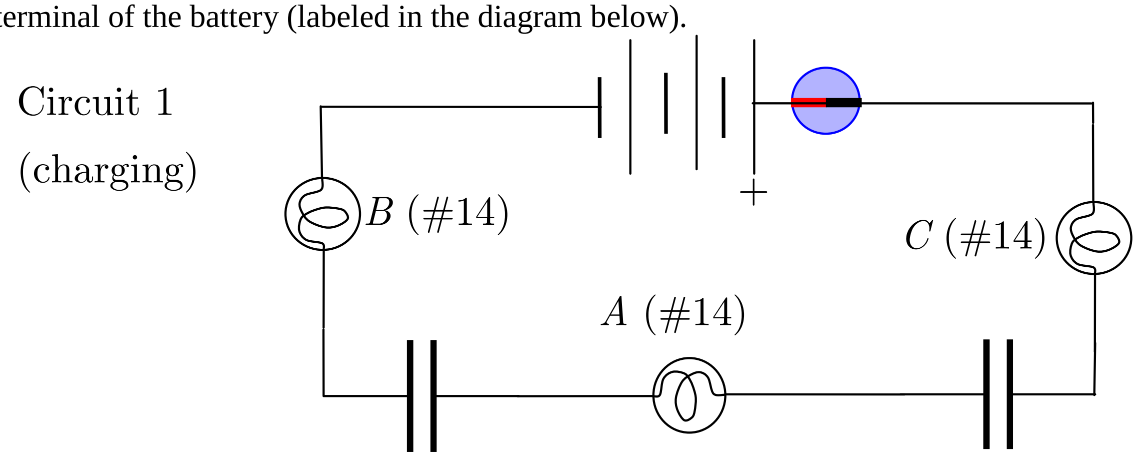
However, do you observe anything that would require <u>the flow</u> to pass this point? If so, say what you observe. [1] Has the initial hypothesis explained the lighting of bulbs in circuit 1? Explain why or why not. [1]

One reaction might be to reject our previous notion of flow and to try and find another concept to replace it. But this might not be wise; the hypothesis doesn't conflict with any observations that we made in electricity I and so might contain some useful ideas. Rather than throwing the hypothesis away, we'll try to modify the hypothesis so that it explains circuit 1.

The very simple picture (of flow being made up of a stream of non-interacting particles) was an initial hypothesis (or 'working-hypothesis'). The initial hypothesis makes a prediction about circuit 1 (that bulb *A* wouldn't light) and that prediction turned out to be untrue. Despite this, <u>careful examination</u> of a failed hypothesis can suggest a suitable modification. Let's see where things stand;

- Only flow makes bulbs light (Observed in electricity 1)
- The capacitor included a break in the conducting path (True from the construction of capacitors)
- Despite the break, bulb *A* lit anyway (Observed in this lab)
- The initial hypothesis was that the flow was made up of non-interacting particles (undetermined)

We also know that the <u>problem</u> with the hypothesis <u>only becomes noticeable when capacitors are involved</u> (because we didn't see bulbs lighting in electricity 1 if there was a break in the circuit). You'll have to return to the statement of the initial hypothesis and the situation in which the hypothesis failed. Try to figure out what in the statement of the hypothesis might account for its failure in the case of circuit 1. Let's begin at the positive terminal of the battery (labeled in the diagram below).



Bulb A is different from the others in that it has no direct connection to the battery. Since they are connected with a conductor, we aren't surprised about flow from the positive terminal of the battery through C to one terminal of the capacitor. But you observed flow in the wires that connect directly to bulb *A*. **If the flow in the wires is made up of particles that can only get to one plate of the capacitor, what property must the particles have in order for any effect to be seen on the other side of the capacitor? [1] Use the property (mentioned in your previous answer) to state a modified hypothesis. [1]** It is important to see if the modification of the hypothesis helps explain our observations any better than the unmodified hypothesis. **Explain how your modified hypothesis accounts for <u>flow</u> occurring in the wires that connect directly to bulb *A*. [2]** (When objects are polarized, you will have to think about where the charges come from and go to. The real point of interest here is how any effect on the capacitor plate directly connected to A can account for <u>flow</u>. Be sure that your modified hypothesis accounts for this.)

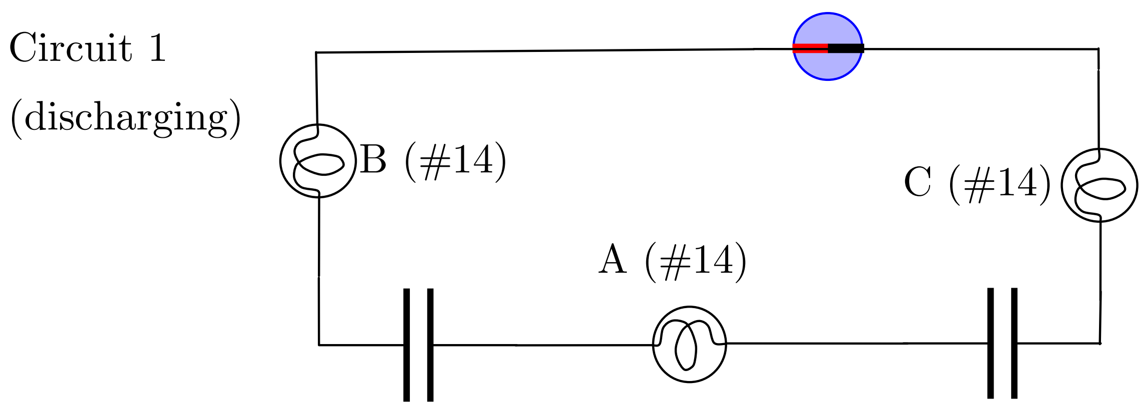
In turn, **how is the capacitor on the other side of bulb *A* effected? [2]** (Begin your answer with the fact that flow leaves bulb A and arrives at the capacitor on the right in the circuit diagram above.) **Will the effect on bulb B be as big as the effect on bulb A? Explain. [2]** *You might need to repeat the charging & discharging if you didn't notice the brightness of the bulbs before.*

Before continuing, have your TA show you a demonstration that involves a neon bulb and a battery. In electrostatics II, you saw a neon bulb light briefly. **What caused the neon bulb to light briefly in electrostatics II? [1]** I hope that the TAs demonstration suggested something to you. **Can you identify something that makes the neon bulb light briefly in electrostatics II and makes the #14 bulb light briefly in circuit one? [1]**

Ask your TA to check your last answers.

The previous questions might have broadened your thinking about flow; the word 'flow' originated with our ideas of 'particles that flow'. You (correctly) pointed out that the particles can't get from one capacitor plate to the other. Nonetheless, bulb *A* flickered and so that flow must have passed through bulb *A*. Since bulb *A* is in series with a capacitor then flow must have come from a plate in a capacitor. We'll broaden our word 'flow' to include this movement of electricity through the capacitor even though no particles flow through a capacitor. **Is there a difference between the speed at which charged particles move and the speed at which electricity flows? Explain. [2]**

Remove the battery from circuit 1. Connect the two wires that used to connect to the battery so that you have;



When charging and discharging the capacitors, *keep the circuit connected for at least 2 s after the bulbs have stopped lighting*.

You may have to repeat charging and discharging several times in order the make the next four comparisons. **Compare the following when the capacitors are charging with when they are discharging;**

- **sense of the rotation of the compass [1]**
- **size of the deflection of the compass [1]**
- **brightness of the bulbs [1]**
- **the time(s) for which the bulbs light [1]**

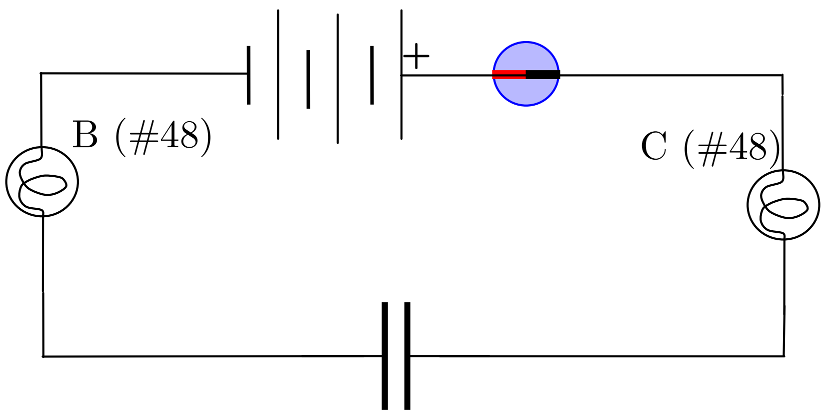
Charge flows into the capacitor during charging and flows out during discharging. **From any evidence that you have seen, how much electricity is permanently lost? Which of the preceding observations suggest your answer? [2]**

Many people say that the capacitor stores electricity. For now, I don't ask you to figure out how a capacitor might do this, but do want you to use this observed fact in what follows.

Ask your TA to check your last answer.

Build the following;

Circuit 2

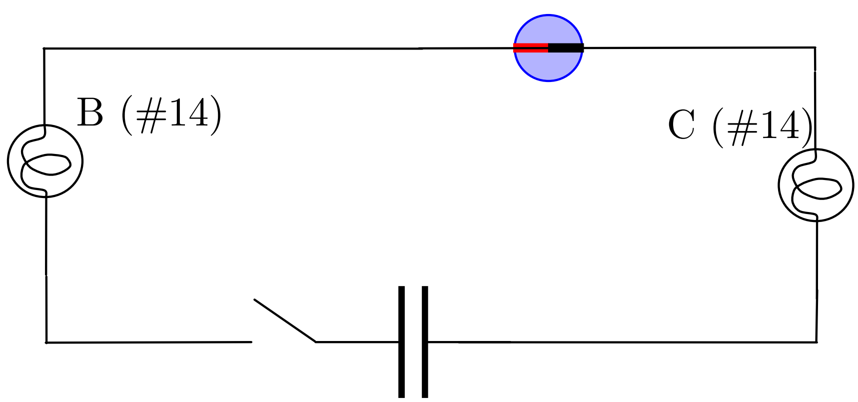


Charge and discharge the capacitor through the #48 bulbs. [There is a simple change to be made to circuit 2 in order to discharge. Hint: look at how circuit 1 (charging) differs from circuit 2 (discharging)]. During both charging and discharging, keep the circuit connected for 2 s after the bulbs have stopped lighting. (You can wait longer if you like.) **How long do the #48 bulbs (in circuit 2) light during charging or during discharging?** (Give an approximate time in seconds. This time will be used for comparison later and doesn't need to be precisely measured.) **[1] What is the maximum deflection of the compass in circuit 2? [1]**

As we saw in the case of circuit 1, the deflection of the compass, the brightness of the bulbs and the time for which the bulbs lit, all suggest that the amount of charge involved in both charging and discharging a capacitor is the same. Now you'll do something just a bit different. You'll charge a capacitor using circuit 2 and discharge it in another circuit. *End this sequence of activities by charging the capacitor through the bulbs of circuit 2.*

Remove the battery, disconnect the capacitor and exchange both bulbs for #14 bulbs, (leaving the bulbs in their holders!). Take care not to accidentally discharge the capacitor. Build circuit 3 but don't connect the capacitor until you are looking at the bulbs and compass.

Circuit 3



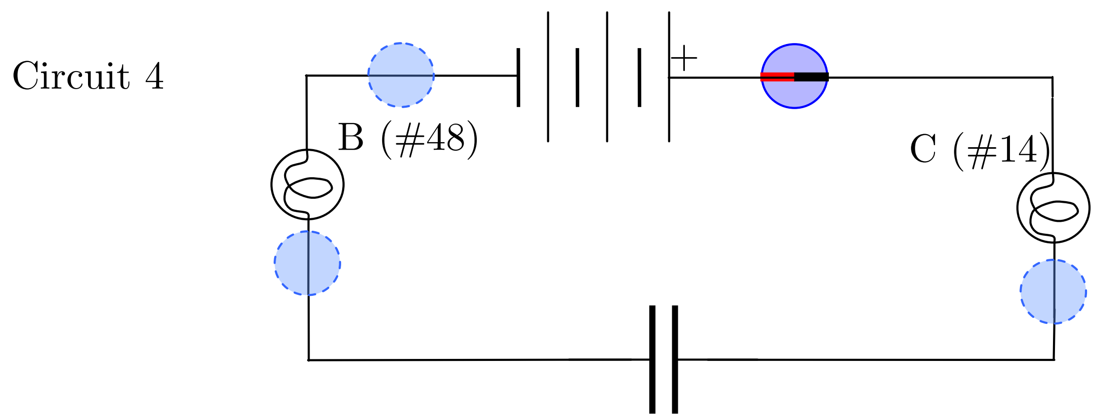
Reconnect the charged capacitor and let it discharge through the #14 bulbs. **How long do the #14 bulbs light during the discharge?** (Give an approximate time in seconds. This time will be used for comparison later and doesn't need to be precisely measured.) **[1]** As before, only a simple change to circuit 3 is needed in order to charge the capacitor. **What is the maximum deflection of the compass in circuit 3? [1]**

As before, you may have to repeat charging (through #48 bulbs as in circuit 2) and discharging (through #14 bulbs as in circuit 3) several times in order the make the following comparisons. **Compare the following in circuit 2 and circuit 3;**

- **the maximum deflection of the compass [1]**
- **the time during which the #14 bulbs light (in circuit 3) to the time for which the #48 bulbs light (in circuit 2) [1]**

Do these observations suggest anything about the <u>maximum</u> size of the flow through the two types of bulb? If so, say which observations suggest this. [3] What difference between circuits 2 and 3 might cause the difference in flow? [1]

In circuit 4, we will use bulbs that are definitely not identical. *Build*;

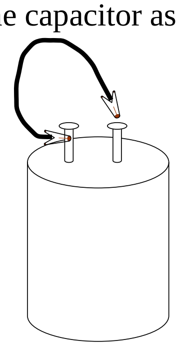


Charge and discharge the capacitor, paying attention to the length of time during which the bulbs light. (When you do this, you might think that one of your bulbs has burned out. If so, build a one-bulb circuit *<u>[with just one cell!!]</u>* and test the bulb that seems to be burned out.) **What can you say about the size of the flow as judged by the compass (placed in all four positions)? [1]**

Which bulb has the greatest maximum brightness; the #14 bulb or the #48 bulb? [1] In many cases, we have used the brightness of bulbs as an indicator of the size of the flow. **Does different brightness indicate different flow *in this case*? [1]**

Let's look at a very different case to see if the size of flow changes there too.

Charge a capacitor with circuit 2. Then take a capacitor out of the circuit and connect an alligator clip to one of the terminals. (If you have done everything carefully, the capacitor will still be charged at this point.) *Briefly touch the other terminal of the capacitor with the other alligator clip*. (You can make the contact brief by just tapping the alligator clip against the terminal of the capacitor as below.)



Remove the battery from circuit 2 and replace it with this capacitor so that it can discharge. **Do the bulbs light? [1]** From this, you should be able to infer an answer to the following question: **Compare the time for the capacitor to discharge through a piece of wire with the time for the capacitor to discharge through the bulbs. [1]** The same amount of electricity was involved in each discharge. **Can you conclude anything about the size of the flow through the wire as compared with the size of the flow through the bulbs**? **[1]**

The size of flow changes in this case, just as it did when we compared the flow through the two types of bulb. The concept of 'flow' doesn't include reasons why that flow might change. We need another concept that tells us <u>why flow changes</u>. To do this, we'll state a hypothesis, use the hypothesis to make predictions and finally you'll check those predictions. If the hypothesis is continually useful in explaining how circuits function, then we can begin to call it a concept and include it in the model of electricity.

The new hypothesis must explain why the discharge through the piece of wire is so rapid and also why it is fairly quick through #14 bulbs but slower through #48 bulbs. One possible hypothesis is as follows. "<u>Other factors being equal, the size of the flow increases if a component presents a small obstacle, and vice versa</u>". <u>In order to use this hypothesis, we'll have to find some way of measuring out the size of the obstacle presented to the flow by any object</u>. **If the hypothesis (of their being various obstacles to the flow) is true**, **what can be predicted about the relative sizes of the obstacles presented by an alligator-to-alligator cable, a #14 bulb and a #48 bulb? Explain. (Say how your answer accounts for the discharge-times that we observe.) [2]** If we don't observe obstacles of this predicted size then our hypothesis won't succeed in explaining anything and we'll reject it.

The plan for the next lab is clear: begin by finding a way to measure the size of an obstacle presented by an object. In particular, we'll need the obstacles presented by an alligator-to-alligator cable, a #14 bulb and a #48 bulb. The result will test our hypothesis about obstacles and the size of the flow.

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

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.

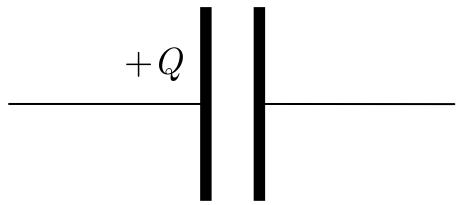
An exercise that uses Excel (to interpret graphs) follows Electricity III in this manual. If you have time now then begin this exercise. The report on '<u>Drawing Graphs</u>' is <u>due at the beginning of Electricity IV</u>.

PRE-LAB

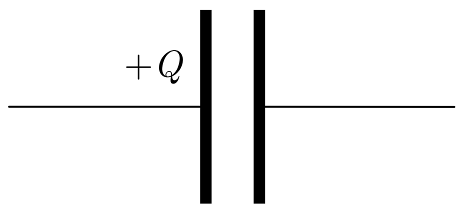
NAME:____________________________ Course & Section: ___________________
Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

These questions can be answered without any prior knowledge of capacitors. All you have to know is how a simple capacitor is constructed (from the introduction to this lab) and you'll have to recall the electrostatics experiments.

An electrophorus is charged (as in electrostatics II). It briefly touches one terminal of a capacitor so that a positive charge, $+Q$, is put on the plate of the capacitor that is connected to the terminal. After the electrophorus is removed, we have;



Will any changes take place at other plate (on the right of the diagram)? If so, draw the charge on the following diagram and explain why it appears. Your **explanation must include** reasons for the sign and size of any charge that appears and **say how these electrostatic charges originate**.



If nothing happens to the other plate then explain why not.

____

____

____**[3]**

What can you infer about the flow at each of the four compass positions? What is happening to the flow at points *P* and *Q*?

____

____

____**[2]**

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.

In circuit zero:
What is the sense of rotation of the compass when the circuit is completed; clockwise or counter-clockwise?

____**[1]**

Compare the direction of the flow in circuit zero and circuit one (charging).

____**[1]**

Compare the size of the flow in circuit zero and circuit one (when the capacitors are charging). Give two observations that support your answer and explain how they support your answer.

____

____

____**[2]**

Identify one point past which the particles can't go (if we assume that the initial hypothesis is true). Explain why they can't pass this point. *Be as specific as you can about the location of this point.*

____

____**[2]**

However, do you observe anything that would require <u>the flow</u> to pass this point? If so, say what you observe.

____**[1]**

Has the initial hypothesis explained the lighting of bulbs in circuit 1? Explain.

____**[1]**

If the flow in the wires is made up of particles that can only get to one plate of the capacitor, what property must the particles have in order for any effect to be seen on the other side of the capacitor?

____

____ **[1]**

Use the property (mentioned in your previous answer) to state a modified hypothesis.

____

____**[1]**

Explain how your modified hypothesis accounts for <u>flow</u> occurring in the wires that connect directly to bulb *A*.

____

____

____

____**[2]**

… how is the capacitor on the other side of bulb *A* effected?

____

____

____**[2]**

Will the effect on bulb B be as big as the effect on bulb A? Explain.

____

____

____**[2]**

What caused the neon bulb to light briefly in electrostatics II?

____**[1]**

Can you identify something that makes the neon bulb light briefly in electrostatics II and makes the #14 bulb light briefly in circuit one?

____**[1]**

Is there a difference between the speed at which charged particles move and the speed at which electricity flows? Explain.

____

____**[2]**

For circuit 1 (discharging);
Compare the following when the capacitors are charging with when they are discharging;

- sense of the rotation of the compass

____**[1]**

- size of the deflection of the compass

____**[1]**

- brightness of the bulbs

____**[1]**

- the time(s) for which the bulbs light

____**[1]**

From any evidence that you have seen, how much electricity is permanently lost? Which of the preceding observations suggest your answer?

____

____**[2]**

Ask your TA to check your last answer

How long do the #48 bulbs (in circuit 2) light during charging or during discharging? (Give an approximate time in seconds. This time will be used for comparison later and doesn't need to be precisely measured.)

____**[1]**

What is the maximum deflection of the compass in circuit 2?

____**[1]**

In circuit 3:
How long do the #14 bulbs light during the discharge? (Give an approximate time in seconds. This time will be used for comparison later and doesn't need to be precisely measured.)

____**[1]**

What is the maximum deflection of the compass in circuit 3?

____**[1]**

Compare the following in circuits 2 and circuit 3;

- the maximum deflection of the compass

____**[1]**

- the time during which the #14 bulbs light (in circuit 3) to the time during which the #48 bulbs light (in circuit 2)

____**[1]**

Do these observations suggest anything about the <u>maximum</u> size of the flow through the two types of bulb? If so, say which <u>two observations</u> suggest this.

____

____

____**[3]**

What difference between circuits 2 and 3 might cause the difference in flow?

____**[1]**

In circuit 4: What can you say about the size of the flow as judged by the compass (placed in all four positions)?

____**[1]**

In circuit 4: Which bulb has the greatest maximum brightness; the #14 bulb or the #48 bulb?

____**[1]**

Does different brightness indicate different flow *in this case*?

____**[1]**

Do the bulbs light?

____**[1]**

Compare the time for the capacitor to discharge through a piece of wire with the time for the capacitor to discharge through the bulbs.

____**[1]**

Can you conclude anything about the size of the flow through the wire as compared with the size of the flow through the bulbs?

____**[1]**

If the hypothesis is true, what can be predicted about the relative sizes of the obstacles presented by an alligator-to-alligator cable, a #14 bulb and a #48 bulb? Explain. (Say how your answer accounts for the discharge-times that we observe.)

____

____

____**[2]**