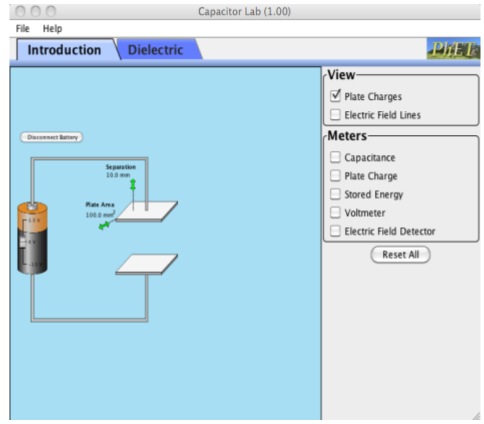
Section: Name: BU ID: .

Partner: Name: BU ID: .

Lab 3: Capacitors and Resistors

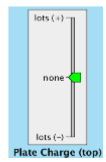
Part I: Properties of Capacitors.



In the following laboratory experiments you will investigate fundamental properties of capacitors and resistors and circuits involving capacitors and resistors. You will use a Java simulation to investigate fundamental properties of a parallel plate capacitor. Open the following link http://phet.colorado.edu/en/simulation/capacitor-lab). After the applet starts you should see a picture similar to the one on the right.

Using the right-bottom corner of the window you may want to stretch it up for a better visibility.

In all your investigations ignore the Plate Charge slider,

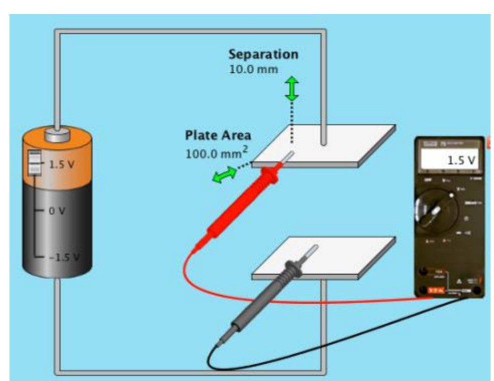


which can be used to manually change the charge of a capacitor.

A. Calculating the capacitance.

Using the given values for the plate area and the distance between the plates, calculate the capacitance of the capacitor in the picture.

B. Charging the capacitor.



In the panel on the right:
Uncheck Plate Charges.
Check Voltmeter.
Attach the red probe to the top plate and the black one to the bottom plate.
Slide the slider on the battery all the way *up*. (it makes the top terminal of the battery having its electric potential 1.5 V higher than the bottom one).
(Make sure the battery is connected to the capacitor; connection is controlled by "Disconnect/Connect Battery" button).
Now you should see the picture similar to the one on the right.

Draw bellow a capacitor (keep the plates horizontal as in the simulation) and draw (clearly indicate) the electric field lines in the region between the plates. Explain your reasoning. Use the data provided by the applet and calculate the strength (magnitude) of the electric field between the plates.

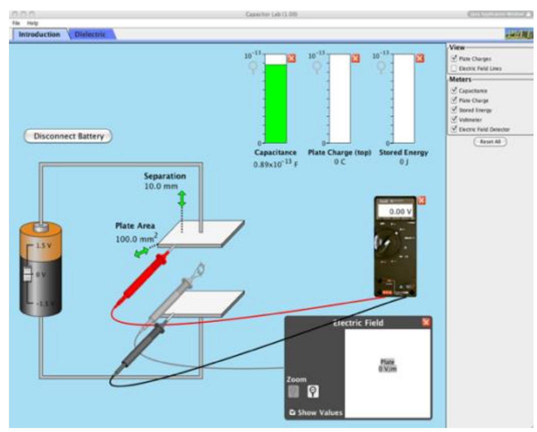
Check on Electric Field Detector and compare your prediction with the reading.

C. Changing the area.

1. Predict which of the physical variables listed below will also change when you change the *area* of the capacitor plates (<u>while keeping the battery ***connected***</u>). Check all that will change. Explain your reasoning.

[ ] Capacitance
[ ] Charge on the plates
[ ] Voltage across the plates
[ ] Electric field between the plates
[ ] Energy of the capacitor

2. Predict in which direction (relative to you) electrons will travel when you will be *increasing* the area of the plates (think how increasing the area affects the capacitance, and how electrons should move to increase or decrease the charge). Check your prediction below.



[ ] clockwise [ ] counterclockwise
[ ] there will be no moving electrons

3. Check all the meters *on*, like in the picture on the right (your battery should have the slider all the way up). Do *not* disconnect the battery.
Slowly increase the area of the plates by dragging the little double arrow away from the plates and observe the changes. If your meter bars are overfilled, click on [zoom icon] to scale them down.

Fill in the table below. Pay attention to the units in the table (piko; p = 10^{-12})!

A (mm^2)	d (mm)	C (pF)	$\|V\|$ (V)	$\|Q\|$ (pC)	$\|E\|$ (V/m)	U (pJ)
100	10					
400	10					

4. Compare your predictions in Q1 and Q2 with the results of your “experiment”. Explain any deviations between your predictions and your observations.

5. Click on Reset All (confirm “Yes” when asked); Uncheck Plate Charges, slide the battery slider all the way *up*, *and disconnect the battery* (click on “Disconnect/Connect Battery” control).

Predict which of the physical variables listed below will also change when you change the area of the capacitor plates (while keeping the battery ***disconnected***). Check all that will change.

[ ] Capacitance
[ ] Charge on the plates
[ ] Voltage across the plates
[ ] Electric field between the plates
[ ] Energy of the capacitor

6. Predict the direction in which the electrons will travel when you increase the area of the plates. Check your prediction below.

[ ] clockwise [ ] counterclockwise [ ] there will be no moving electrons

7. Check all the meters on (do not forget to connect the voltage probes to the plates; make sure the field probe is between the plates).

Slowly increase the area of the plates by dragging the little double arrow away from the plates and observe any changes. Fill in the table below.

Pay attention to the units in the table!

A (mm^2)	d (mm)	C (pF)	$\|V\|$ (V)	$\|Q\|$ (pC)	$\|E\|$ (V/m)	U (pJ)
100	10					
400	10					

8. Compare your predictions in Q5 and Q6 with the results of your “experiment”. Explain any deviations between your predictions and your observations.

9. Describe what happens to the electric field in the capacitor when the capacitor is *disconnected* from a battery and the area of its plates is *decreased*. Explain why this happens.

D. Changing the separation.

1. Click on Reset All (confirm "Yes" when asked); maximize the area of the plates, slide the battery slider all the way *up*, decrease the plates separation from 10 mm to 5 mm, and disconnect the battery.

For each variable listed below predict how will it change (if it will) when the *distance* between the plates will *increase* while keeping the battery *disconnected*. Show your work.

Capacitance

Charge on the plates

Voltage across the plates

Electric field between the plates

Energy of the capacitor

2. Predict in which direction electrons will travel when you increase the separation between the capacitor plates (while keeping the battery *disconnected*). Check your prediction below.

[ ] clockwise [ ] counterclockwise [ ] there will be no moving electrons

3. Check all the meters on (do not forget to connect the voltage probes to the plates, make the reading positive; make sure the field probe is between the plates).

Slowly change the separation between the plates by dragging the little double arrow down (or up) and observe the changes. Fill in the table below. Pay attention to the units in the table!

A (mm^2)	d (mm)	C (pF)	$\lvert V \rvert$ (V)	$\lvert Q \rvert$ (pC)	$\lvert E \rvert$ (V/m)	U (pJ)
400	5					
400	10					

4. Compare your predictions in Q1 and Q2 with the results of your "experiment". Explain any deviations between your predictions and your observations.

5. Click on Reset All (confirm “Yes” when asked); maximize the area of the plates, decrease the plates separation to 5 mm, slide the battery slider all the way *up*, and do not disconnect the battery.

For each variable listed below predict how will it change (if any) when the distance between the plates will increase while keeping the battery *connected*. Show your work.

Capacitance

Charge on the plates

Voltage across the plates

Electric field between the plates

Energy of the capacitor

6. Predict the direction in which the electrons will travel when you increase the separation between the capacitor plates (while keeping the batter *connected*). Mark your prediction below.

[ ] clockwise [ ] counterclockwise [ ] there will be no moving electrons

7. Check all the meters on (do not forget to connect the voltage probes to the plates; make sure the field probe is between the plates).

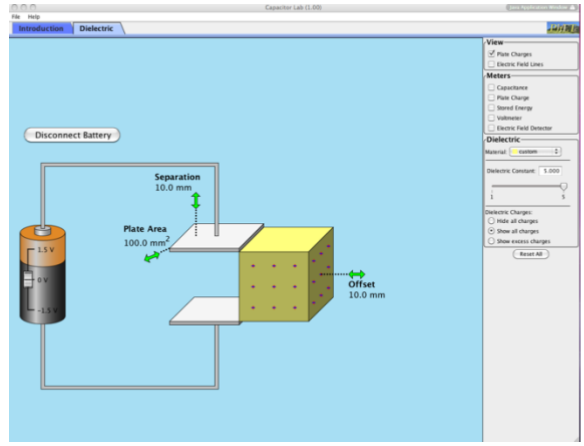
Slowly change the separation between the plates by dragging the little double arrow down (or up) and observe the changes. Fill in the table below. Pay attention to the units in the table!

A (mm^2)	d (mm)	C (pF)	$\|V\|$ (V)	$\|Q\|$ (pC)	$\|E\|$ (V/m)	U (pJ)
400	5					
400	10					

8. Compare your predictions in Q5 and Q6 with the results of your “experiment”. Explain any deviations between your predictions and your observations.

9. Describe what happens to the electric field in the capacitor when the capacitor is connected to a battery and the separation between its plates is increased. Explain why this happens

E. Changing the dielectric



Click on tab Dielectric to switch to another window.

1. Slide the battery slider all the way *up*, and disconnect the battery.
For each variable listed below predict how will it change (if any) when a dielectric will be inserted between the plates, while keeping the battery *disconnected*. Show your work.

Capacitance

Charge on the plates

Voltage across the plates

Electric field between the plates

Energy of the capacitor

2. Check all the meters on. (Do not forget to connect the voltage probes to the plates; make sure the field probe is between the plates and within a dielectric; the field you are interested in is the net field!).
Slowly insert the dielectric between the plates by dragging the little double arrow to the left and observe the changes. Fill in the table below. Pay attention to the units in the table!

A (mm^2)	d (mm)	κ	C (pF)	$\lvert V\rvert$ (V)	$\lvert Q\rvert$ (pC)	$\lvert E\rvert$ (V/m)	U (pJ)
100	10	1					
100	10	5 (filled completely)					

3. Compare your predictions in Q1 and Q2 with the results of your "experiment". Explain any deviations between your predictions and your observations. Note: the actual electric field is the net field represented but the sum of plate field and dielectric field.

4. Click on Reset All (confirm "Yes" when asked); slide the battery slider all the way up, and do not disconnect the battery.

For each variable listed below predict how will it change (if any) when a dielectric will be inserted between the plates, while keeping the battery *connected*. Show your work.

Capacitance

Charge on the plates

Voltage across the plates

Electric field between the plates

Energy of the capacitor

5. Check all the meters on. (Do not forget to connect the voltage probes to the plates; make sure the field probe is between the plates and within a dielectric; the field you are interested in is the net field!)
Slowly insert the dielectric between the plates by dragging the little double arrow to the left and observe the changes. Fill in the table below. Pay attention to the units in the table!

A (mm^2)	d (mm)	κ	C (pF)	$\lvert V\rvert$ (V)	$\lvert Q\rvert$ (pC)	$\lvert E\rvert$ (V/m)	U (pJ)
100	10	1					
100	10	5 (filled completely)					

6. Compare your predictions in Q5 and Q6 with the results of your "experiment". Note: the actual electric field is the net field represented but the sum of plate field and dielectric field. Explain any deviations between your predictions and your observations.

7. Switch to tab "Multiple capacitors", First, draw *all* different configurations of *three* 10^{-13} F capacitors, calculate the equivalent capacitance for each case, and then compare with the numbers provided by the applet (check on Total Capacitance).

Part II: Ohms Law experiment

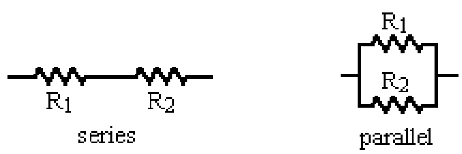
In this experiment you will investigate different aspects of Ohm's Law, which relates voltage, current, and resistance. At first, a computer will be used to collect, display, and help you analyze the data. You may share sometimes your equipment with other students (or ask them for an extra time, like a bulb or a resistor). This lab does NOT require the use of LED (do not use it, if LED is provided).

ATTENTION! When you are finished with the all measurements, please, disconnect and turn off everything, and only then leave the lab station! (in general, ethic rules require to leave a work station in the same condition it was left to you)

A resistor is a device with some resistance. Examples include the element in a toaster, the filament in a light bulb, or even just a length of wire. For a wire of length L and cross-sectional area A, made from a material with a resistivity ρ, the resistance is given by: $R = \rho L/A$.

On a circuit diagram the symbol for a resistor is: 

When resistors are connected together in a circuit, the overall (net, total, equivalent, effective) resistance of the circuit can be found by using the relationships for resistors connected in series or in parallel.



1. Check below all the correct statements.

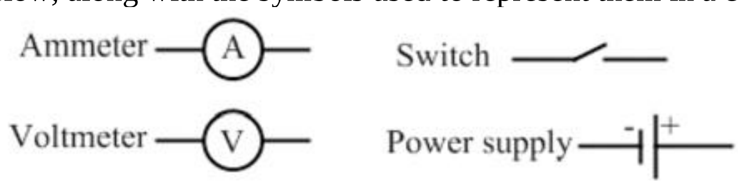
[ ] For resistors connected in series, the voltage is the same across each resistor.

[ ] For resistors connected in series, the current is the same through each resistor.

[ ] For resistors connected in parallel, the current is the same through each resistor.

[ ] For resistors connected in parallel, the voltage is the same across each resistor.

In addition to resistors, you will use several other devices in the circuit in this experiment (all treated as ideal!). These are shown below, along with the symbols used to represent them in a circuit diagram.



A current at any point in a circuit can be measured with an ammeter. Potential rise or drop in a circuit can be measured using a voltmeter.

2. Check all the correct statements below.

[ ] Ammeters are placed in parallel with the device through which the current is being measured.

[ ] Ammeters are placed in series with the device through which the current is being measured.

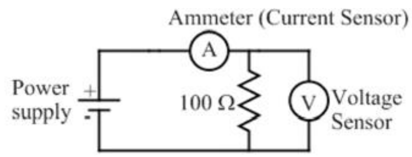
[ ] Voltmeters are placed in series with the device across which voltage is measured.

[ ] Voltmeters are placed in parallel with the device across which voltage is measured.

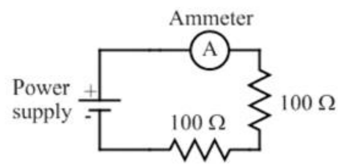
WIRING CIRCUITS

The following page shows circuit diagrams (a.k.a. schematics) for the different circuits you will use in the experiment. The lines on the diagrams represent the wires you will use to connect the different components to one another.

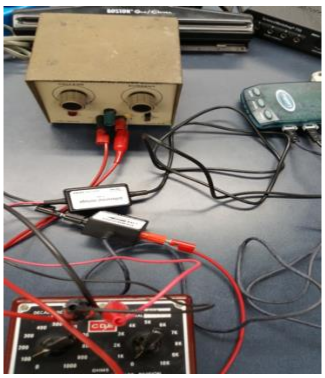
For Circuit I, you will wire up together the power supply, current sensor, and resistor in one big loop (for a resistor use either a decade box or a blue 100 Ohm or 200 Ohm container). Make sure the current will flow from the power supply through the current sensor in the direction indicated by an arrow on the sensor (it the current reading will be negative you can just switch the direction). That puts all those things in series with one another. Then connect one end of the voltage sensor to one end of the resistor, and the other end of the voltage sensor to the other end of the resistor. That puts the voltage sensor in parallel with the resistor. Check that the voltage sensor is connected to the *first* input of the digital interface and the current sensor is connected to the second input of the interface.



Circuit I



Circuit II



PROCEDURE

Load the software for the experiment by double-clicking on the "Ohm's Law". The screen should show a graph filed, a table, and, and (in the lower left corner) boxes with the voltage and current readings. Set the voltage and the current knobs on the power supply to the minimum and turn it on. Click the Zero button and select "Zero All Sensors" to make sure the voltage and current readings read almost zero. **Slowly increase the voltage and the current to the maximum and notice its maximum value indicated on the screen, it should be close to 6V, otherwise one of your sensors is faulty, call a TF.** Turn the voltage knob and the current knob back to the minimum, do *not* turn the power supply off, and ZERO all the sensor again.

Note: whenever you hit the Collect button, the computer will start recording voltage and current.

Following Circuit Diagram I, wire up the circuit to measure the voltage and current across a 100 Ω resistor. For a resistor, use a resistance decade box (or a small blue container), you chose if you use a 100 Ohm or 200 Ohm resistor.

On the power supply turn the current limit to the maximum, but keep the voltage to the minimum. Hit the Collect button. Slowly (over 5 - 7 seconds, as uniform as possible) turn the voltage knob up to maximum and stop collecting data.

This should give you a graph of current vs. voltage, covering from about 0 volts to 6 volts (scale it using Ctrl-J combination); it might look noisy, but on average it should look as a straight line (otherwise, try again).

3. What do you expect the slope of the current vs. voltage graph to be equal to? Why?

4. Select a large portion of a graph (but leave the initial and the final points outside of your selection). Find the slope of the line by selecting the Curve Fit button, . Select "Linear Fit" from the list and click Try Fit . If you get an error message, select the Data menu, and choose "Sort data set", choose "Latest"; choose "Potential" (keep "Ascending"). Try linear fit again. If you get a message that you do not have enough data to make a fit, start from a square one, i.e. zero all the sensors again and retake the measurements. Write down the slope before hitting OK, because after hitting OK not enough significant figures might be shown. If still you have no good data, repeat the experiment again.

5. Determine the resistance from the slope.

Write down the maximum voltage supplied by the power supply. $V =$

You do not need using a computer anymore; from this point forward, you can use a multimeter to measure current and/or voltage (hint: also you can use the computer as a second multimeter, if you need an extra device). You have many different wires, some have banana plugs, some have alligator-like connectors/clips, be creative when wiring up a circuit.

6. For Circuit II on page 9, what value for the current do you expect to read with the ammeter when the power supply is at the maximum voltage? What voltage do you expect across a *single* resistor? What voltage do you expect across two resistors? Justify your answer.

$I =$ $V_1 =$ $V_2 =$

7. Wire up Circuit II. Use two 100 Ohm resistors (not bulbs!) in series and include an ammeter (i.e. the multimeter set to measure current). Turn the current limit to the maximum. What is the current in the circuit when the power supply voltage is at its maximum; write the current. Take the multimeter out of the circuit, connect the resistors again without the multimeter (if you have two multimeters you can keep one in the circuit). What is the voltage across a single resistor (use a multimeter to measure it)? What is the voltage across two resistors? If it is different from your prediction, explain the difference.

$I =$ $V_1 =$ $V_2 =$

8. Rewire the circuit so that the ammeter is between the two resistors. Do NOT measure the current yet. What value for the current do you expect? Why? If you added the switch into the circuit, what would be the voltage *across the switch* when it is open and when it is closed?

$I =$ $V_{open} =$ $V_{closed} =$

9. Rewire the circuit so that the ammeter is between the two resistors and measure the current. Now rewire the circuit by adding the switch to it (you chose its location). Measure the voltage across the switch when it is open and when it is closed. If the results are different from your prediction, explain the difference.

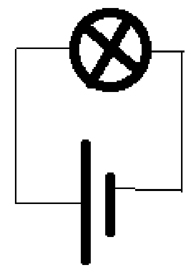
$I =$ $V_{open} =$ $V_{closed} =$

For all the experiments described below, **do *not* use the power supply**, instead use a battery (for your experiments to work as expected you need a **fresh** battery which supplies EMF close to the original voltage/EMF).

Measure the voltage provided by the battery (if it close to 5.5 V ask for a newer battery or try 9 V battery):

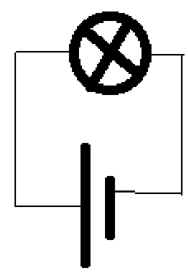
$V =$

For all your experiments below try using the bulbs on *a wooden base* (bulbs on a plastic base might draw higher current which might be too high for the battery to produce, which affects the brightness). If needed, share the equipment with your fellow classmates.



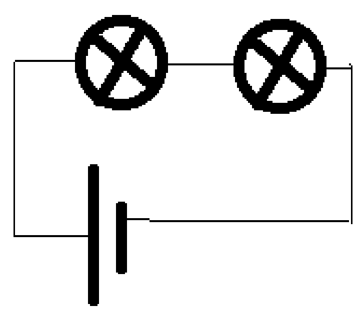
10. Connect a bulb to a battery as shown in the picture on the right. Predict what will happen to the brightness of the bulb if you connect another bulb (identical with the first one) in *series* with the first bulb. Explain your prediction.

11. Connect another bulb (identical with the first one) in series with the first bulb, and check your prediction.



12. Connect a bulb to a battery as shown in the picture on the right. Predict what will happen to the brightness of the bulb if you connect another bulb (identical with the first one) in *parallel* with the first bulb. Explain your prediction.

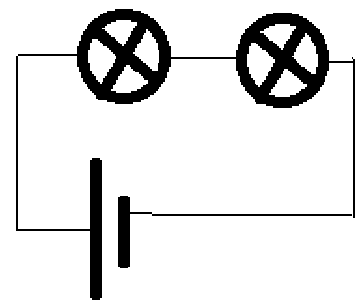
13. Connect another bulb (identical with the first one) in parallel with the first bulb, and check your prediction.



14. Connect two identical bulbs to a battery as shown in the picture on the right. Predict what will happen to the brightness of the bulbs if you connect the third bulb (identical with the two) in parallel with the first bulb. Your goal is to compare the brightness of the same bulb before and after the third bulb was connected. Explain your prediction.

15. Connect the third bulb in parallel with the first bulb and check your prediction.

16. Connect two identical bulbs to a battery as shown in the picture on the right. Predict what would happen to the brightness of the bulbs if you connect another bulb (identical with the first and second) in parallel with the battery (assume the battery is ideal). Your goal is to compare the brightness of the same bulb before and after the third bulb was connected. Explain your prediction.



17. Connect the third bulb in parallel with the battery, and check your prediction.

Equipment

Lab 3:
Part 1 (12 tables): Computers
Part 2 (12 tables): Ohm's Law Apparatus; Computers; 3 identical light bulbs, two multimeters (or one multimeter and LabPro probes), a 6 V battery, wires.

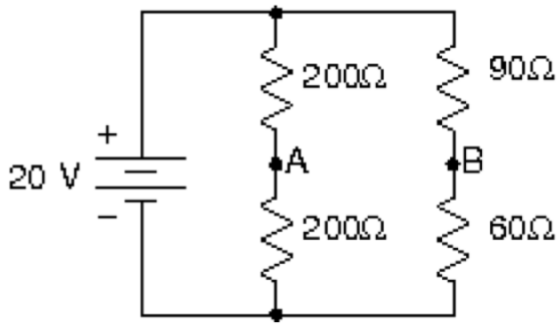
Unit layout

L3: 140 min

PE3: 60 min

Breaks when needed

Practice Exercise 3:



For the circuit on the left:

1. Calculate the electric current flowing through point A, describe its direction.

2. Calculate the electric current flowing through point B, describe its direction.

3. Set the potential of the negative terminal/electrode of the battery to 0 V and calculate electric ***potential*** at points A, and B.

4. Calculate the total/equivalent resistance of the circuit.

5. Redraw the circuit by connecting points A and B with an ideal wire and calculate the new total/equivalent resistance of the circuit.

6. For the new circuit find the current through the battery.