

Concepts of this Module

In this module, we will explore concept involving capacitors, including:

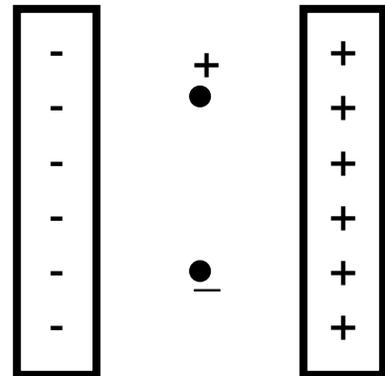
- The electric field inside a capacitor
- Potential and kinetic energy of charged particles inside a capacitor
- Charging and discharging capacitors
- RC circuits

The Activities



Course Concepts Activity 1

Positive and negative test charges are placed inside a parallel plate capacitor as shown. These test charges interact only with the capacitor. Their presence does not alter the field of the capacitor, nor do they interact with each other.



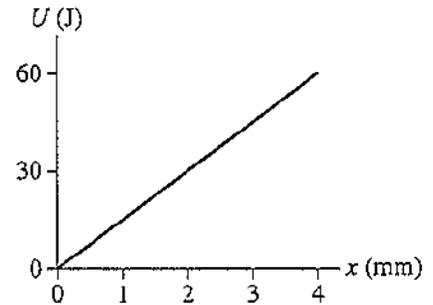
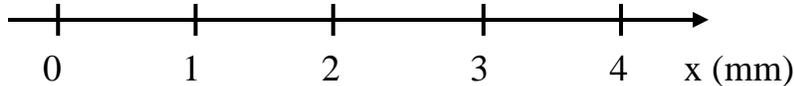
- An enlarged version of the diagram shown to the right is provided at the end of this module. Tear off the page and staple it into your lab notebook. Use a **black** pen or pencil to draw the electric field vectors due to the capacitor inside the capacitor on that enlarged version.
- Use a **red** pen or pencil (if available) to draw the forces acting on the two charges.
- Pick a point of your choosing for the zero of potential energy. Label it “ $U = 0$ ” on the diagram.
- Is the potential energy of the positive point charge positive, negative, or zero? Explain.
- In which direction (right, left, up, or down) does the potential energy of the positive charge decrease? Explain.
- In which direction will the positive charge move if it is released from rest? Use the concept of energy to explain your answer.
- Does your answer to part F agree with the force vector that you drew in part B?
- Repeat steps D to G for the negative point charge.



Course Concepts Activity 2

The figure to the right shows the potential energy of a positively charged particle in a region of space.

A. What arrangement of source charges is responsible for this potential energy? Draw the source in your lab notebook using the axis given below.



B. With what kinetic energy should the charged particle be launched from $x = 0$ mm to have a turning point at $x = 3$ mm? Explain.

C. How much kinetic energy does the charged particle of part B have as it passes $x = 2$ mm?



Expt Activity 3 - Measuring Capacitance

The unit of capacitance is the Farad, F, named after Michael Faraday. One Farad is equal to one Coulomb/Volt. As you will demonstrate shortly, one Farad is a very large capacitance for a conventional capacitor (see discussion in Appendix). Thus actual capacitances are often expressed in smaller units with alternate notation:

$$\begin{aligned} \text{microfarad:} & \quad 10^{-6} = 1 \mu\text{F} \\ \text{nanofarad:} & \quad 10^{-9} = 1 \text{nF} \\ \text{picofarad:} & \quad 10^{-12} = 1 \text{pF} \end{aligned}$$

Typically, there are several types of capacitors used in electronic circuits, including disk capacitors, foil capacitors, electrolytic capacitors, and so on. You might want to examine some typical capacitors. To do this, you'll need:

- 4 capacitors (assorted collection)

A. What is the capacitance of these four capacitors?

To complete this activity, you will need to construct a parallel plate capacitor and use a multimeter to measure capacitance. You will use the following items:

- 2 pieces of thin aluminum sheet or aluminum foil, $15 \text{ cm} \times 15 \text{ cm}$
- 1 textbook
- 1 multimeter with capacitance-measuring capability
- 2 insulated wires

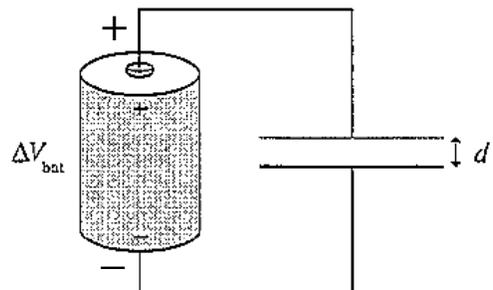
- 1 ruler
- 1 Vernier caliper

You can make a parallel plate capacitor out of two rectangular sheets of aluminum foil separated by pieces of paper. A textbook works well as the separator for the foil since you can slip the two foil sheets between any number of sheets of paper and weight the book down with something heavy and non-conducting like another massive textbook. You can then use your digital multimeter in its capacitance mode for the measurements. Notes:

- Insert the wires into the capacitance slots of your multimeter as “probes”. When you measure the capacitance of your “parallel plates”, be sure that the aluminum sheets arranged carefully so they don’t touch each other and “short out”.
 - Paper acts differently than air when separating the plates of a parallel plate capacitor. For this experiment, you should have paper separating the plates over their entire area, for consistency.
 - To change the “effective area” of your parallel plate capacitor, you could change the amount of area over which the two plates overlap.
- B. Devise a way to measure how the capacitance depends on the foil area and on the separation between the foil sheets. (i) First, hold the area constant and do a series of measurements while varying the separation. (ii) Then hold the separation constant and do a series of measurements while varying the area. In both cases, be sure to record the dimensions of the foil so you can calculate its area, and record the distance between the foil sheets. Take at least five data points in each case. Describe your methods and then create a data table with proper units and display a graph of the results for each case.
- C. Can straight lines be drawn through the data in your graphs? If not, you should make a guess at the functional relationship that your data set represents and create a model that matches the data. Draw a corresponding graph and compare it with your graph in part A for each case. Be sure to label your graph axes properly. Can you explain your results based on physical reasoning?
- D. Use the ohmmeter to measure the resistance of a page in your textbook. What is its resistance? Can current flow through the pages of your book?

Course Concepts Activity 4

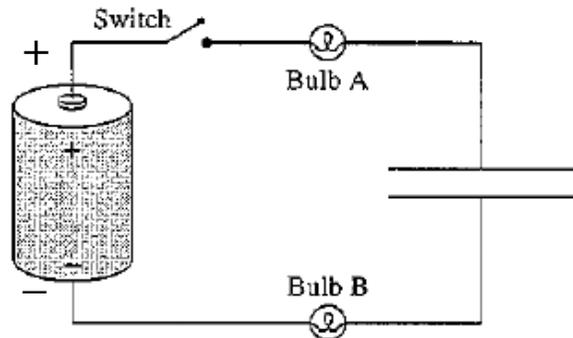
A parallel plate capacitor with plate separation d is connected to a battery that has potential difference ΔV_{bat} , as shown. Without breaking any of the connections, insulating handles are used to increase the plate separation to $2d$.



- A. Does the potential difference ΔV_C across the capacitor change as the separation increases? If so, by what factor? If not, why not?
- B. Does the capacitance C change? If so, by what factor? If not, why not?
- C. Does the capacitor charge Q change? If so, by what factor? If not, why not?
- D. As the plates are being pulled apart, does current flow clockwise, counterclockwise, or not at all? Explain.


Course Concepts Activity 5

Light bulbs can be used to indicate current flow in a circuit. The brightness of a bulb increases with increasing current passing through it. The figure shows a battery, a switch, two light bulbs, and a capacitor that is initially uncharged.



- Immediately after the switch is closed, are either or both bulbs glowing? Explain.
- If both bulbs are glowing, which is brighter? Or are they equally bright? Explain.
- For any bulb (A or B or both) that lights up immediately after the switch is closed, does its brightness increase with time, decrease with time, or remain unchanged? Explain.


Expt Activity 6 - Capacitors, Batteries, and Light bulbs

Now let's do an experiment using capacitors, batteries, and light bulbs to see what happens to the current flowing through a resistor (the bulb) when a capacitor is charged by a battery and then discharged. You are provided with two light bulbs (6V 1W and 6V 3W), two capacitors (0.47 F and 1 F), and a 6 V battery. The capacitors are built using nanotechnology and are called *supercapacitors*; further information appears in the Appendix to this Guide.

- Connect the 6V 1W light bulb (the elongated one) in series with the 0.47 F capacitor, a switch, and the 6 V battery. Draw a circuit diagram of your setup. Describe what happens when you close the switch.
- Now, can you make the bulb light up again without the battery in the circuit? Mess around and see what happens. Describe your observations and draw a circuit diagram showing the setup when the bulb lights up without a battery.
- Repeat parts A and B with a voltmeter across the capacitor. Draw a rough sketch of the voltage across the capacitor as a function of time for both cases.
- Draw a sketch of the approximate brightness of the bulb as a function of time when it is placed across a charged capacitor without the battery present. Let $t = 0$ when the bulb is first placed in the circuit with the charged capacitor. Note: You can examine the change in the current is by wiring an ammeter in series with the bulb.
- Explain what is happening. Is there any evidence that charge is flowing between the plates of the capacitor as it is charged by the battery with the resistor (the bulb) in the circuit, or as

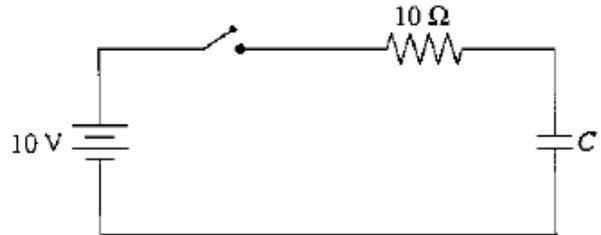
it discharges through the resistor? Is there any evidence that charge is not flowing through the capacitor? Hints: (1) You may want to repeat the observations described in parts A and B several times; placing the voltmeter across the capacitor or placing an ammeter in series with the capacitor and bulb in the two circuits you have devised might aid you in your observations. (2) Theoretically, how should the voltage across the capacitor be related to the amount of charge on each of its conductors at any given point in time?

- F. What happens when more capacitance is put in the circuit? What happens when more resistance is put in the circuit? You can use the 6V 3W light bulb (the rounded one) in the circuit to get more resistance. Hint: Be careful how you wire the extra capacitance and resistance in the circuit. Does more capacitance result when capacitors are wired in parallel or in series? How should you wire resistors to get more resistance?

Course Concepts Activity 7

The charge on the capacitor shown in the figure is zero when the switch closes at $t = 0$ s.

- A. What will be the current in the circuit after the switch has been closed for a long time? Explain.
- B. Immediately after the switch closes, before the capacitor has had time to charge, the potential difference across the capacitor is zero. What must be the potential difference across the resistor in order to satisfy Kirchoff's Loop Law? Explain.
- C. Based on your answer to part B, what is the current in the circuit immediately after the switch closes?
- D. Sketch a graph of current versus time, starting from just before $t = 0$ s, and continuing until the switch has been closed a long time. There are no numerical values for the horizontal axis, so you will have to think about the shape of the graph.

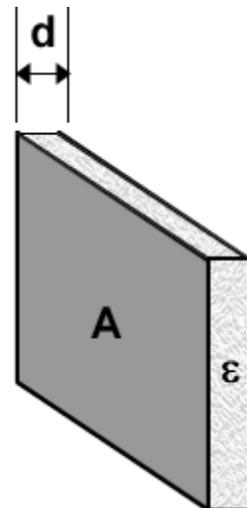


Appendix – Supercapacitors

For a parallel plate capacitor with each plate having a surface area A , the plates separated by a distance d , and the space between the plates filled with a dielectric of constant ϵ , the capacitance C is:

$$C = \epsilon \frac{A}{d}$$

So there are three ways to increase the capacitance:



1. Use a dielectric with a higher constant.
2. Increase the surface area of the plates
3. Decrease the distance between the plates.

If the space between the plates is air and the plates are separated by 1 mm, then a 1 Farad capacitor must have a plate surface area of about 10^8 m^2 . For square plates this means the plates must be $10 \text{ km} \times 10 \text{ km}$.

Supercapacitors use *nanotechnology* to achieve extremely high effective surface areas. Often highly porous carbon is used, which can achieve effective areas of as much as 2000 m^2 per gram. Although the basic idea was known as early as 1957, it is only since the mid-1990's that advances in material science have led to reliable inexpensive supercapacitors.

Over time chemical redox reactions can occur on the electrodes which will degrade performance, and some manufacturers minimize this effect by making the two electrodes somewhat differently. Thus supercapacitors have their two terminals marked to indicate which is positive and which is negative. Some other more conventional capacitors, such as electrolytic types, also have a polarity. Using the correct polarity for supercapacitors extends their life somewhat but is not terribly important for our purposes. Electrolytic capacitors can explode if they are wired incorrectly.

This Guide was written in December 2007 by Kimberly Strong, Dept. of Physics, Univ. of Toronto. The Appendix was written by David M. Harrison, Dept. of Physics, Univ of Toronto in February 2008.

The activities are based on Randall D. Knight, **Student Workbook** (Pearson, 2004) and Priscilla W. Laws, **Workshop Physics Activity Guide, Module 4: Electricity and Magnetism** (John Wiley & Sons, 2004).

First version: December 11, 2007.

Last revision: March 12, 2010 by Jason Harlow.

Enlarged version of the diagram in Activity 1

