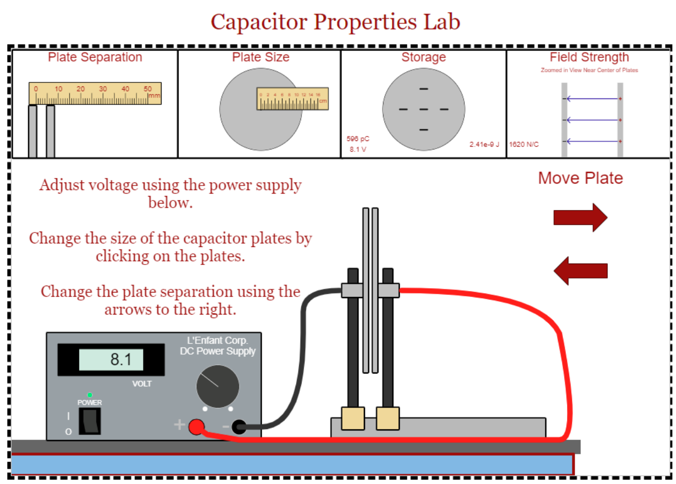
Experiment: Parallel Plate Capacitors

Objectives

- To explore how the capacitance of conducting parallel plates is related to the separation distance between the plates and the surface area of the plates.
- To determine the permittivity in free space, ε_o

Materials

- Computer with internet access
- LoggerPro software



Screenshot from ThePhysicsAviary.com

Capacitors are widely used in electronic circuits where it is important to store charge and/or energy or to trigger a timer electrical event. For example, circuits with capacitors are designed to do such diverse things as setting a flashing rate of Christmas lights, selecting what station a radio picks up, and string electrical energy to run an electronic flash unit. Any pair of conductors that can be charged electrically so that one conductor has positive charge and the other conductor has an equal in magnitude, negative charge on it is called a capacitor.

A capacitor can be made up of two arbitrarily shaped blobs of metal or it can have any number of regular symmetric shapes such as one hollow sphere inside another, or a metal rod inside a hollow cylinder (see the figure below). The type of capacitor that is easiest to analyze is the parallel plate capacitor. We will focus exclusively on the study of the properties of parallel plate capacitors because the behavior of such capacitors can be predicted using only simple mathematical calculations and basic physical reasoning. Also, parallel plate capacitors are easy to construct.

When a parallel-plate capacitor holds an amount of electric charge (q), it will support an electric potential difference (V) across the two parallel, conducting plates. The magnitude of the voltage difference across the plates is proportional to the magnitude of stored charge:

$$V = V_+ - V_- = \frac{qL}{\varepsilon_o A}$$

where ε_o is the permittivity in free space, $8.85 \times 10^{-12} C^2/N{\cdot}m^2$. For an air-filled, parallel-plate capacitor, the ratio of stored charge to electric potential difference across the plates is called the capacitance (or C):

$$C = \frac{q}{V}$$

Substituting for V from above yields the relationship between C and the physical properties of the capacitor: the permittivity in free space, the inner plate surface area (A), and the distance between the inner plate surfaces (L):

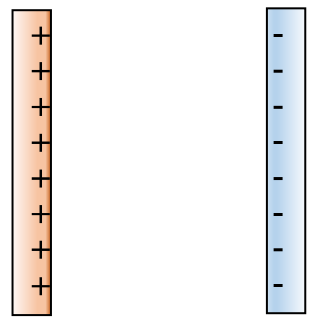
$$C = \frac{\varepsilon_o A}{L}$$

Conceptually, capacitance can be considered a measure of capacity of two separated conductors to store electric charge per unit voltage. The SI unit for capacitance is the farad (F). Can you identify the farad in terms of the SI units C, N, and m? Try it.

1F = __________

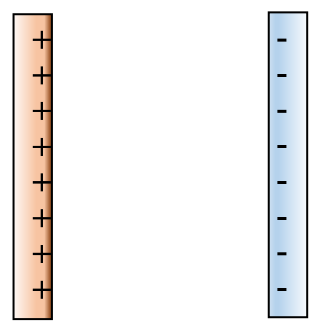
Preliminary questions:

1. Consider parallel plate capacitor (air filled) with a surface area of 225.0cm^2 and a charge of 1.5μC (q) on each of its plates and a plate separation distance of 1.0x10^{-4}m.



a. Calculate the voltage difference field between the plates.

b. Determine the capacitance.



2. Consider charged, parallel plate capacitor (air-filled) with a surface area of 125.5cm^2 and a plate separation distance of 5.7x10^{-5}m. The voltage difference between the plates is 1.5V.

a. Determine the capacitance.

b. Calculate the magnitude of charge (q) that resides on the inner surface of either plate.

Part 1: *Capacitance vs Separation Distance*

1. Open the Phet Physics simulation:
   https://www.thephysicsaviary.com/Physics/Programs/Labs/CapacitorPropertiesLab/
2. Record the plate radius then calculate the surface area of the plates Table 1.
3. Adjust the plate separation distance to the lowest setting.
4. Record the distance and stored charge in Table 1.
5. Repeat step 4, for a total of seven data points, increasing the separation distance by approximate increments of 5.0mm.

Table 1: *Capacitance vs Separation Distance*				
Voltage		**Separation Distance**	**Stored Charge**	**Capacitance**
Radius	**Surface Area**			
Fit Equation:				
Fit Constant A				
Fit Constant B				

6. Use stored charge and voltage to calculate the capacitance for each of your data points.
7. Use LoggerPro to create a graph of capacitance vs separation distance.
8. Fit the graph to an appropriate best fit equation and record the fit constants (with ±standard deviations for the fit).
9. Evaluating your graph of capacitance vs distance, explain the physical significance of the fit constants obtained from the fit.

10. Using your calculated fit constants, calculate the permittivity constant (in free space), ε_o and % Error with the accepted value. Show your calculations.

Part 2: *Capacitance vs Surface Area*

1. Set the separation distance between the plates to 2.0mm then record the value Table 2.
2. Adjust the plate area to the lowest setting.
3. Record the plate radius, surface area, and stored charge in Table 2.
4. Repeat step 3, with increasing the plate area, for a total of six data points.

Table 2: *Capacitance vs Surface Area*

Voltage		**Radius ( )**	**Plate Area ( )**	**Stored Charge ( )**	**Capacitance ( )**
Separation Distance					
Fit Equation:					
Fit Constant A					
Fit Constant B					

5. Calculate the capacitance for each data point. Record values in Table 2.

6. Use LoggerPro to create a capacitance vs plate area.
7. Fit the graph to an appropriate best fit equation and record the fit constants (with ±standard deviations for the fit).
8. Evaluating your graph of capacitance vs plate area, explain the physical significance of the fit constants obtained from the fit, in terms of Equation 1.

9. Using your calculated fit constants, calculate the permittivity constant (in free space), ε_o and % Error with the accepted value. Show your calculations.

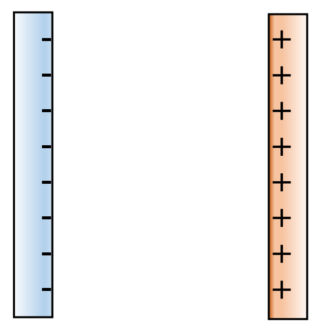
Final Questions:

1. Suppose have a charged, parallel-plate capacitor, with the power supply unattached.
   a. How would you expect increasing or decreasing the spacing between the plates would affect the electric field within the capacitor?

   b. How would you expect increasing or decreasing the separation between the plates would affect the electric potential difference across the capacitor?

   c. Use the capacitor simulation to check your answers. Disconnect the power supply by left-clicking the on/off switch. Do your observations agree with your previous predictions? Why or why not?

2. Consider charged, parallel-plate capacitor (air filled) consisting of two flat, circular plates (radius=12.0cm) and separation distance of 20.0cm, with a stored charge (q) of 120pC on each of its plates.



   a. Calculate the electric field magnitude between the plates and corresponding voltage difference between the plates.

   b. The spacing between the plates is then doubled.
      i. What is the electric field between the plates?

      ii. What is the voltage across the capacitor?

3. Summarize what you learned during this experiment. List at least three things.