Name______________________________________ Section_____________ Date__________

CONCEPTUAL PHYSICS · Hewitt/Baird | **Tech Lab**

The Two-Plate Special

Purpose
To learn the characteristics and relationships that govern parallel-plate capacitors

Apparatus
computer PhET simulation, "Capacitor Lab" (available at http://phet.colorado.edu)

Discussion
The flash of a camera and the jolt provided by a heart defibrillator require sudden bursts of electric energy. The relatively small batteries used in these devices could not supply such bursts without the use of capacitors. Capacitors are devices that store energy in the form of an electric field. This energy can be delivered to an electric circuit very rapidly.

The field is typically produced by separating opposite charges on two parallel plates. To understand capacitors, we must examine the process in detail.

Procedure

PART A: CAPACITANCE

Step 1: Start the computer and allow it to complete its startup process.

Step 2: Launch the PhET simulation, "Capacitor Lab." If you need assistance, ask your instructor for help.

The simulation opens showing two parallel, conducting plates connected to a battery. In the Control Panel, the View: Plate Charges option is selected.

Step 3: Notice that the battery has a variable voltage. Move the voltage slider up and down and observe the effect. Set the voltage slider so that 9 charges appear on each plate.

Once a particular voltage is set, a corresponding amount of charge appears on each plate.

To move charge from one plate to another, the battery must exert a ***force*** on that charge. The force must act through a ***distance***.

In other words, the battery must do ________________________________ on the charge, and the

amount of ________________________________ a battery can do depends—in part—on its voltage.

Step 4: From the Meters section of the Control Panel, activate the plate charge meter.

a. Which plate does the plate charge meter show the charge of? _____Top _____Bottom

b. The color used to represent positive charge is ________________________________

The color used to represent negative charge is ________________________________

Step 5: Vary the battery voltage (V) and observe the plate charge (Q). Which proportionality corresponds to your observations?

_____Q ~ V _____Q ~ 1/V

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Step 6: From the Meters section of the Control Panel, activate the capacitance meter. Leave the plate charge meter activated. Set the battery to maximum voltage.

With voltage held constant by the battery, what relationship, if any, can you find between plate charge and capacitance?

Step 7: Use simulator options to monitor capacitance and vary the voltage while plate charge is held constant. (Remember: when the battery is connected, varying the voltage varies the plate charge.)

a. How did you accomplish this?

b. With plate charge held constant, what relationship, if any, can you find between voltage and capacitance?

Step 8: a. Which equation for capacitance (*C*) is consistent with your findings from Steps 6 and 7?

______ $C = QV$ ______ $C = Q/V$ ______ $C = V/Q$

b. Based on your selection above, what is the unit of measure for capacitance? Use only coulombs and volts; write the unit using symbols, and write the unit using words.

c. The abbreviated unit for capacitance is the farad (F) in honor of British physicist, Michael Faraday.

Step 9: Make side-by-side sketches of high and low capacitance plate configurations. (The capacitance meter will measure capacitance even when there is no charge on the plates and no voltage between them.)

High Capacitance Plate Configuration	Low Capacitance Plate Configuration

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Step 10: Which expression below corresponds to your observations regarding capacitance (*C*), plate area (*A*), and separation (*d*)?

______ C ~ Ad　　　______ C ~ A/d　　　______ C ~ d/A

PART B: ENERGY

Step 1: In the Control Panel, click the on-screen Reset All button and confirm your intention. In the Meters section, activate the capacitance meter, the plate charge meter, and the voltmeter.

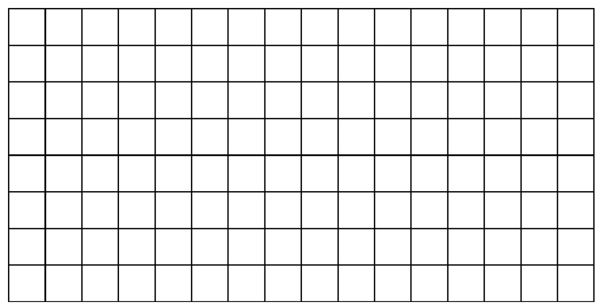
Step 2: Move the voltmeter probes to the upper and lower right corners of the wire connecting the battery to the plates. Make sure the voltmeter is properly connected by varying the voltage on the battery and observing the corresponding variation on the voltmeter. Leave the battery voltage set to 0.00 V.

Step 3: Arrange the area and separation of the parallel plates so that their capacitance is 0.5 picofarads (0.5 pF = 0.5×10^{-12} F).

Step 4: Complete the table below. Set the voltage values on the table and record the plate charge that corresponds to that voltage. Note the plate charge is expressed in the table with units of 10^{-12} C. (If you can't get the exact voltage value listed, use a nearby value. But use a value that ends in an even number.)

Voltage V (V)	Plate Charge Q ($\times 10^{-12}$ C)
0.00	0
0.20	
0.44	
0.70	
0.96	
1.34	
1.50	

Plate Charge vs. Voltage



Step 5: Complete the Plate Charge vs. Voltage graph above. Plot the points from your data table. Make a line of best fit. Don't forget to label the axes of the graph.

Step 6: Interpret the slope.

a. Calculate the value of the slope of the line of best fit. Don't forget to include the units of this slope.

b. What is the meaning of that slope? (Hint: consider the units of the slope.)

Step 7: Interpret the area.

a. Calculate the value of the area under the line of best fit. (Hint: what's the area of a triangle?)

b. What is the meaning of that area? (Hint: consider the units of the area.)

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Step 8: From the Meters section of the Control Panel, activate the stored energy meter and examine the value it shows. What does it mean?

____

Step 9: Which equation below is consistent with your observations and calculations involving stored energy (*W*), plate charge (*Q*) and voltage (*V*) in a capacitor?

______ W = Q/V ______ W = V/Q ______ W = QV/2 ______ W = 2QV

Step 10: Going to Extremes I. Using a battery at full voltage (1.50 V),

a. what is the ***maximum*** energy that can be stored in the plates? ______________________________

b. Describe the corresponding configuration. Discuss the plate arrangement and capacitance, but do so ***qualitatively***, not ***quantitatively.***

____

____

c. What is the ***minimum*** energy that can be stored in the plates? ______________________________

d. Describe the corresponding configuration. Again, limit the discussion to ***qualitative*** terms.

____

____

Step 11: Going to Extremes II. Disconnect the battery. With the plates holding maximum charge (0.53×10^{-11} C = 5.3 pC),

a. what is the ***maximum*** energy that can be stored in the plates? ______________________________

b. Describe the corresponding configuration. Discuss the plate arrangement, voltage, and capacitance, but do so ***qualitatively***, not ***quantitatively.***

____

____

c. What is the ***minimum*** energy that can be stored in the plates? ______________________________

d. Describe the corresponding configuration. Again, limit the discussion to ***qualitative*** terms.

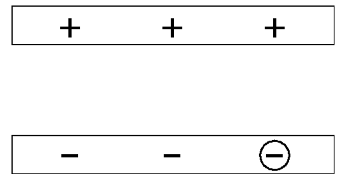
____

____

Summing Up

1. Parallel plates with a ***high capacitance*** can
   _____hold a large charge at high voltage
   _____hold a small charge at high voltage
   _____hold a large charge at low voltage
   _____hold a small charge at low voltage

2. The figure shows a side view of two charged parallel plates.

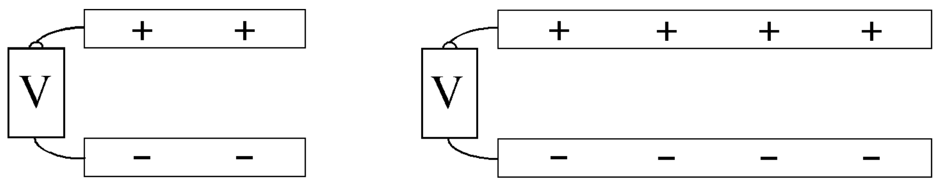


   a. Sketch all five electrostatic forces acting ***on*** the negative charge (circled) at the right end of the negative plate. Notice that some forces repel the negative charge and some attract it. Some act to push it off the edge of the plate; some act to hold it on the plate.

   b. Which forces, those that attract or those that repel, vary with the separation distance between the plates?

   c. A battery can hold more charge on parallel plates when the plates are ___closer ___farther.

3. The figure shows two parallel plate configurations. Both use the same voltage and the plates are at the same separation in both configurations. But one has larger plates.



   A battery can hold more charge on parallel plates when the plates are ___larger ___smaller.

4. a. Write the equation for capacitance in terms of plate charge and voltage. (See Part A, Step 8.)

   b. Write the equation of energy stored in a capacitor in terms of plate charge and voltage.

   c. Use substitution to derive two new equations for energy stored in a capacitor: one in terms of capacitance and voltage, and one in terms of capacitance and plate charge.

5. Examine the equation for the energy stored in the plates in terms of ***charge*** and ***capacitance***. When the voltage was held constant, doubling the plate charge also doubles the capacitance. As a result, the stored energy increased. According to the equation, energy increases with plate charge but decreases with capacitance. Why didn't the increase of both factors simply cancel and leave energy unchanged?

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6. Examine the equation for the energy stored in the plates in terms of ***capacitance*** and ***voltage***. When the charge was held constant, doubling the voltage halved the capacitance. As a result, the stored energy increased. According to the equation, energy varies directly with capacitance ***and*** voltage. Why didn't the increase in voltage and the decrease in capacitance simply cancel and leave energy unchanged?

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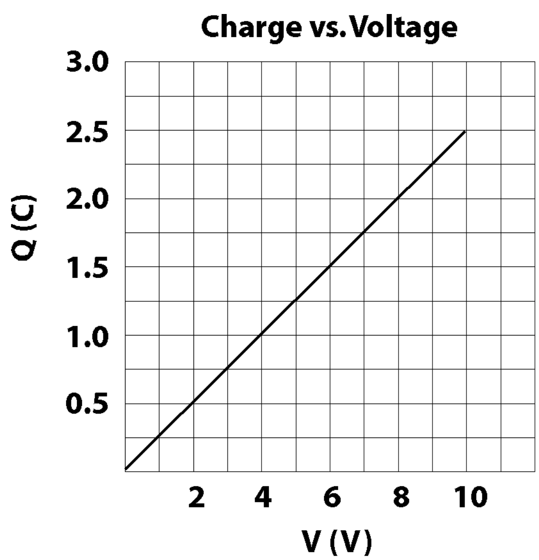
7. Consider parallel plates whose plate charge vs. voltage plot is shown.



a. Determine the capacitance of the plates.

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b. Determine the energy stored in the plates.

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8. A 3600-μF capacitor is connected to a 12-V battery.

a. Calculate the charge separated on the plates.

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b. Calculate the energy stored in the plates.

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9. The capacitor's charge (and stored energy) can be made available to an electric circuit, such as one in an electronic flash or a heart defibrillator. The capacitor can deliver the charge and energy faster than a battery can. A device that uses a great deal of energy in a short interval of time can ***best*** be described as high

___ charge ___ current ___ energy ___ power ___ voltage.

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