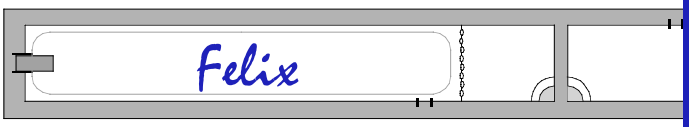
PhyzSpringboard: Capacitance



The flash of a camera and the jolt provided by a heart defibrilator 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.

1. Consider two parallel plates. To transfer charge from one plate to another so that one plate becomes charged positive while the other becomes charged negative, we must do

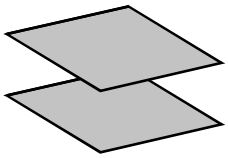
_____work_____ on the charge.

2. What becomes of the _____work_____ we do to separate the charge?

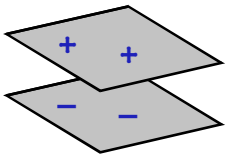
It is stored as electric potential energy.

3. a. As we separate more and more charge, moving additional charge from one plate to another

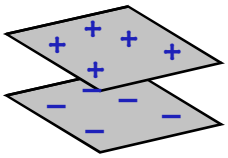
___becomes harder. ___becomes easier. ___maintains a constant level of difficulty.



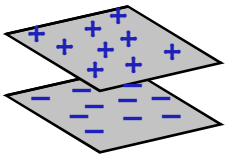
Plates uncharged



Plates slightly charged



Plates more charged



Plates highly charged

b. This is because...

each additional electron moved from the + to the plate is attracted back to the + plate and repelled from the – plate

c. The more accurate mechanical analogy to the work done to separate the charge would be

___lifting a heavy stone ___compressing a stiff spring

4. a. As the battery continues to separate charge on the two parallel plates, what prevents it from moving *all* the charge so that one plate has only positive charge and the other has only negative charge?

The battery is limited by its voltage (the potential difference it can create between its terminals).

b. If a battery with a larger voltage were used, would it separate ___more charge, ___less charge, or ___the same amount of charge?

5. How—if at all—is the amount of charge separated on the plates (Q) related to the voltage of the battery (V)?

___$Q \propto V$ ___$Q \propto 1/V$ ___Q and V are unrelated

6. Not all parallel plates are identical. Some plates are bigger, some are smaller; some are closer together, some are farther apart. Suppose a battery connected to one set of plates separates a large amount of charge but the same battery connected to another set of plates separates only a small amount of charge.

The plates on which the large charge separation occurred have
___a higher capacity (high **capacitance**) than the other plates.
___a lower capacity (low **capacitance**) than the other plates.

7. a. Which expression best represents **capacitance**, denoted with the symbol *C*?
___$C = QV$ ___$C = Q/V$ ___$C = V/Q$

b. Is this expression consistent with the proportionality selected in question 5 above? If so, rewrite the proportionality as an equation.

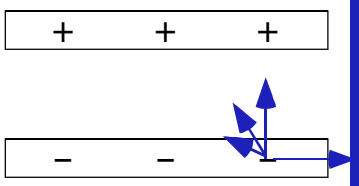
$Q \propto V \Rightarrow V = Q/C \Rightarrow Q = CV$

c. What are the SI units of capacitance and what is the abbreviation for these units?

$C/V = F$

d. A pair of plates with a high capacitance is one that can
___hold a great quantity of charge at a high potential.
___hold a great quantity of charge at a low potential.
___hold a small quantity of charge at a low potential.

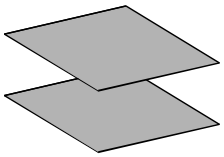
8. Suppose a battery were used to separate charge on two parallel plates. The battery has moved all the charge it can. Sketch the forces acting on the negative charge on the right end of the lower plate.



a. What effect do these forces have on the two plates?
attraction

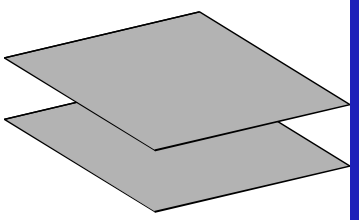
b. What effect do these forces have on the neighboring charges?
repulsion

c. Which forces would be reduced if the plates were moved farther apart? (Check all that apply.)
___Those that cause the plate charges to attract.
___Those that cause the plate charges to repel.



CAPACITOR CHARACTERISTICS

9. a. What will be the effect of increasing the area of the plates?
___More charge can be stored at the same potential.
___Less charge can be stored at the same potential.
___The same amount of charge can be stored.



b. Why? Discuss the forces involved.

neighboring charges repel; more area means the same number of charges would have more space.

c. Determine the amount of charge that can be separated in terms of the potential difference of the battery, the area of the plates, and the distance between the plates. Hints: consider the relationship between the voltage, electric field, and distance, then consider the relationship between the uniform electric field, charge, area, and distance.

$V = Ed$ $E = 4\ kQ/A$

$V = 4\ kQd/A$

$Q = VA/4\ kd$

d. Examine the equation from part c above. With constant potential and distance and increased plate area,

___more charge can be stored.
___less charge can be stored.
___the same amount of charge can be stored.

10. a. What will be the effect of increasing the distance between the plates?

___More charge can be stored.
___Less charge can be stored.
___The same amount of charge can be stored.

b. Why? Discuss the forces involved.

The weakening of the attraction that keeps charges in place.

c. Examine the equation from part c of number 9 above. With constant voltage and area and increased plate separation,

___more charge can be stored.
___less charge can be stored.
___the same amount of charge can be stored.

d. Another way to increase the capacitance of a set of parallel plates is to place a sheet of a dielectric (insulating) material between the plates. But that's a story for another course.

11. a. Summarize your findings regarding plate area and separation distance.

___$C \propto Ad$ ___$C \propto A/d$ ___$C \propto d/A$

b. Describe the characteristics of a high capacitance capacitor.

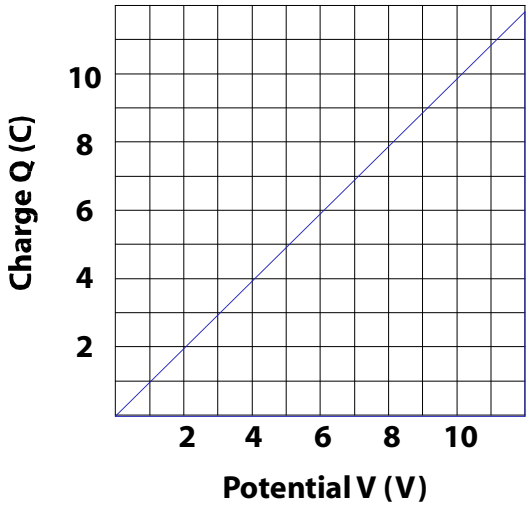
large surface area and small separation distance.

c. A constant of proportionality, ε_0, turns this proportionality into an equation. The constant is called the **permittivity of free space.** Rewrite the proportionality as an equation.

$C = \varepsilon_0 A/d$

ENERGY STORAGE

12. Suppose a variable voltage power supply were used to charge a 1.0 F capacitor. What would happen as the voltage was increased from 0 to 12 V?



a. Describe the result and plot it on the axes to the right.

b. What is the area bounded by the plot?

i. Write an equation.

$A = VQ/2$

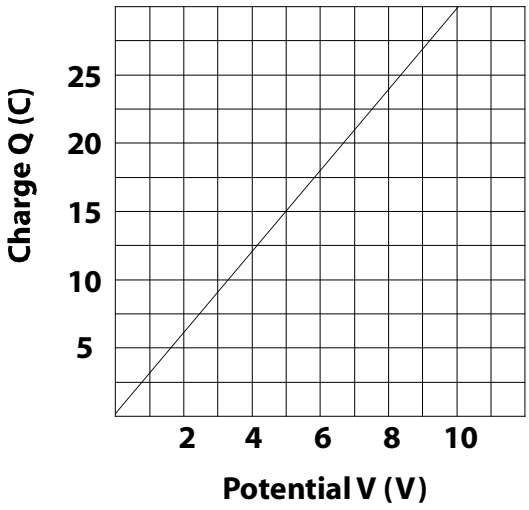
ii. Calculate the area. Don't forget the units.

$A = 12\ V \cdot 12\ C\ /\ 2 = 72\ J$

c. What does that area represent?

Electric potential energy stored

d. Another capacitor is charged with a variable voltage power supply. It yields the plot shown to the right.



i. What is the capacitance of the capacitor?

$Q/\ V = Q/V = C = 3F$

ii. How much electrical energy is stored in the capacitor?

$VQ/2 = 10\ V \cdot 30\ C\ /\ 2 = 150\ J$

e. Use the expression from question 7 to write two more independent forms of the equation from part b above.

$W = QV/2 = CV^2/2 = Q^2/2C$

13. 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 defibrilator. 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 voltage. ___high amperage. ___high charge.
___high energy. ___high wattage. ___high capacitance.