Lecture 11

Chapter 26

Capacitance

Set #3, Problem #4

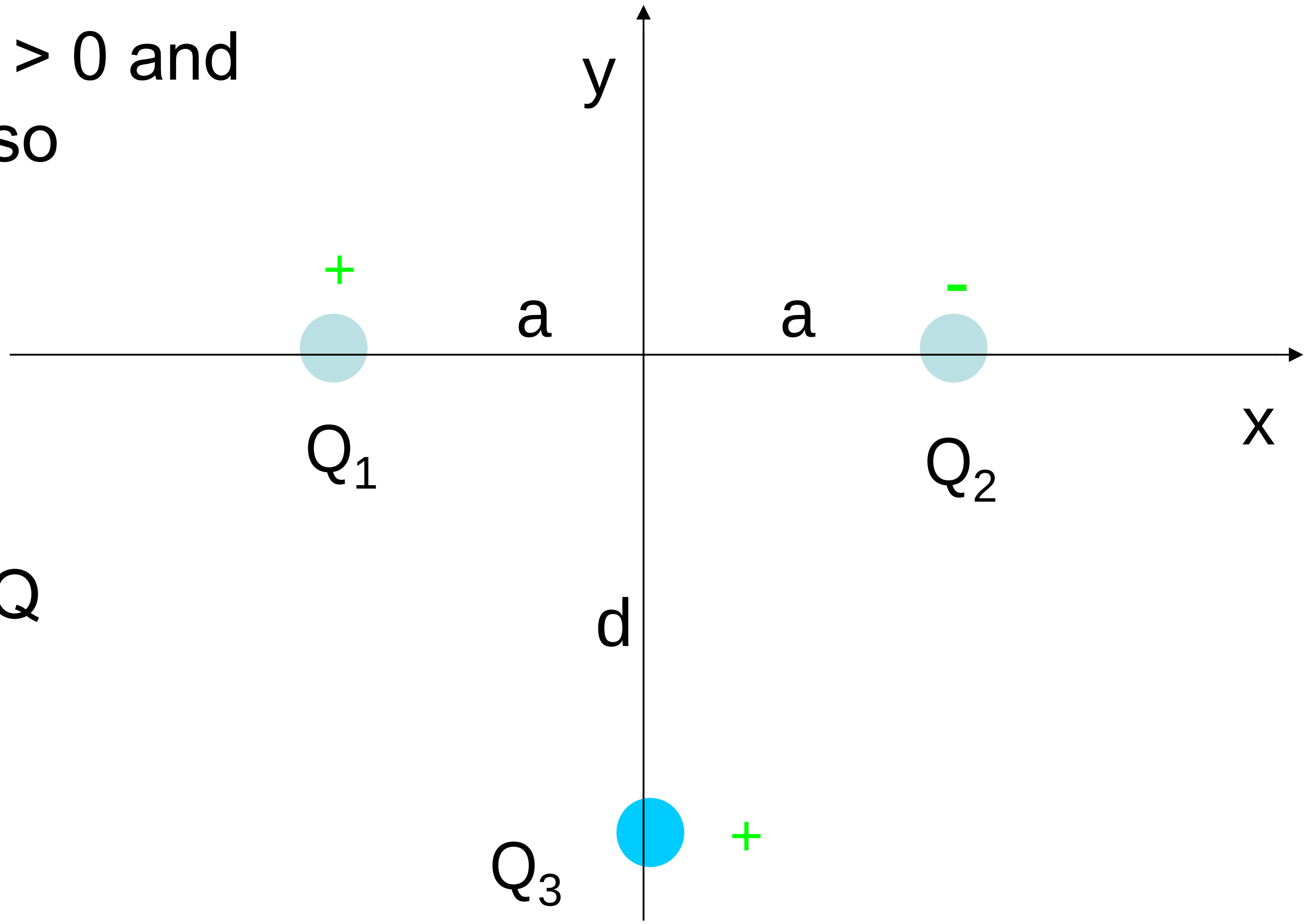
- Let Q_1, $Q_3 > 0$ and $Q_2 = - Q_1$ so

Q_1 is +

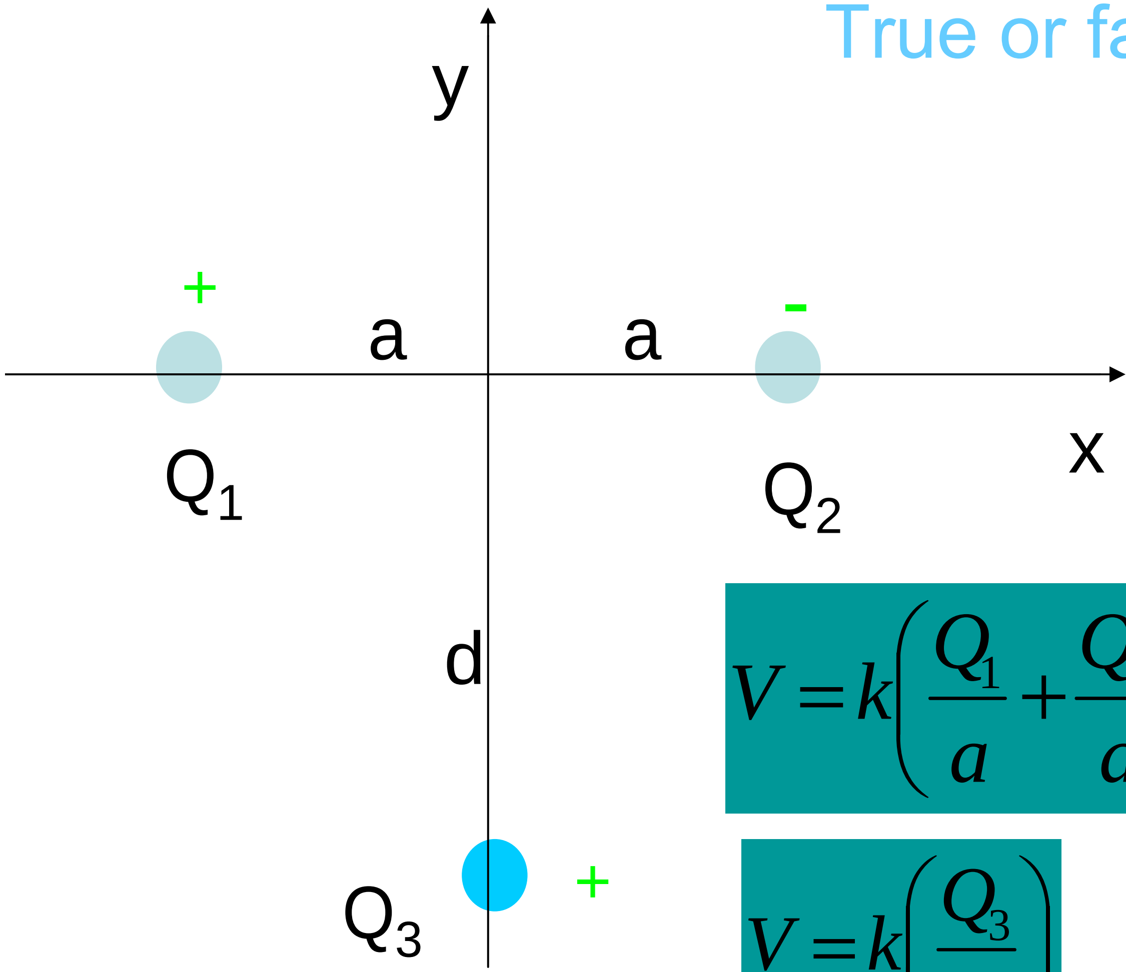
Q_3 is +

Q_2 is -

$Q_1 = Q_2 = Q$



Set #3, Problem #4



True or false: *V* at (0,0) is zero

FALS
E

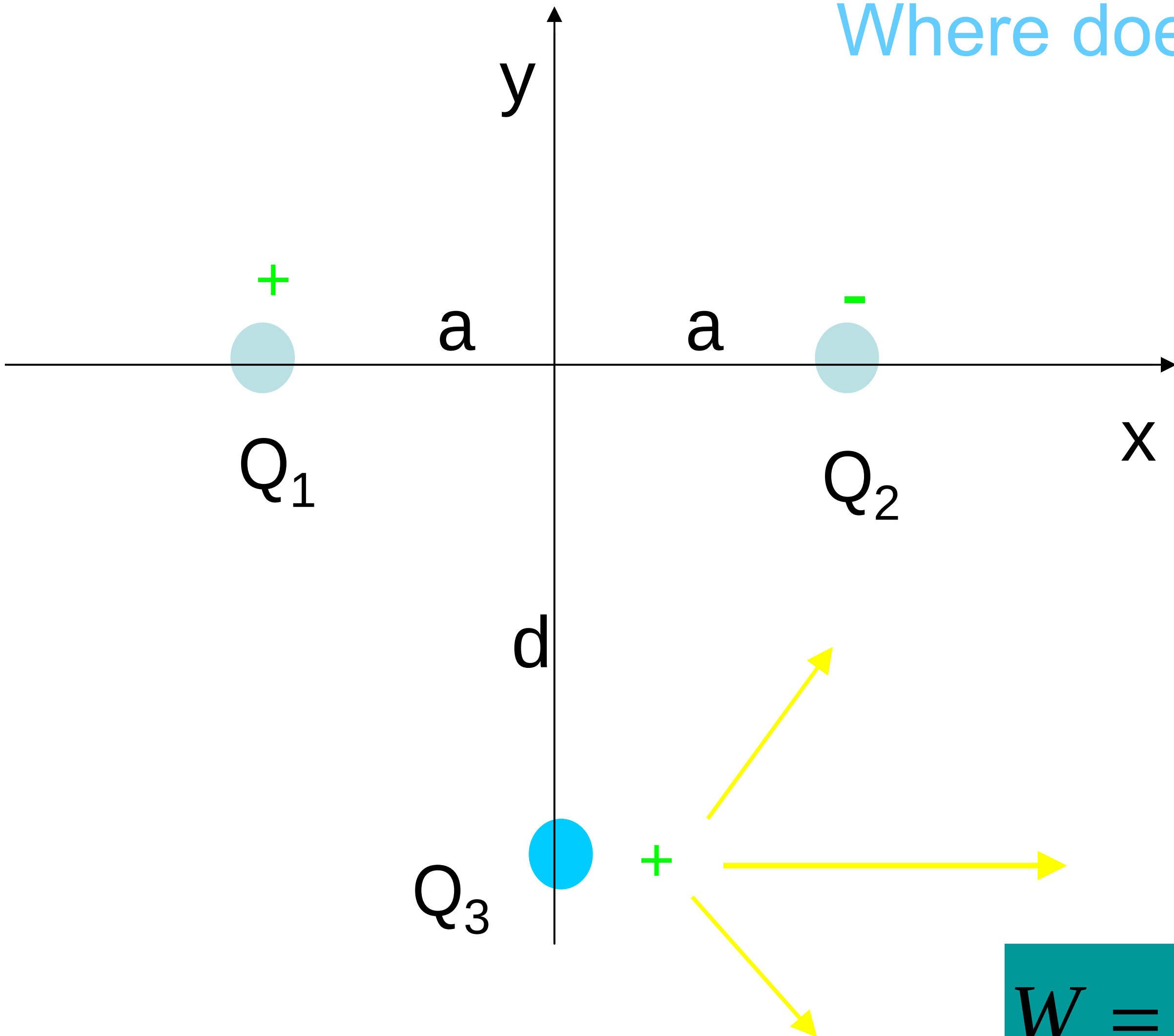
$$V = \sum_{1}^{n} V = k\left(V_1 + V_2 + V_3\right)$$

$$V = k\left(\frac{Q_1}{a} + \frac{Q_2}{a} + \frac{Q_3}{d}\right) = k\left(\frac{Q}{a} - \frac{Q}{a} + \frac{Q_3}{d}\right)$$

$$V = k\left(\frac{Q_3}{d}\right)$$

V is + for any position along y-axis

Set #3, Problem #4



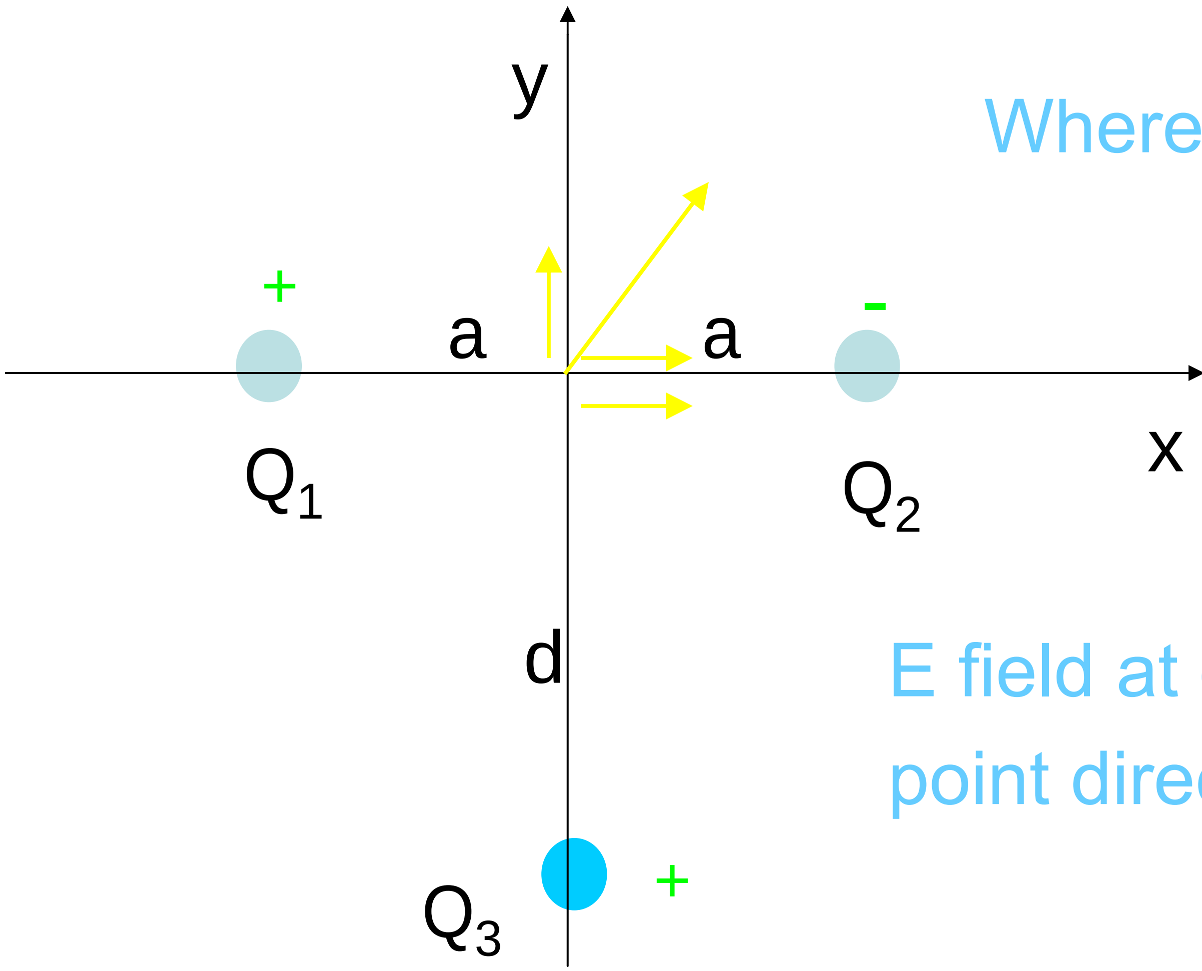
Where does *F* point at Q_3?

It is TRUE that:

- Q_3 will accelerate to right
- F_y on Q_3 due to other charges is zero
- W to move Q_3 to origin is zero

$$W = \vec{F} \bullet \vec{d} = Fd\cos(90)$$

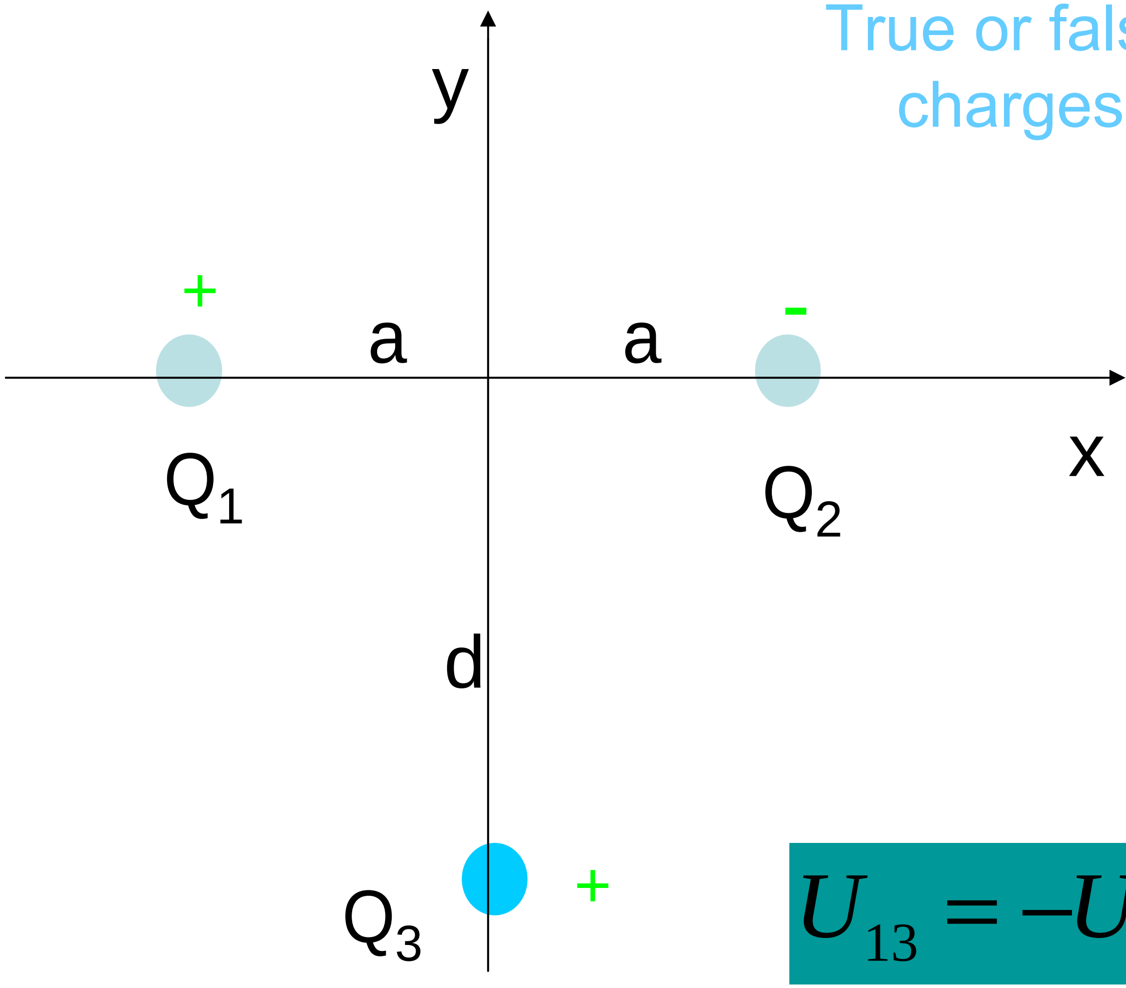
Set #3, Problem #4



Where does *F* point at 0?

E field at origin does not point directly away from Q_1

Set #3, Problem #4



True or false: External work to bring charges together is negative

True

$$W = \Delta U = k\frac{qq'}{r}$$

$$U = U_{12} + U_{13} + U_{23}$$

$$U_{13} = -U_{23}$$

$$U_{12} = k\frac{Q(-Q)}{2a}$$

Capacitance (23)

- Parallel-plate capacitor charged to potential V by battery
- Disconnect battery to have isolated system
- If decrease distance, d, between the plates what happens to C ?

LARGER

- What happens to V ?

Isolated system q stays same so V decreases if C increases

$$C = \frac{\varepsilon_0 A}{d}$$

$$q = CV$$

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

Capacitance (24)

- What happens if put material between the plates?

- Will the capacitance of the plates increase or decrease?

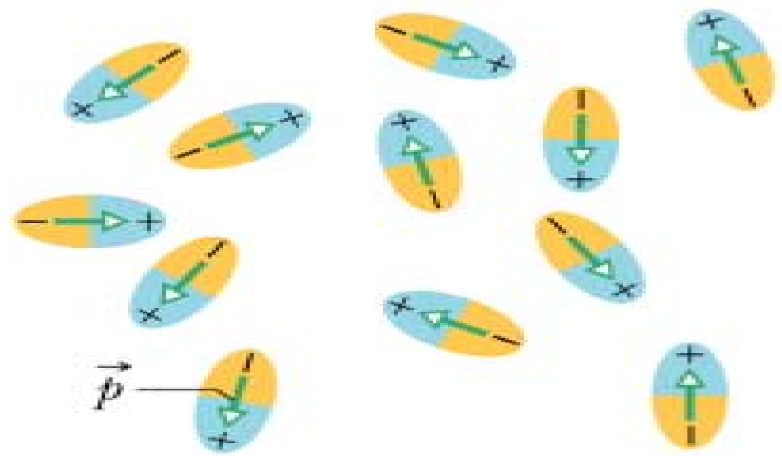
$$C = \frac{q}{V}$$

V decreases so *C* increases

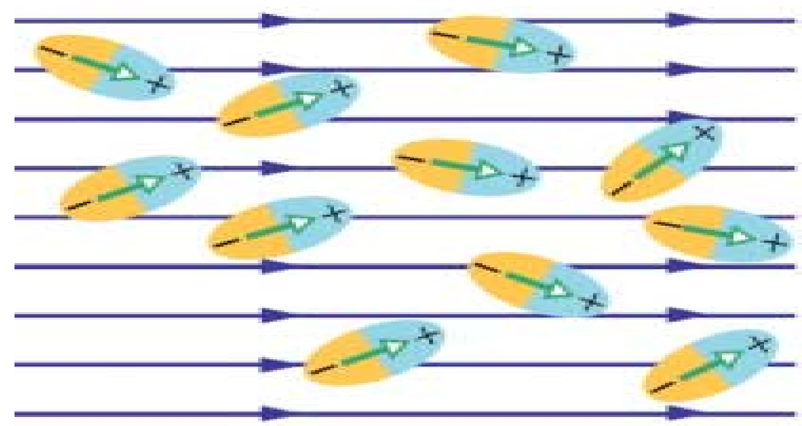
Capacitance (25)

- Why does C increase if add material?

- Material made up of molecules which are dipoles
- Molecules align with E field from capacitor



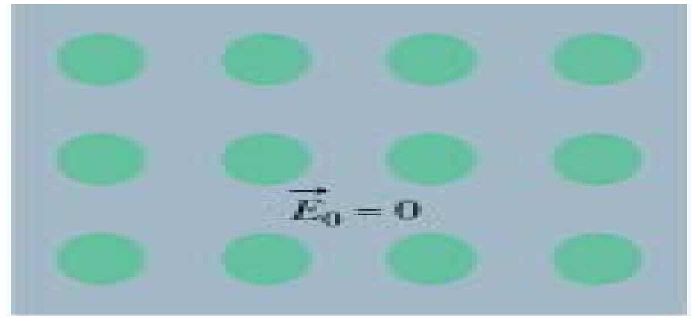
(a)



(b)

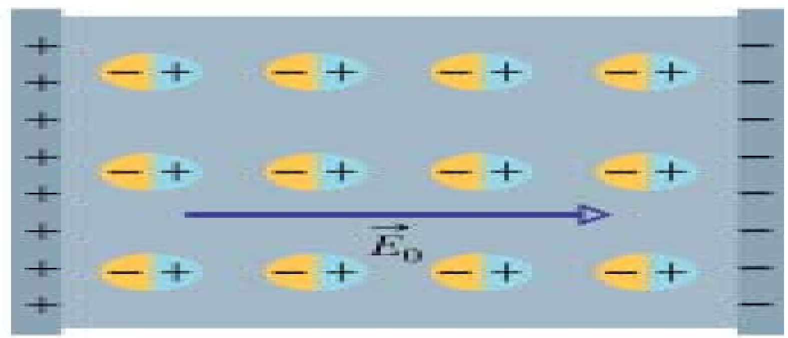
Capacitance (26)

- Dipoles set up *E* field which opposes capacitors *E* field



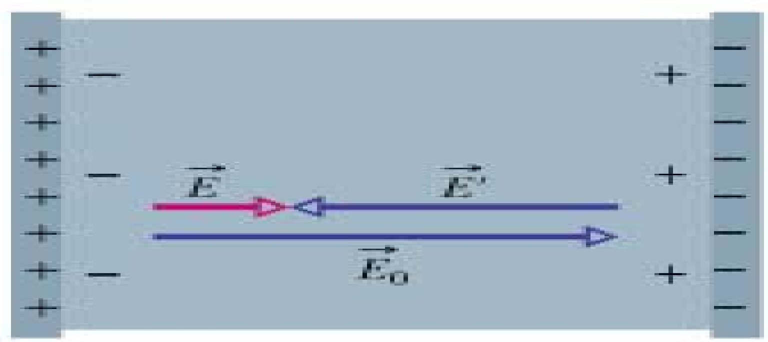
(a)

- Total *E* field is weakened by adding material



(b)

- Material is called a dielectric



(c)

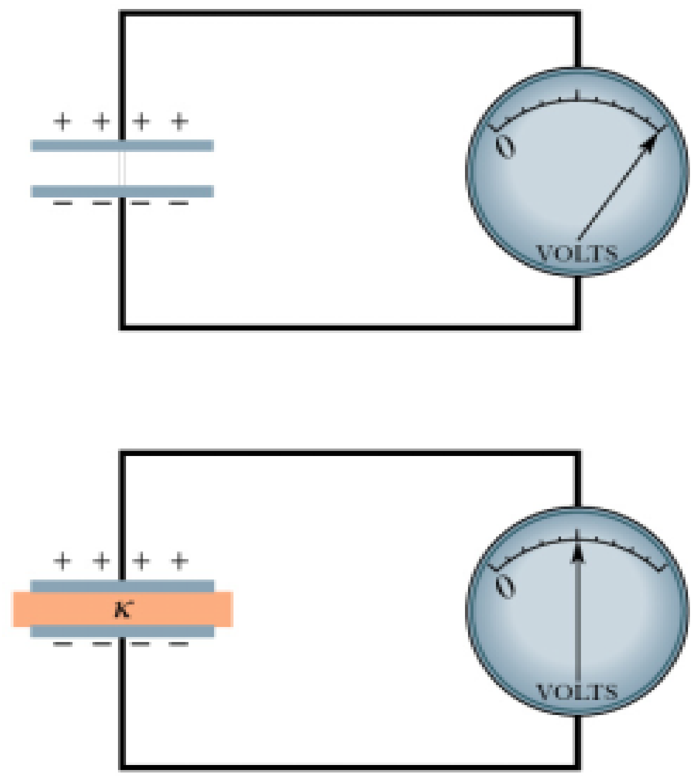
Capacitance (27)

$$V = Ed$$

- *E* field is weaker so *V* decreases

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

- *q* is constant so *C* INCREASES



q = a constant

(*b*)

Capacitance (28)

- Place a dielectric in capacitor its capacitance increases by numerical factor
  - Called dielectric constant, κ

$$C_{dielectric} = \kappa C_{air}$$

- Modify all electrostatic equations by replacing ε_0 with $\kappa\varepsilon_0$

$$E = \frac{1}{4\pi\kappa\varepsilon_0}\frac{q}{r^2}$$

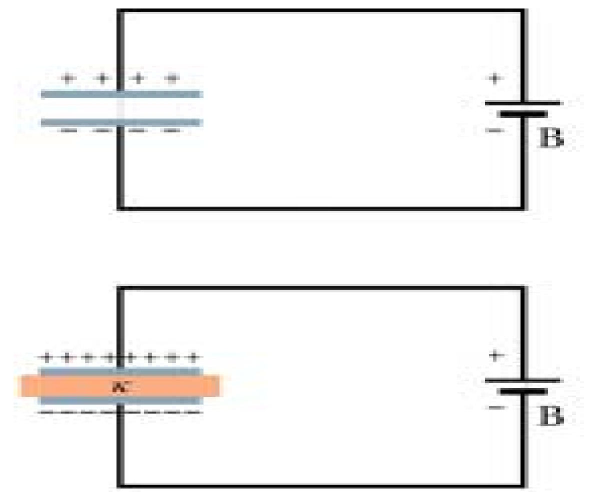
$$\varepsilon_0 \oint \kappa\vec{E} \bullet d\vec{A} = q$$

Capacitance (29)

- If system connected to battery, *V* is a constant
- *C* increases with dielectric so *q* must increase

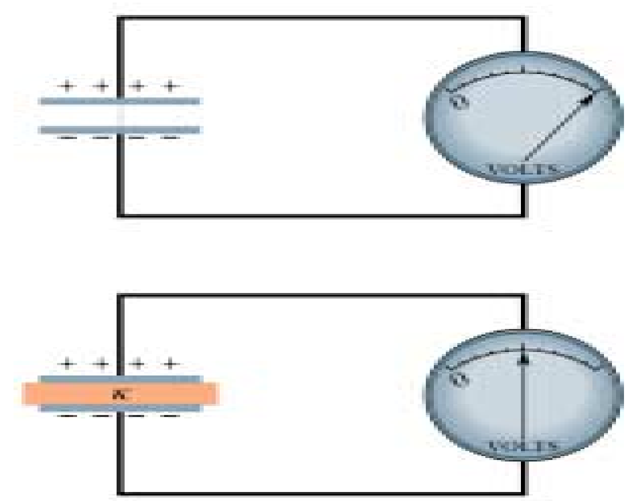
$$q = CV$$

- If system isolated, *q* is a constant
- *C* increases with dielectric so *V* must decrease



V = a constant

(*a*)



q = a constant

(*b*)

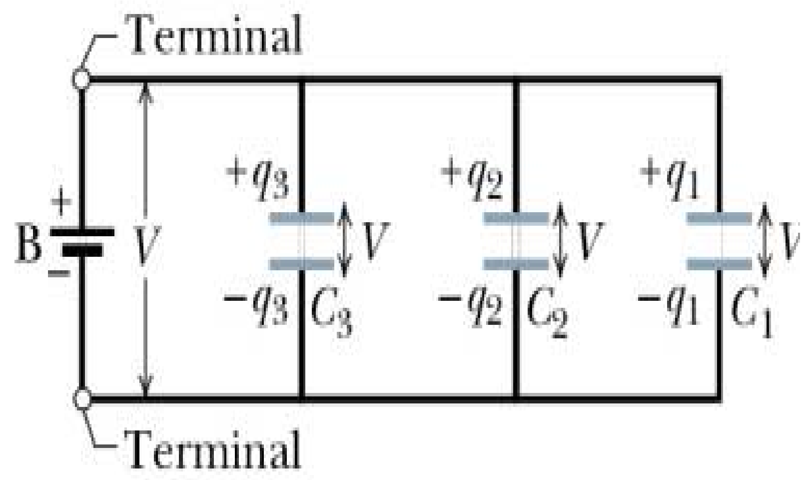
Capacitance (30)

- What if we have more than one capacitor in a circuit?
  - Replace combination with equivalent capacitor C_{eq}

- 2 basic combinations
  - Parallel
  - Series

Capacitance (31)

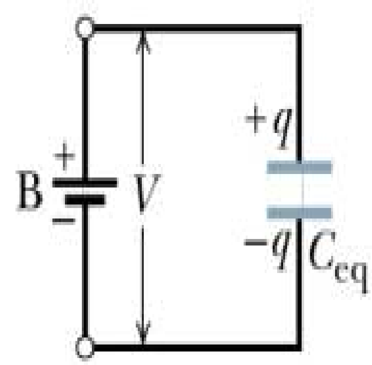
- Capacitors in parallel
- Capacitors are directly wired together at each plate and V applied across the group of plates



(*a*)

- V is same across all capacitors

$$V_1 = V_2 = V_3 = V$$



(*b*)

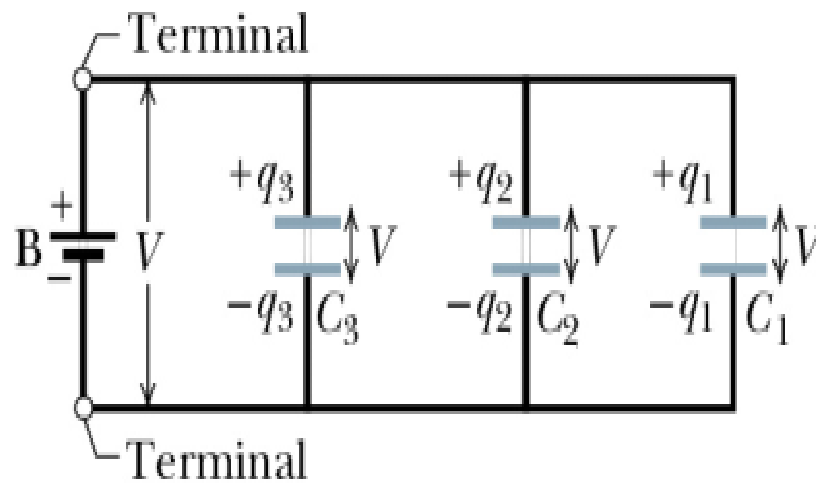
Capacitance (32)

- Capacitors in parallel
- Total q stored on capacitors is sum of the charges of all capacitors

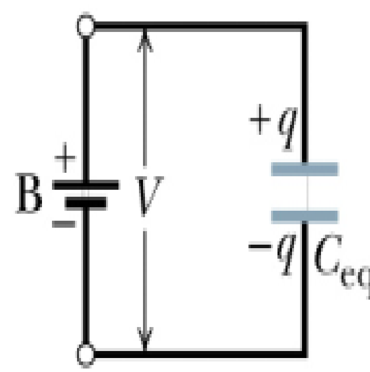
$$q = q_1 + q_2 + q_3$$

- C_{eq} has total charge q and same V as original capacitors

$$C_{eq} = \frac{q}{V}$$



(a)



(b)

Capacitance (33)

- Capacitors in parallel

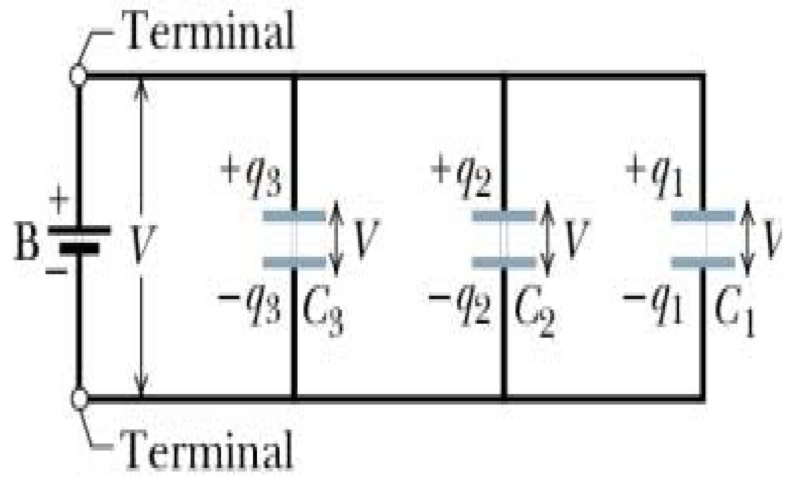
$$q = q_1 + q_2 + q_3$$

$$q_1 = C_1 V \quad q_2 = C_2 V \quad q_3 = C_3 V$$

$$q = (C_1 + C_2 + C_3)V$$

$$C_{eq} = C_1 + C_2 + C_3$$

$$C_{eq} = \sum_{i}^{n} C_i$$



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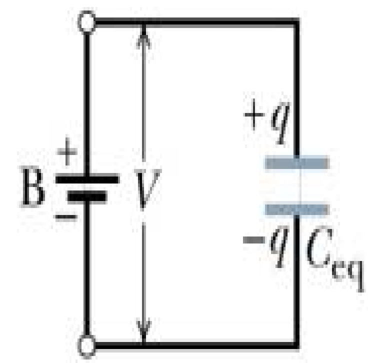


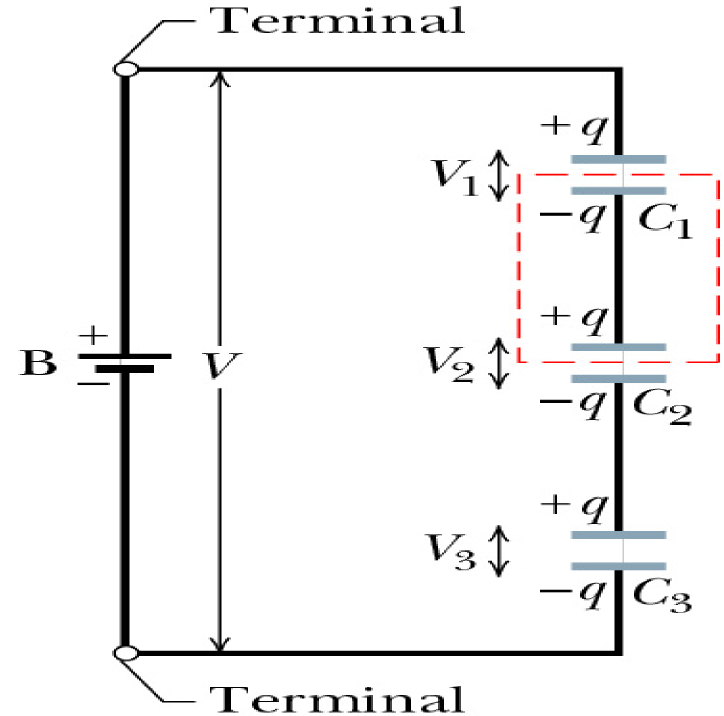
(b)

Capacitance (34)

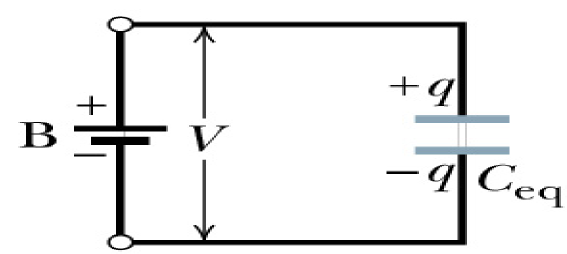
- Capacitors in series
- Capacitors are wired one after the other and V is applied across the two ends of the series
- Capacitors have identical q

$$q_1 = q_2 = q_3 = q$$

- Battery produces q only on top and bottom plates, induced q on other plates



(a)



(b)

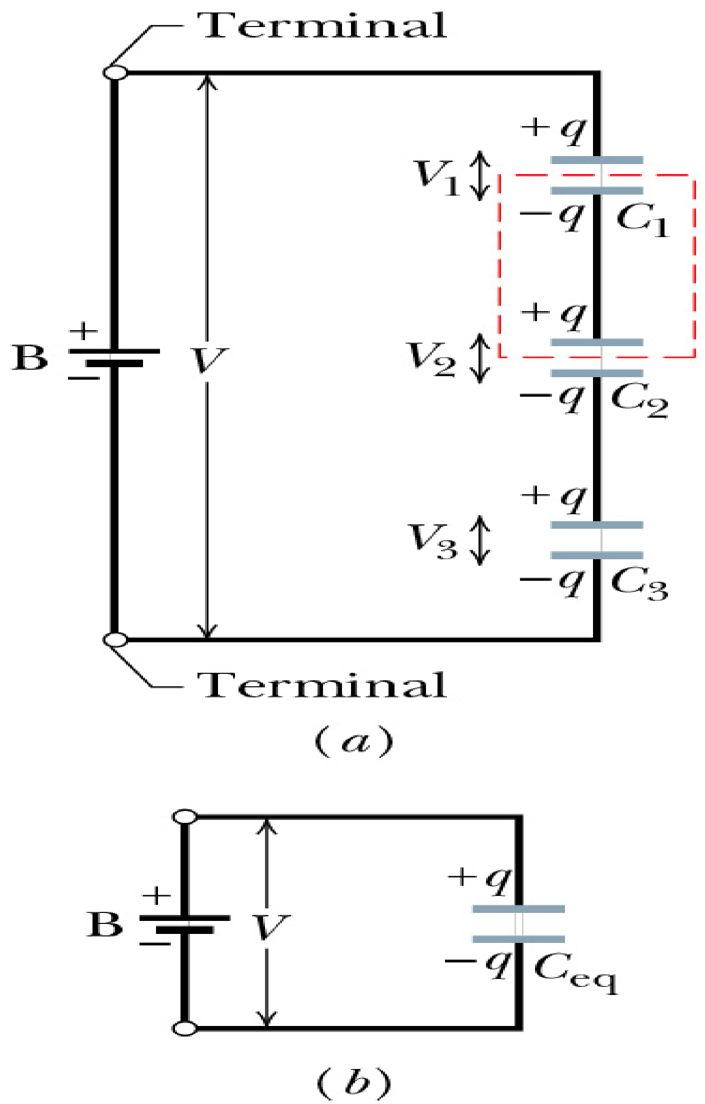
Capacitance (35)

- Capacitors in series
- Sum of V across all capacitors is equal to applied V

$$V = V_1 + V_2 + V_3$$

- C_{eq} has same q and total V as original capacitors

$$C_{eq} = \frac{q}{V}$$



Capacitance (36)

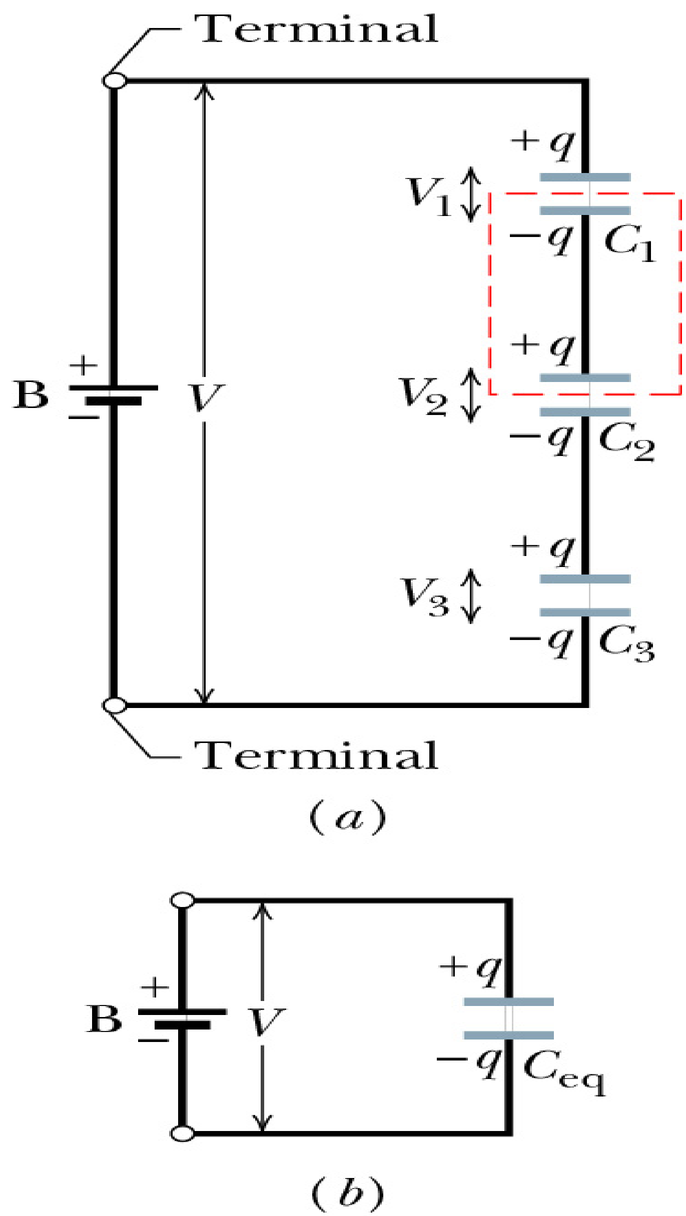
- Capacitors in series

$$V = V_1 + V_2 + V_3$$

$$V_1 = \frac{q}{C_1} \qquad V_2 = \frac{q}{C_2} \qquad V_3 = \frac{q}{C_3}$$

$$V = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C_{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

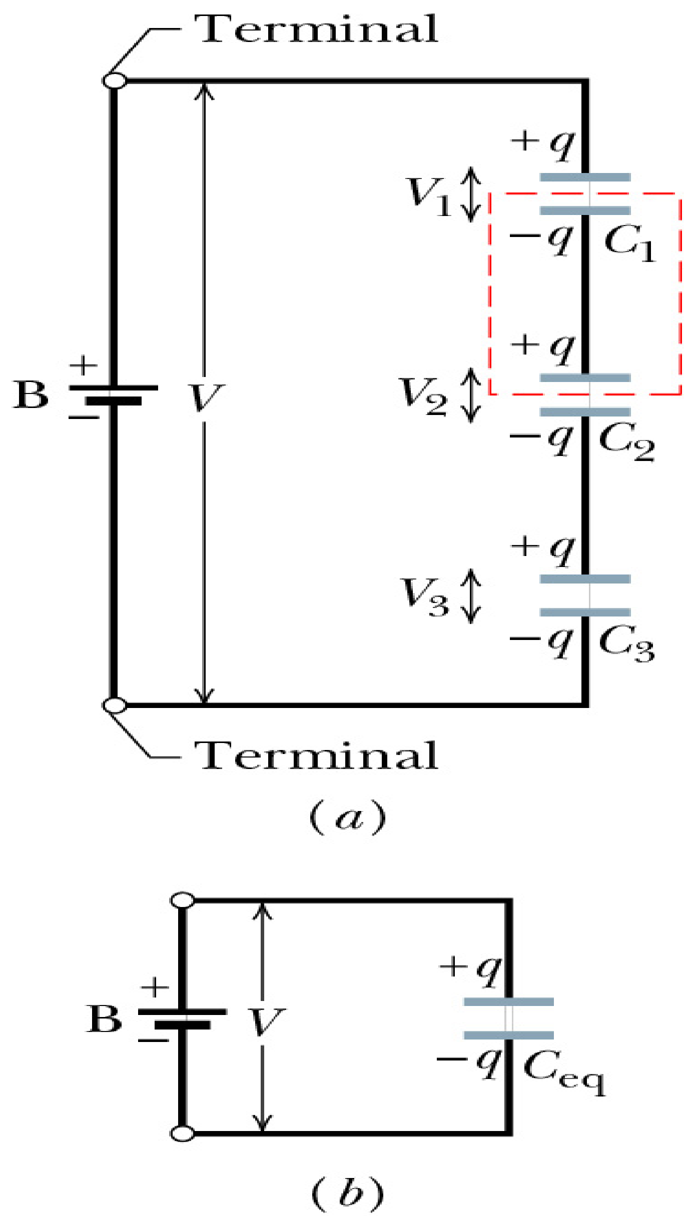


Capacitance (37)

- Capacitors in series
- Charge can only be shifted from one capacitor to another
- If alternate routes not in series

$$\frac{1}{C_{eq}} = \sum_{i}^{n} \frac{1}{C_i}$$

- C_{eq} is always less than smallest capacitance



Capacitance (38)

- Capacitors in parallel
  - V across each is equal
  - Total q is sum

$$C_{eq} = \sum_{i}^{n} C_i$$

- Capacitors in series
  - q is equal on each
  - Total V is sum

$$\frac{1}{C_{eq}} = \sum_{i}^{n} \frac{1}{C_i}$$

Capacitance (39)

- Checkpoint #3 – A battery with V stores charge q on 2 identical capacitors
- A) What is V across and q on either capacitor if they are in parallel?
- V is same for each and equal to V of battery
  - Total charge conserved so

$$q = q_1 + q_2 = 2q_1$$

$$q_{cap} = \frac{q}{2}$$

Capacitance (40)

- Checkpoint #3 – A battery with *V* stores charge *q* on 2 identical capacitors
- A) What is *V* across and *q* on either capacitor if they are in series?
    - *q* is same for each
  - *V* is sum of *V* across capacitors

$$V = V_1 + V_2 = 2V_1$$

$$V_{cap} = \frac{V}{2}$$