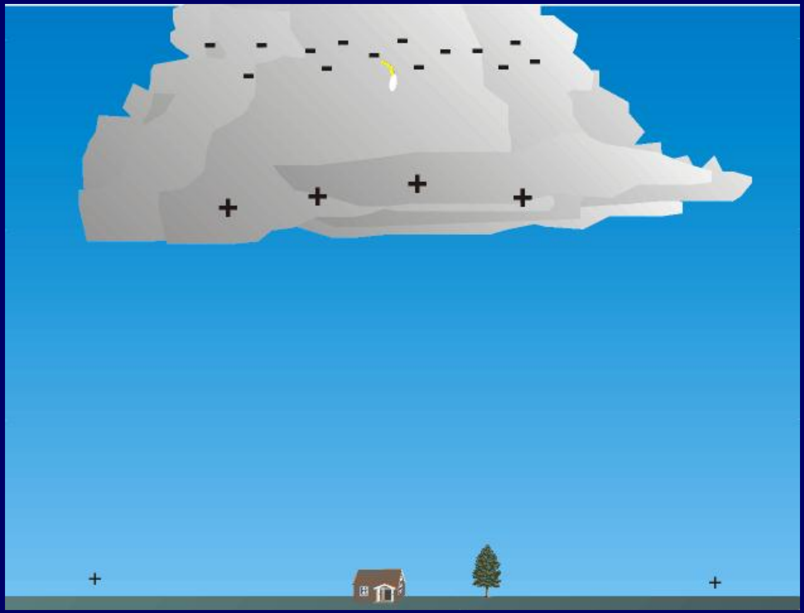
Physics 102: Lecture 04

Capacitors
(& batteries)



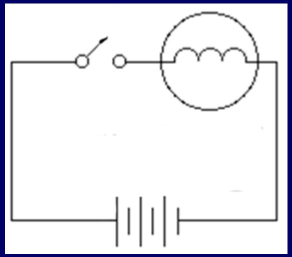
Physics 102 so far

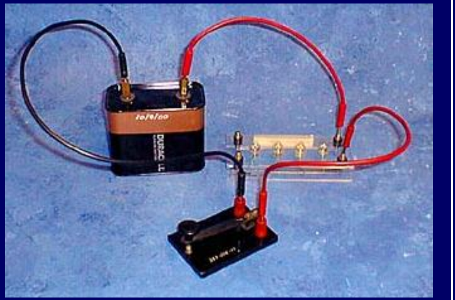
Basic principles of electricity

- Lecture 1 – electric charge & electric force
- Lecture 2 – electric field
- Lecture 3 – electric potential energy and electric potential

Applications of electricity – circuits

- Lecture 4 – capacitance
- Lecture 5 – resistance
- Lecture 6 – Kirchhoff’s rules
- Lecture 7 – RC circuits
- Lecture 12 & 13 – AC circuits

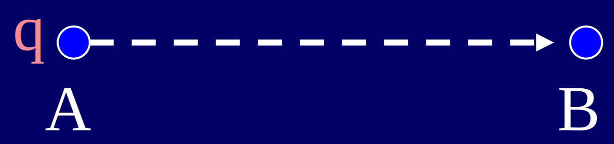




Recall from last lecture…..
Electric Fields, Electric Potential

Comparison:

Electric *Potential Energy* vs. Electric *Potential*



ΔV_{AB} : the difference in electric potential between points B and A

ΔU_{AB} : the change in electric potential energy of a charge q when moved from A to B

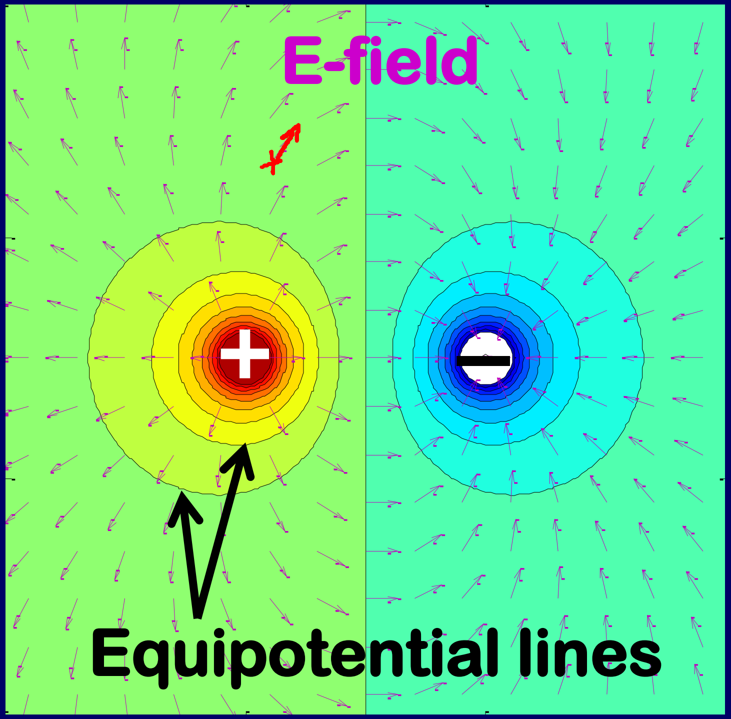
$$\Delta U_{AB} = q\,\Delta V_{AB}$$

Electric Potential: Summary

- E field lines point from higher to lower potential
- For positive charges, going from higher to lower potential is "downhill"

  Positive charges tend to go "downhill", from + to –

  Negative charges go in the opposite direction, from – to +



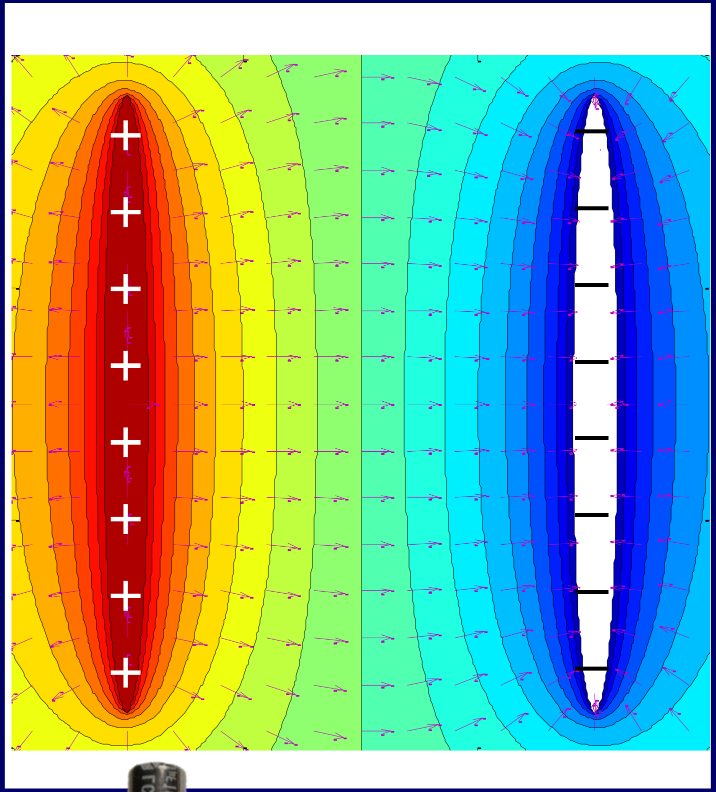
$$\Delta U_{AB} = q\ \Delta V_{AB}$$

Important Special Case:
Uniform Electric Field

Two large parallel conducting plates of area A

+Q on one plate

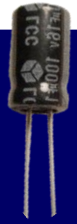
–Q on other plate



Then E is

- uniform between the two plates: $E=4\pi kQ/A$
- zero everywhere else
- This result is independent of plate separation

This is called a parallel plate capacitor



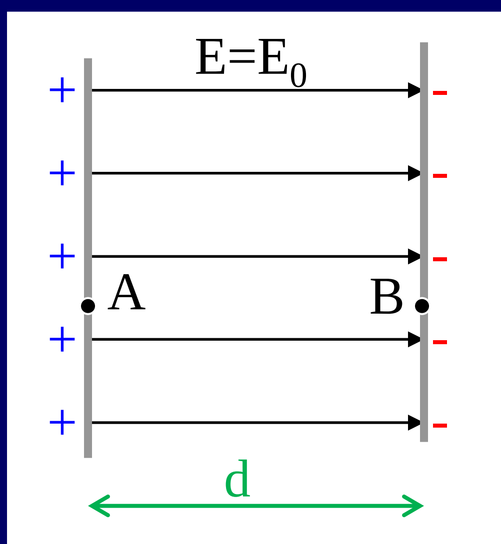
Parallel Plate Capacitor: Potential Difference

Charge Q on plates

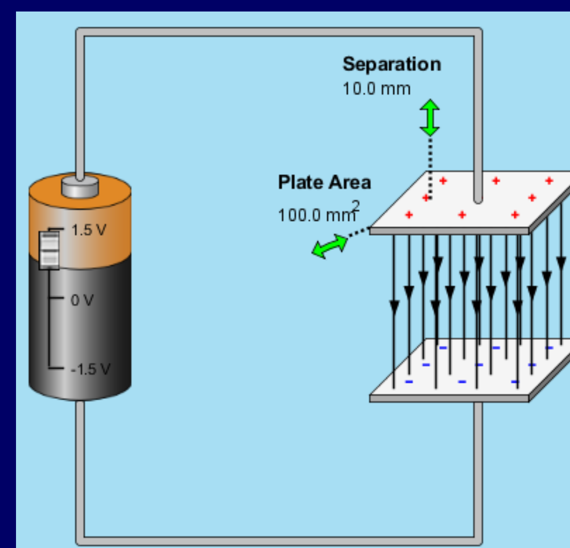
$V = V_A - V_B = +E_0\, d$

$= 4\,\pi\, k\, Q\, d \,/\, A$

Voltage is proportional to the charge!

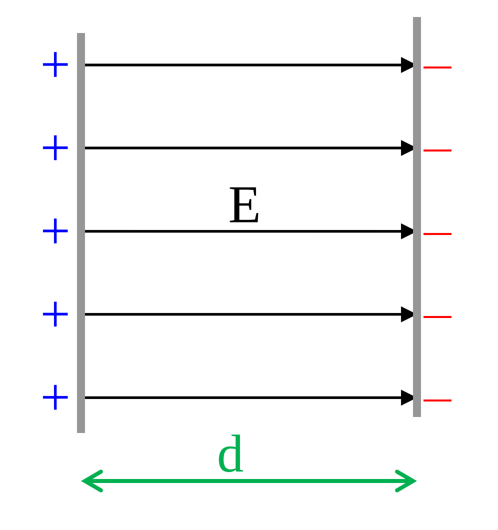


[PhET Simulation]



Capacitance: The ability to store separated charge $C \equiv Q/V$

- Any pair conductors separated by a small distance. (e.g. two metal plates)
- Capacitor stores <u>separated charge</u> $Q=CV$
  - Positive Q on one conductor, negative Q on other
  - Net charge is zero
- Stores Energy $U = (½)\ Q\ V$

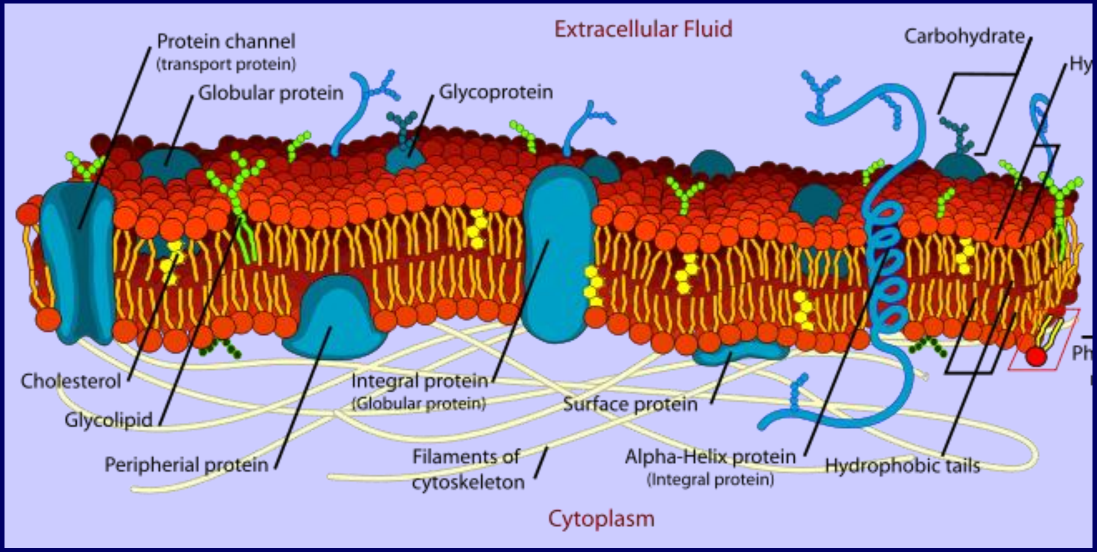


Units:
1 Coulomb/Volt
= 1 Farad (F)

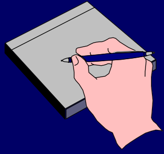
Why Separate Charge?

A way to store *and release* energy!

- Camera Flash
- Defibrillator
- AC → DC
- Tuners / resonant circuits
  - Radio
  - Cell phones
- Cell membranes



Capacitance of Parallel Plate Capacitor



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

(Between two large plates)

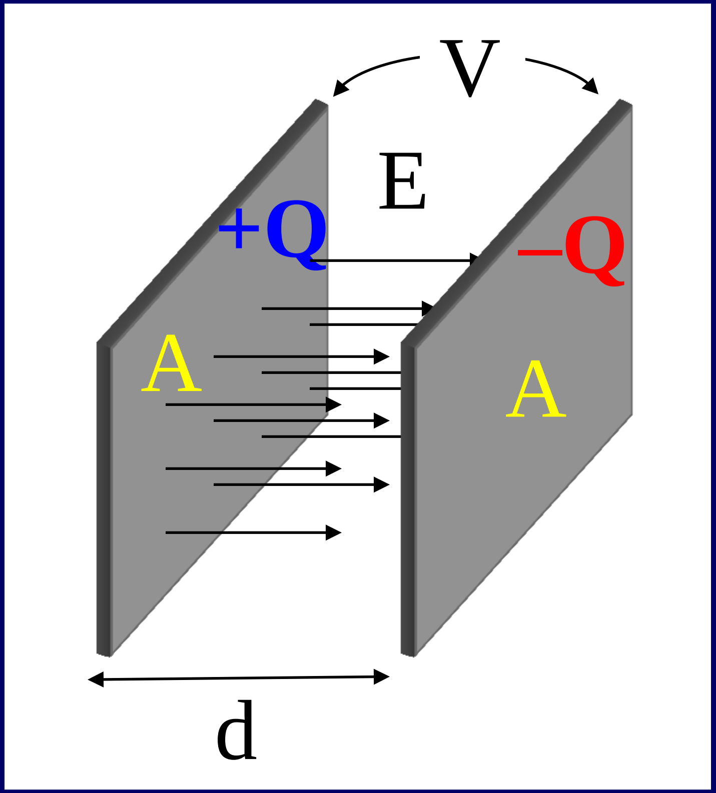
So: $V = 4\pi kQd/A$

Recall: $C \equiv Q/V$

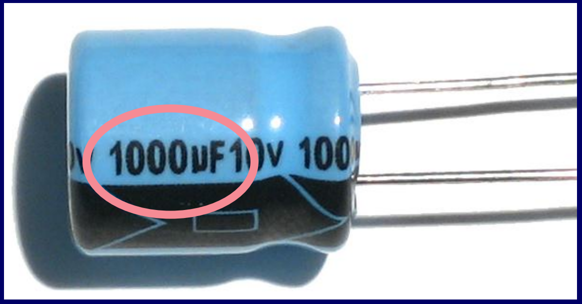
So: $C = A/(4\pi kd)$

Recall:

$\varepsilon_0 = 1/(4\pi k) = 8.85\times10^{-12}\ C^2/Nm^2$

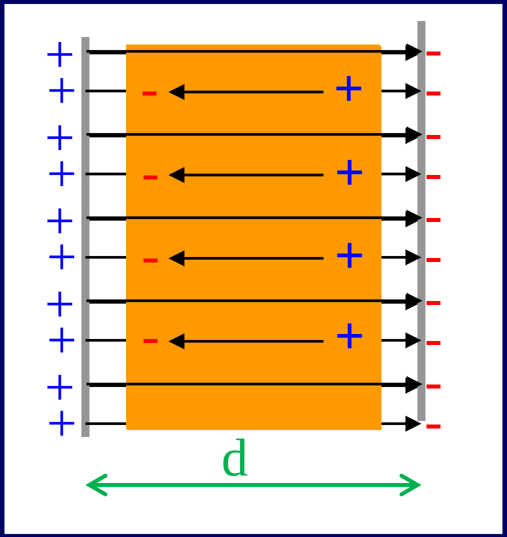


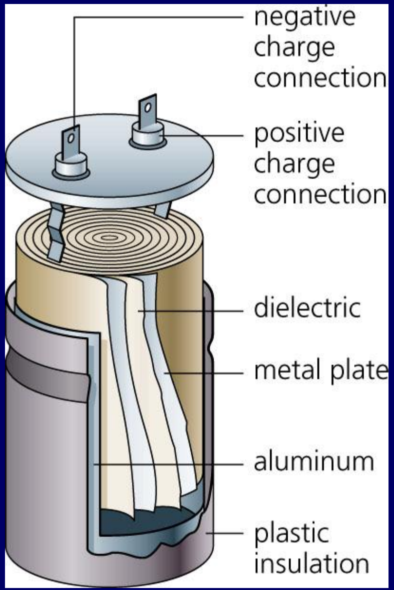
$C = \varepsilon_0 A/d$
Parallel plate capacitor



Dielectric

- Placing a dielectric (insulator) between the plates **increases** the capacitance.





$$C = \kappa C_0$$

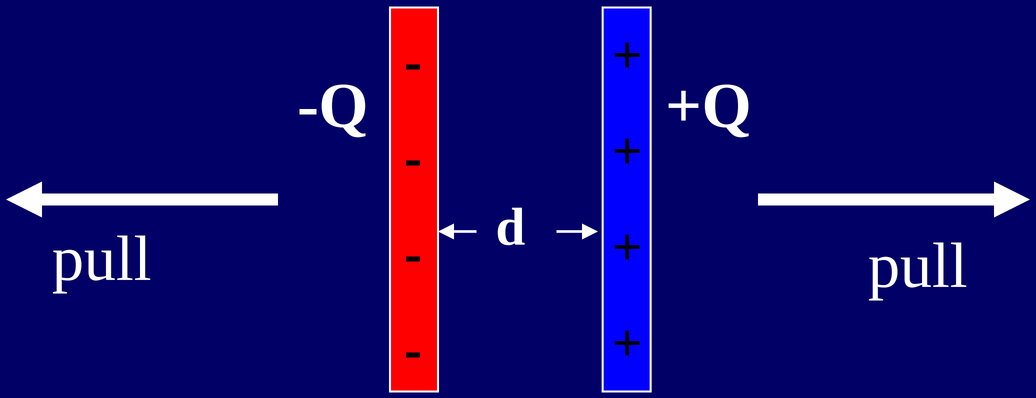
Dielectric constant ($\kappa > 1$)

Capacitance **without** dielectric

Capacitance **with** dielectric

For same charge Q, E (and V) is reduced so C = Q/V increases

ACT: Parallel Plates



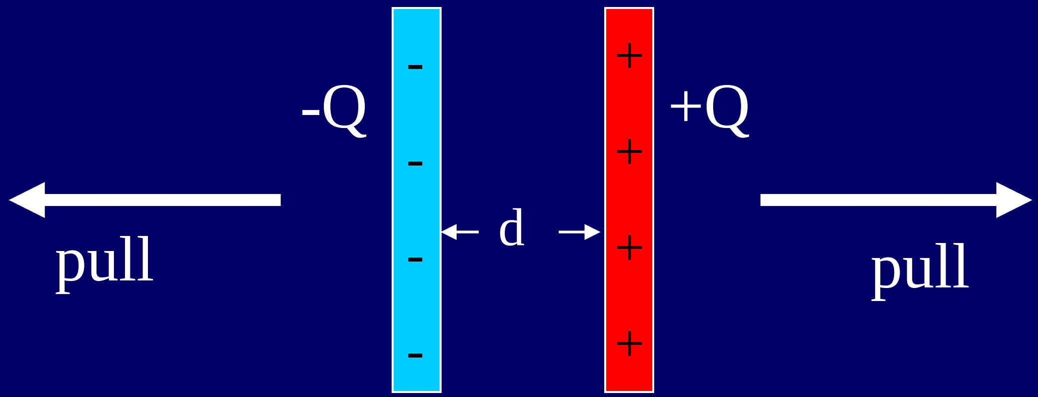
A parallel plate capacitor given a charge Q. The plates are then pulled a small distance further apart. What happens to the charge Q on each plate of the capacitor?

A) Increases

B) Constant

C) Decreases

CheckPoint 4.1



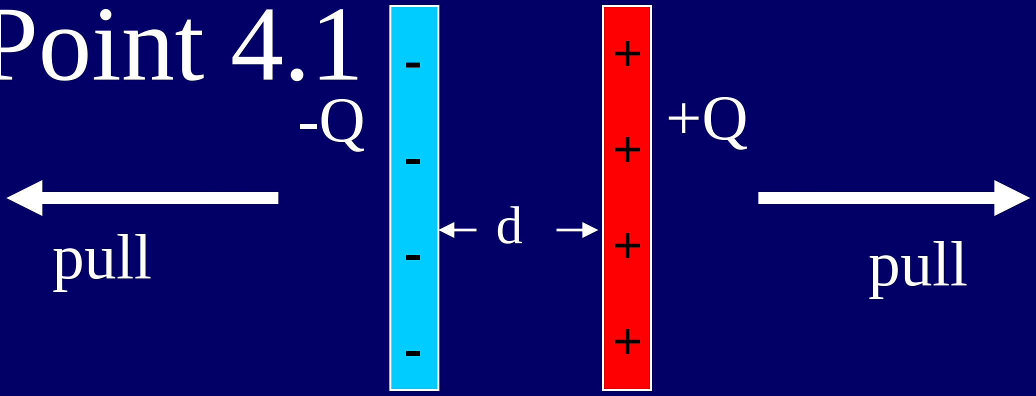
A parallel plate capacitor given a charge Q. The plates are then pulled a small distance further apart. Which of the following apply to the situation after the plates have been moved?

1)The capacitance increases True False

2)The electric field increases True False

3)The voltage between the plates increases True False

ACT/CheckPoint 4.1



A parallel plate capacitor given a charge Q. The plates are then pulled a small distance further apart. Which of the following apply to the situation after the plates have been moved?

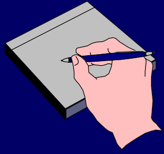
The energy stored in the capacitor

A) increases

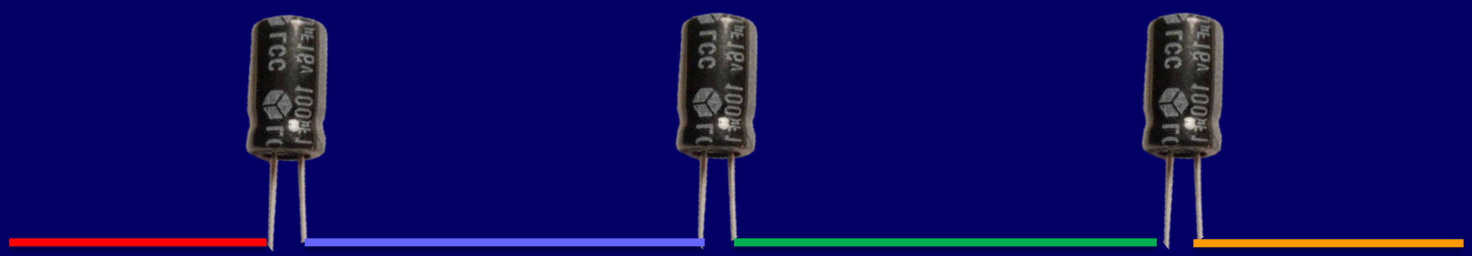
B) constant

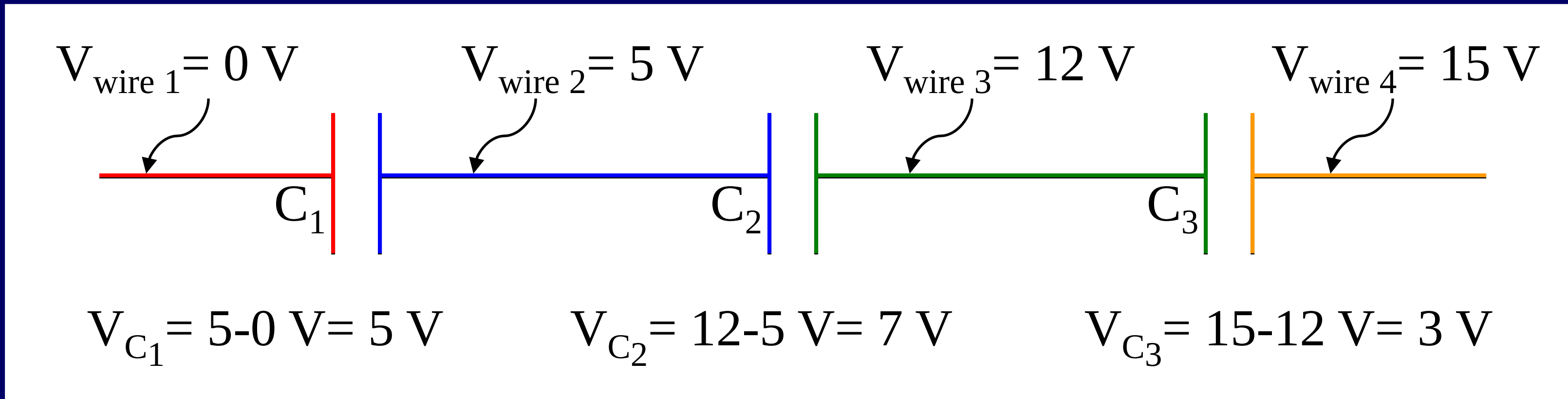
C) decreases

Capacitors are used in circuits!

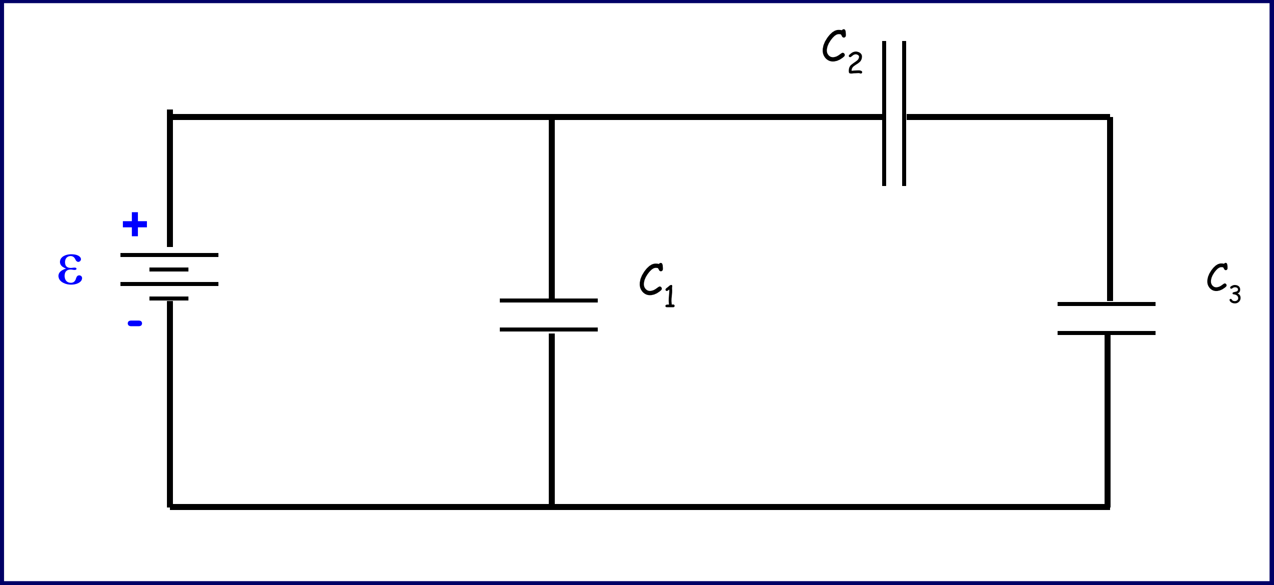


- In circuits, elements are connected by wires.
- Any connected region of wire has the same potential.
- The potential difference across an element is the *element's* "voltage."

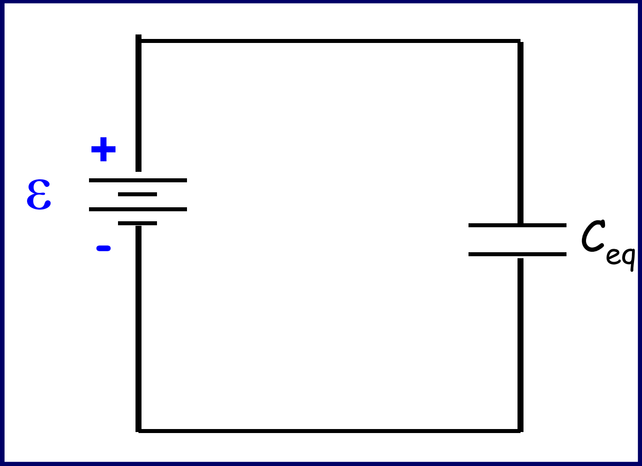




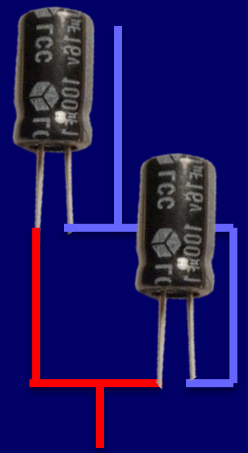
To understand complex circuits…



…treat capacitors in series and parallel as a fictitious equivalent capacitor!

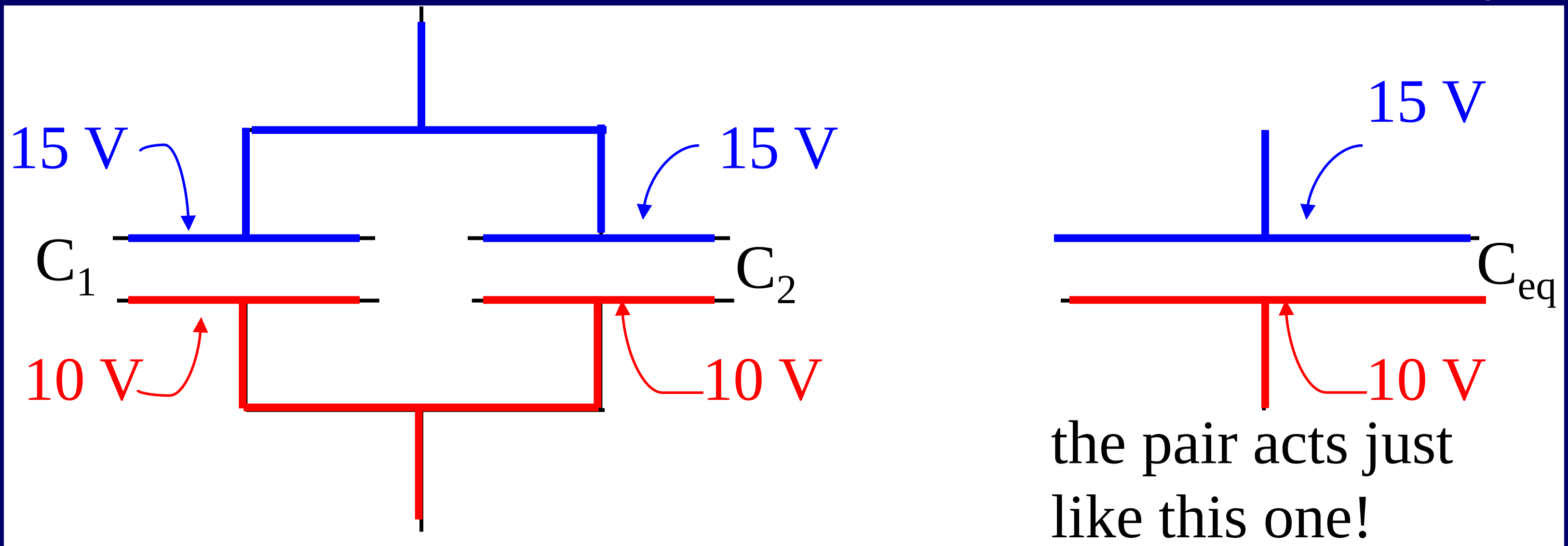


Capacitors in Parallel

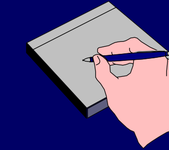


- Both ends connected together by wire
- Same voltage: $V_1 = V_2 = V_{eq}$
- Share Charge: $Q_{eq} = Q_1 + Q_2$
- Equivalent C: $C_{eq} = C_1 + C_2$

Add areas – remember $C = \varepsilon_0 A/d$



Example



Parallel Practice

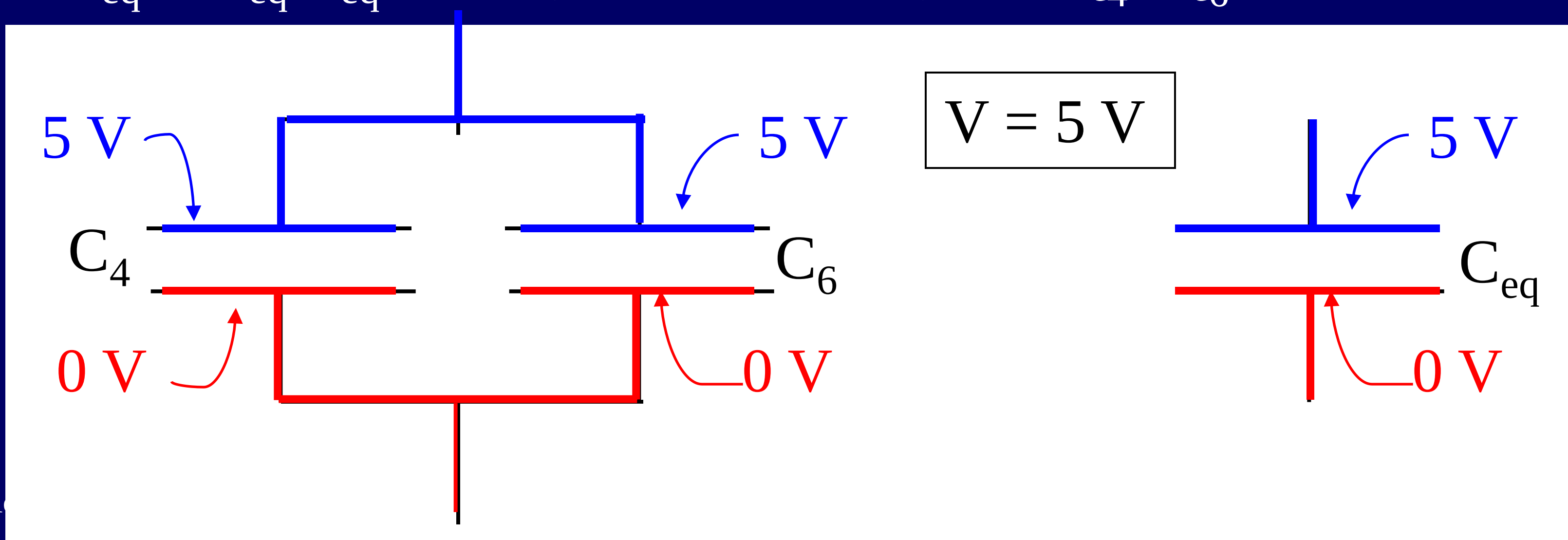
A 4 μF capacitor and 6 μF capacitor are connected in parallel and charged to 5 volts. Calculate C_{eq}, and the charge on each capacitor.

$$C_{eq} = C_4 + C_6 = 4\ \mu F + 6\ \mu F = 10\ \mu F$$

$$Q_4 = C_4 V_4 = (4\ \mu F)(5\ V) = 20\ \mu C$$

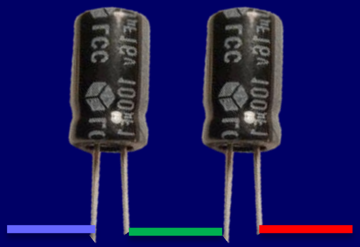
$$Q_6 = C_6 V_6 = (6\ \mu F)(5\ V) = 30\ \mu C$$

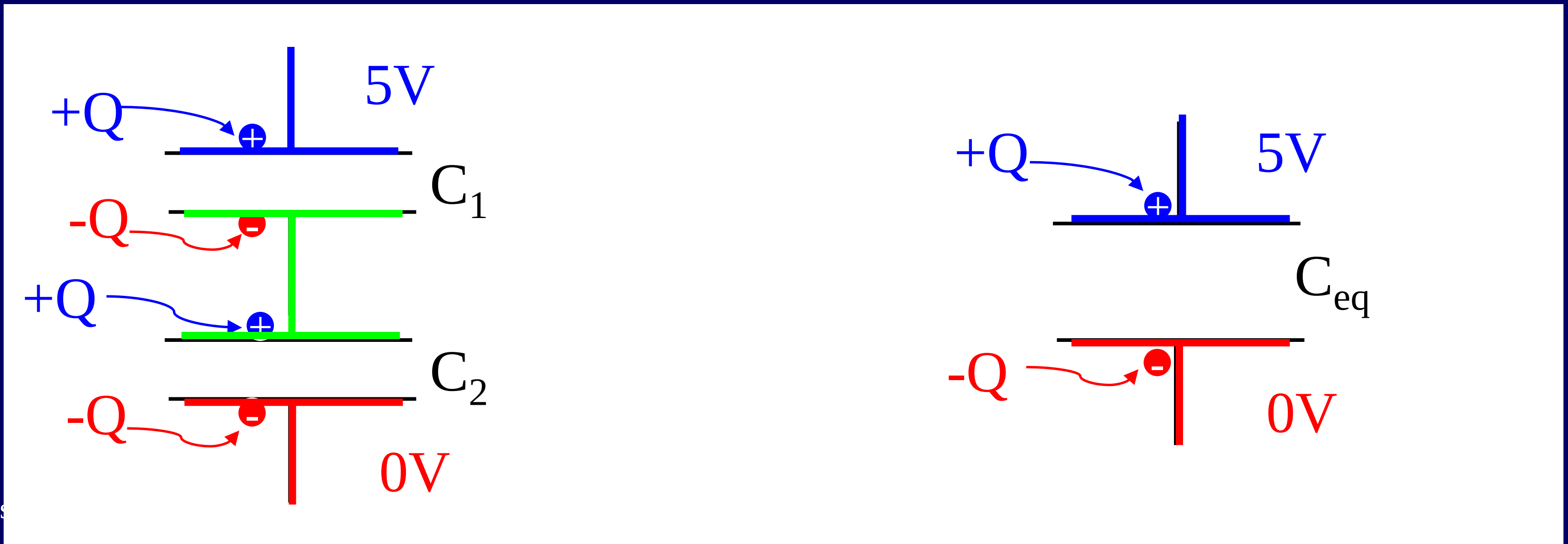
$$Q_{eq} = C_{eq} V_{eq} = (10\ \mu F)(5\ V) = 50\ \mu C = Q_4 + Q_6$$



Capacitors in Series

- Connected end-to-end with NO other exits
- Same Charge: $Q_1 = Q_2 = Q_{eq}$
- Share Voltage: $V_1 + V_2 = V_{eq}$
- Equivalent C: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$ Add d – remember $C = \varepsilon_0 A/d$





Series Practice

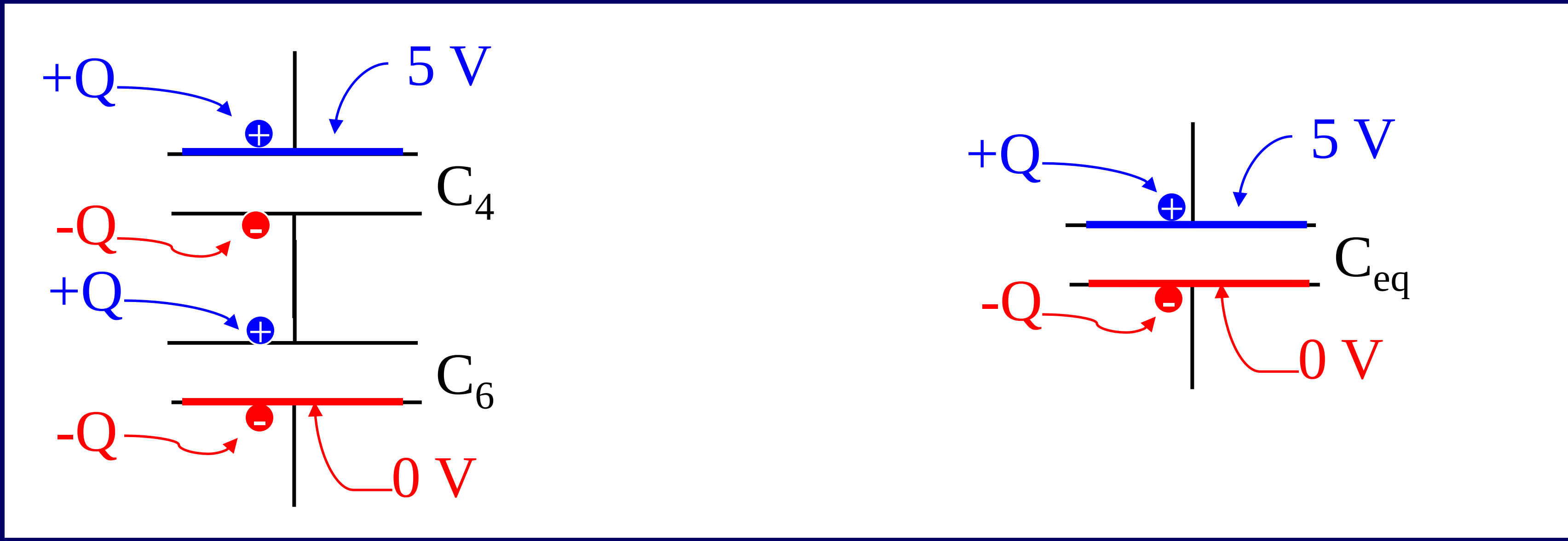
Example

A 4 μF capacitor and 6 μF capacitor are connected in series and charged to 5 volts. Calculate C_{eq}, and the charge on the 4 μF capacitor.

$$C_{eq} = \left(\frac{1}{C_4} + \frac{1}{C_6}\right)^{-1} = \left(\frac{1}{4\mu F} + \frac{1}{6\mu F}\right)^{-1} = 2.4\mu F$$

$Q = CV$

$$Q_4 = Q_6 = Q_{eq} = C_{eq}V = (2.4\mu F)(5V) = 12\mu C$$



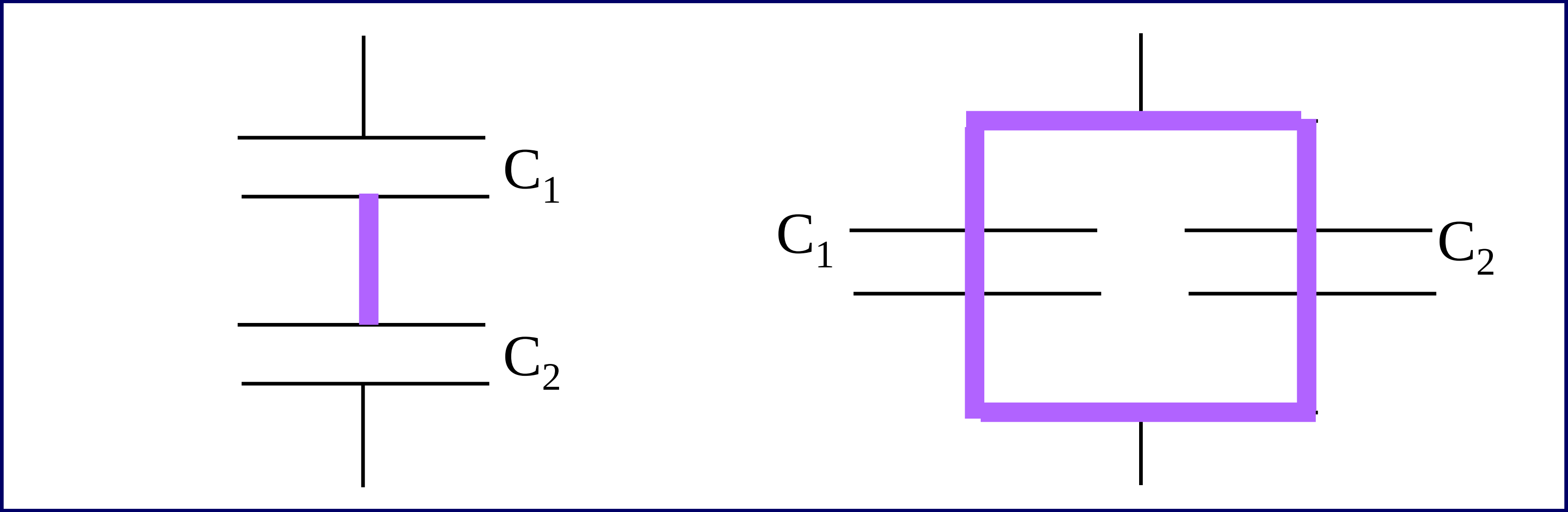
Comparison:
Series vs. *Parallel*

Series

- Can follow a wire from one element to the other with no branches in between.

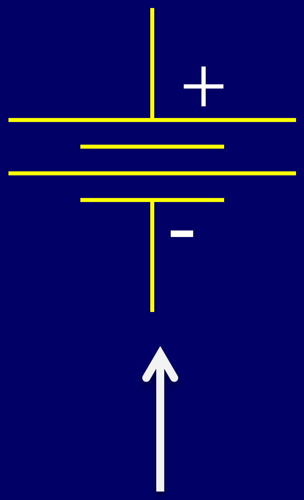
Parallel

- Can find a loop of wire containing both elements but no others (may have branches).



Electromotive Force

- Battery
  - Maintains constant potential difference V (electromotive force – emf ε)
  - Does NOT produce or supply charges, just "pushes" them.



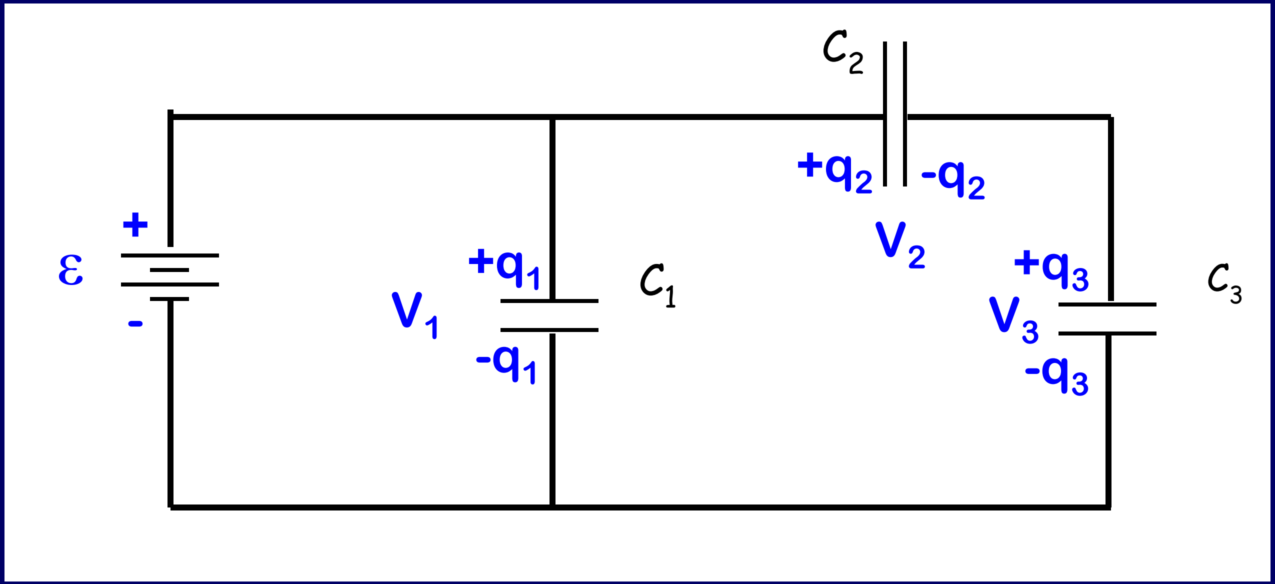
Like a pump for charge!

Usually "0V" by convention

CheckPoint 4.4

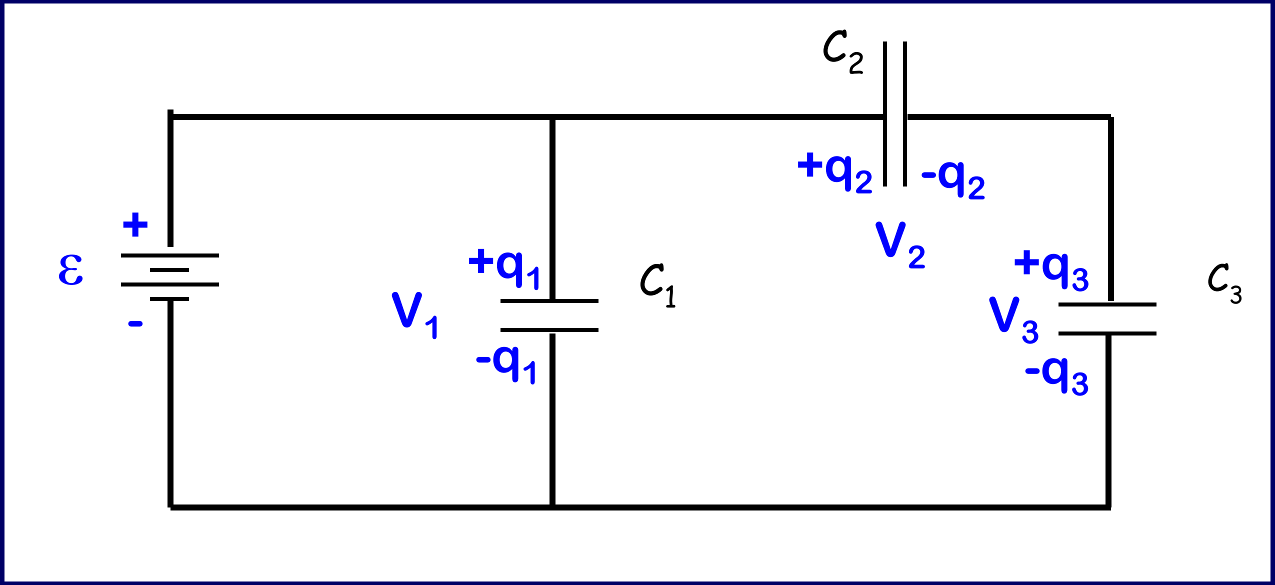
A circuit consists of three initially uncharged capacitors C_1, C_2, and C_3, which are then connected to a battery of emf ε. The capacitors obtain charges q_1, q_2, q_3, and have voltages across their plates V_1, V_2, and V_3. C_{eq} is the equivalent capacitance of the circuit. Which of these are true?

1) $q_1 = q_2$
2) $q_2 = q_3$
3) $V_2 = V_3$
4) $\varepsilon = V_1$
5) $V_1 < V_2$



ACT/CheckPoint 4.4: Which is true?

A circuit consists of three initially uncharged capacitors C_1, C_2, and C_3, which are then connected to a battery of emf ε. The capacitors obtain charges q_1, q_2, q_3, and have voltages across their plates V_1, V_2, and V_3. C_{eq} is the equivalent capacitance of the circuit.

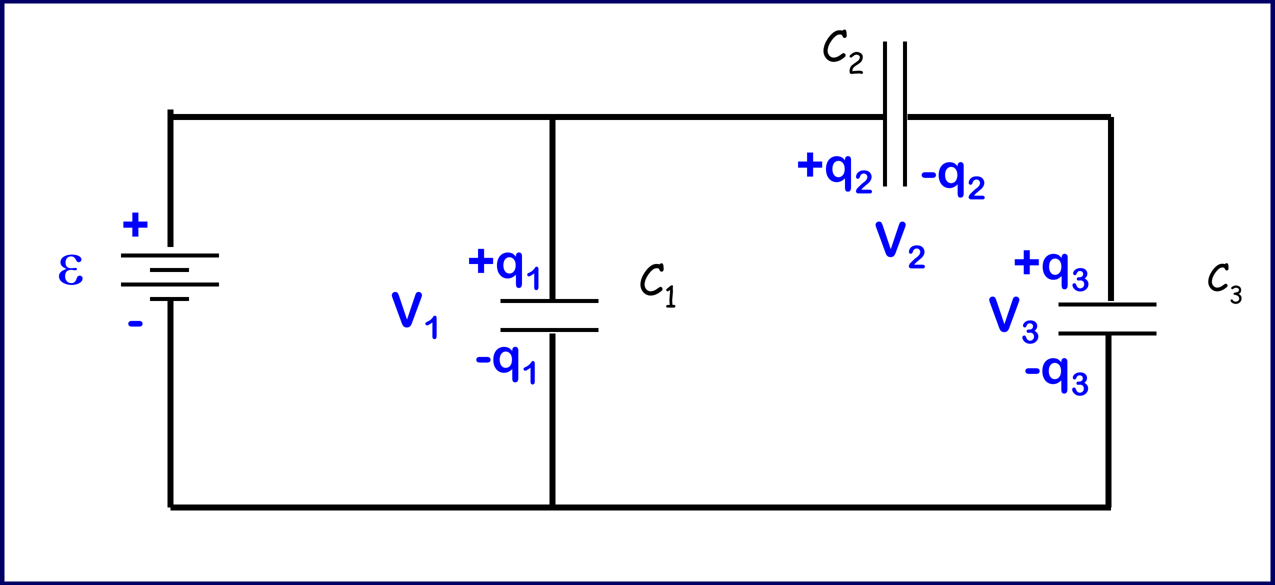


1) $q_1 = q_2$

2) $q_2 = q_3$

ACT/CheckPoint 4.4: Which is true?

A circuit consists of three initially uncharged capacitors C_1, C_2, and C_3, which are then connected to a battery of emf ε. The capacitors obtain charges q_1, q_2, q_3, and have voltages across their plates V_1, V_2, and V_3. C_{eq} is the equivalent capacitance of the circuit.



1) $V_2 = V_3$

2) $\varepsilon = V_1$

Recap of Today's Lecture

- Capacitance C = Q/V
- Parallel Plate: $C = \varepsilon_0 A/d$
- Capacitors in parallel: $C_{eq} = C_1 + C_2$
- Capacitors in series: $1/C_{eq} = 1/C_1 + 1/C_2$
- Batteries provide fixed potential difference