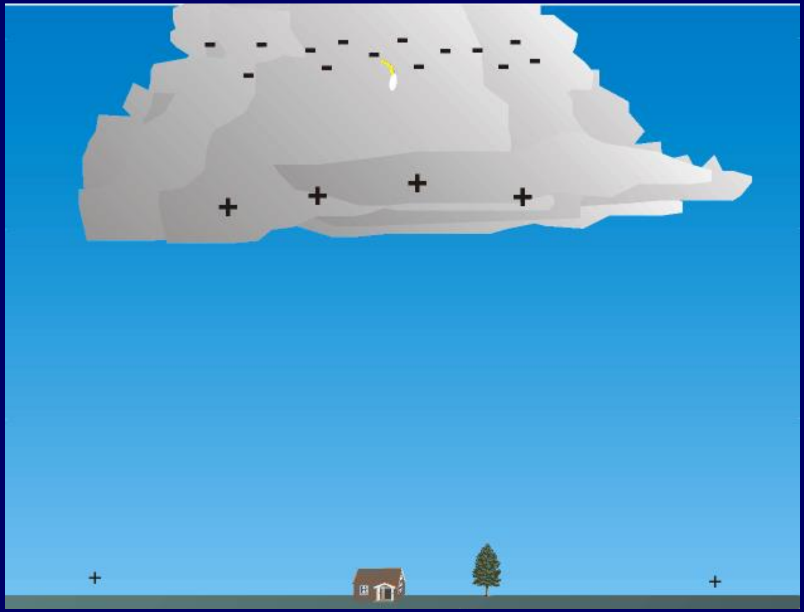
Physics 102: Lecture 04

Capacitors
(& batteries)



Your Comments

I wish the checkpoints were given to us on material that we learned from the previous lecture, rather than on material from the upcoming lecture that we had not seen yet. In this way, we could use them as review tools rather than having not seen them before

Everything please. I'm so lost.

I would really appreciate more time to discuss the clicker questions, and a warning before ending the timer.

More examples would be great!

I would like to go over the main differences between series and parallel circuits... but im assuming you already have that planned :)

would like if there were more seats put into the lecture hall. There are not enough seats to be able to seat every student and standing up for 50 minutes or sitting on the floor isn't fun.

In lecture, I think that it is nice to interact as much as we do but at the same time I feel like the exmples we do in lecture do not reflect what we are expected to know how to do for the discussion quizzes or the homework. I would like to see more of these kind of problems so I can learn before being quizzed on it.

Nothing yet but I don't like how the homework covers material we learn the Monday before its due. That only gives me one night to do it, which isn't enough.

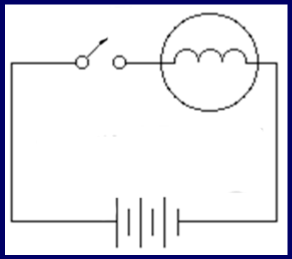
Physics 102 so far

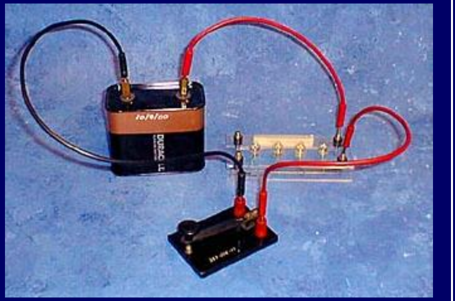
Basic principles of electricity

- 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



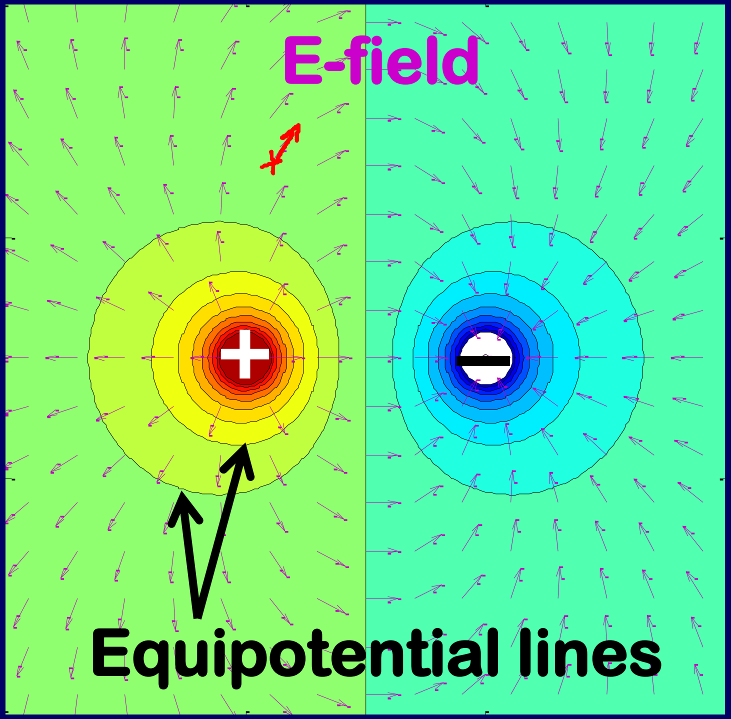


Electric Potential: Summary

- 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 +



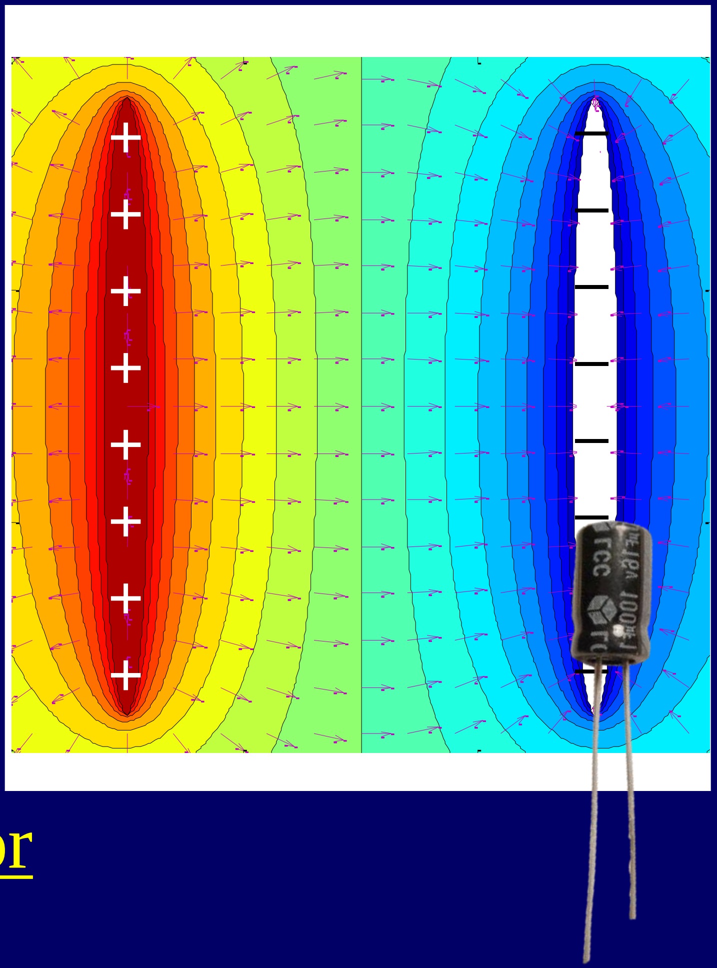
$$\Delta U_{AB} = q \, \Delta V_{AB}$$

Uniform Electric Field: Important Special Case

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

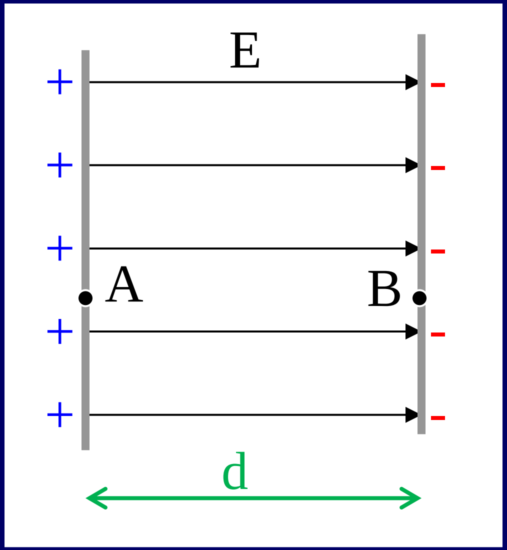
Parallel Plate Capacitor: Potential Difference

Charge Q on plates

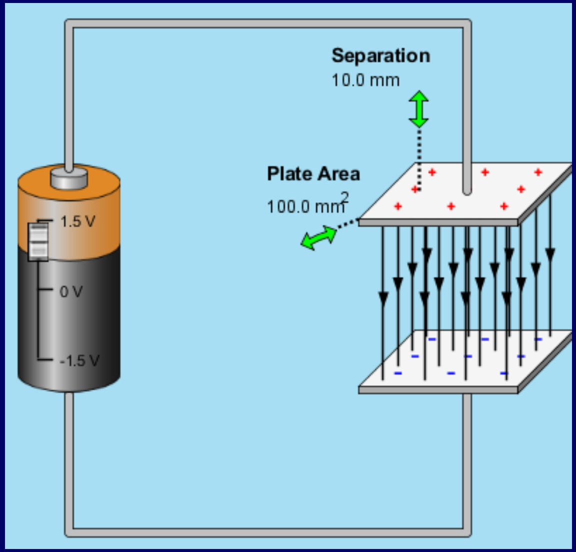
$V = V_A - V_B = +E\,d$ (like $W = qEd = \Delta U; \Delta V = \Delta U/q$)

$= 4\pi k Q d / A$

Voltage is proportional to the charge!

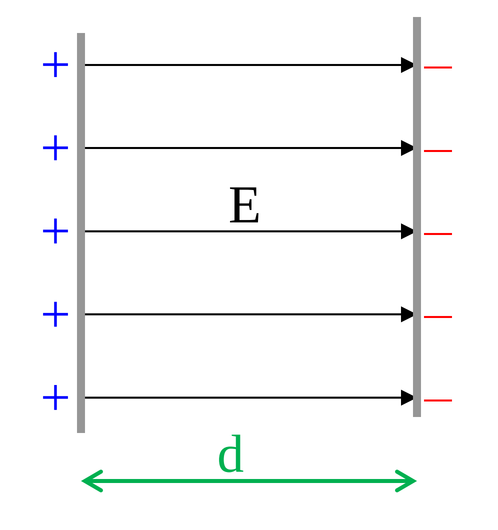


PhET Simulation



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> $\boxed{Q=CV}$
  - Positive Q on one conductor, negative Q on other
  - Net charge is zero
- Stores Energy $\boxed{U = (½)\,Q\,V}$

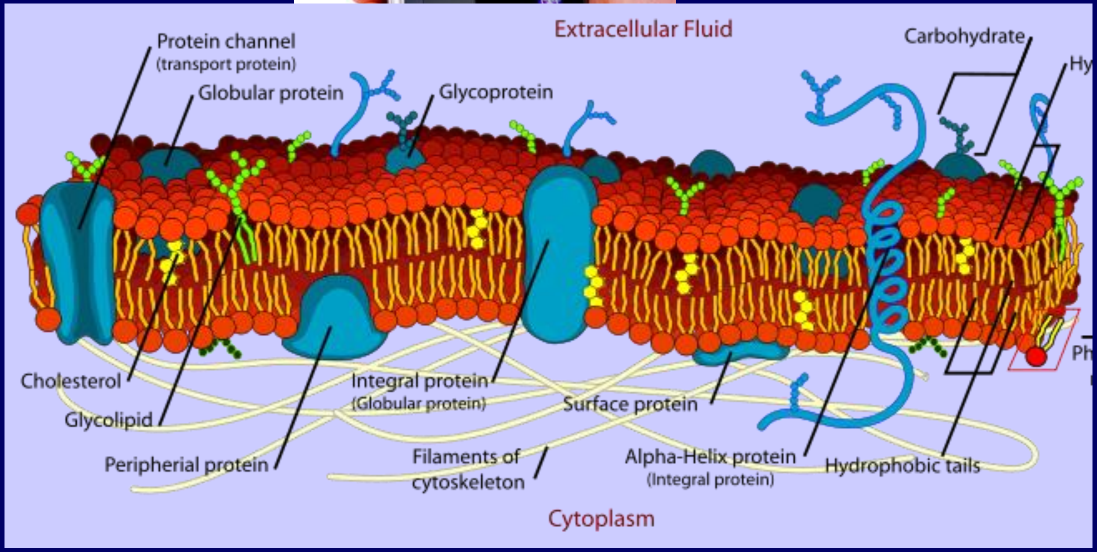


Units:
1 Coulomb/Volt
= 1 Farad (F)

Why Separate Charge?

A way to store *and release* energy!

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



Capacitance of Parallel Plate Capacitor

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

(Between two large plates)

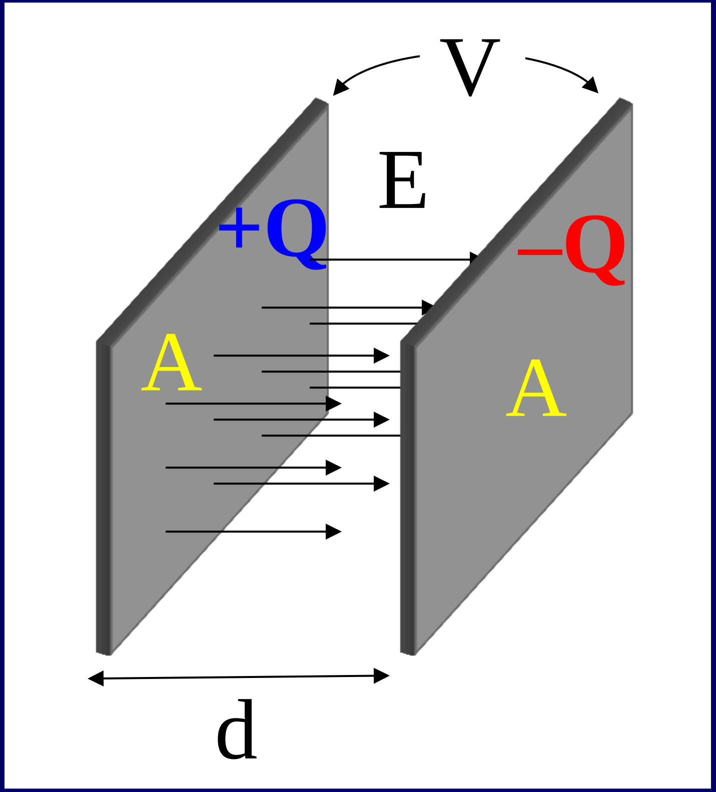
So: $V = 4\pi kQd/A$

Recall: $C \equiv Q/V$

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

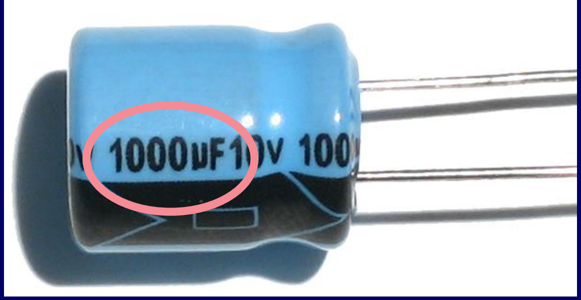
Recall:

$\varepsilon_0 = 1/(4\pi k) = 8.85\text{x}10^{-12}\ C^2/Nm^2$



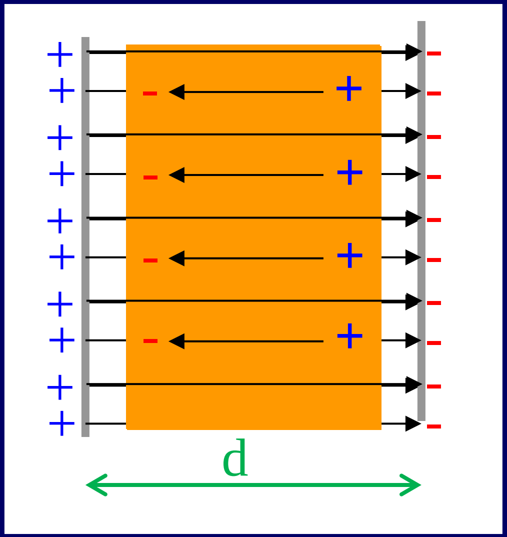
$$\boxed{C = \varepsilon_0 A/d}$$

Parallel plate capacitor



Dielectric

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

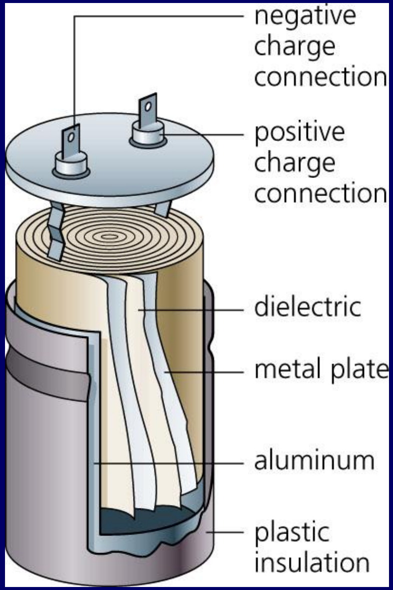


Dielectric constant ($\kappa > 1$)

$$C = \kappa C_0$$

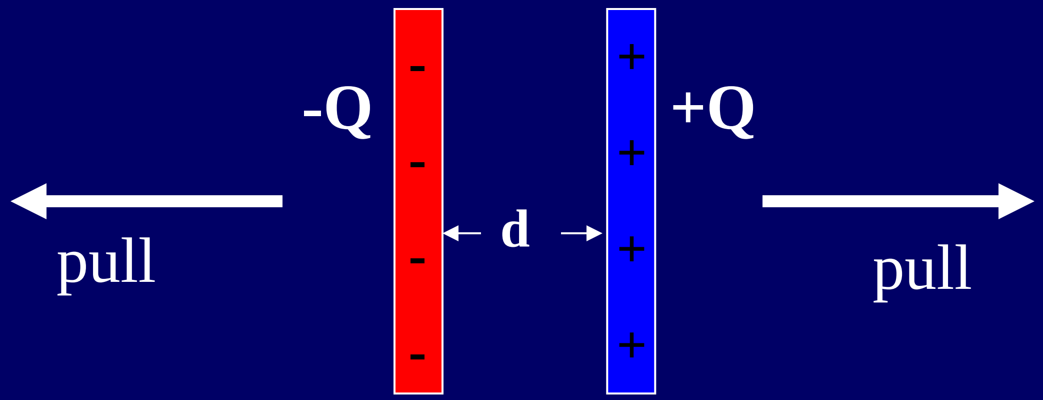
Capacitance **without** dielectric

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?

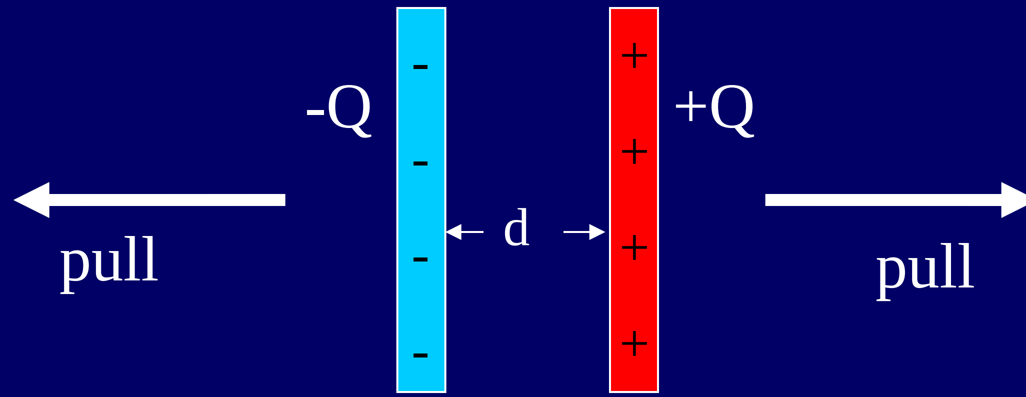
A) Increases

B) Constant

C) Decreases

Remember charge is real/physical. There is no place for the charges to go.

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 — 87% — True — False

$C = \varepsilon_0 A/d$ C decreases!

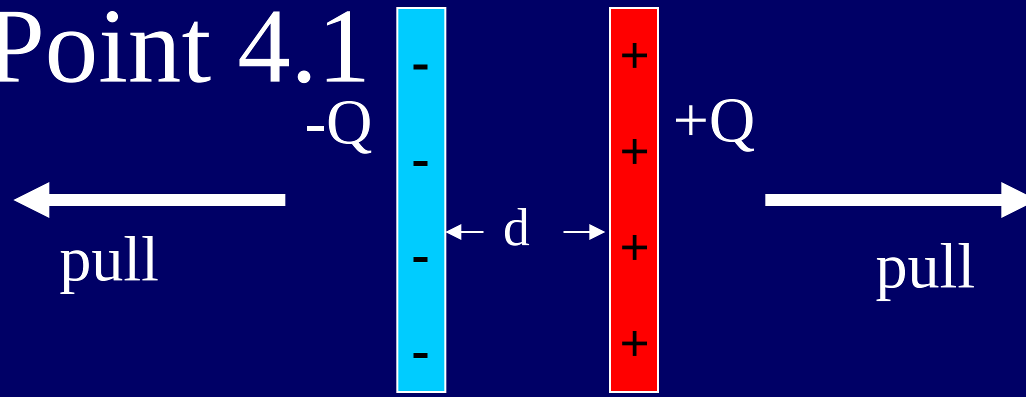
2)The electric field increases — 92% — True — False

$E = Q/(\varepsilon_0 A)$ Constant

3)The voltage between the plates increases — 19% — True — False

$V = Ed$

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

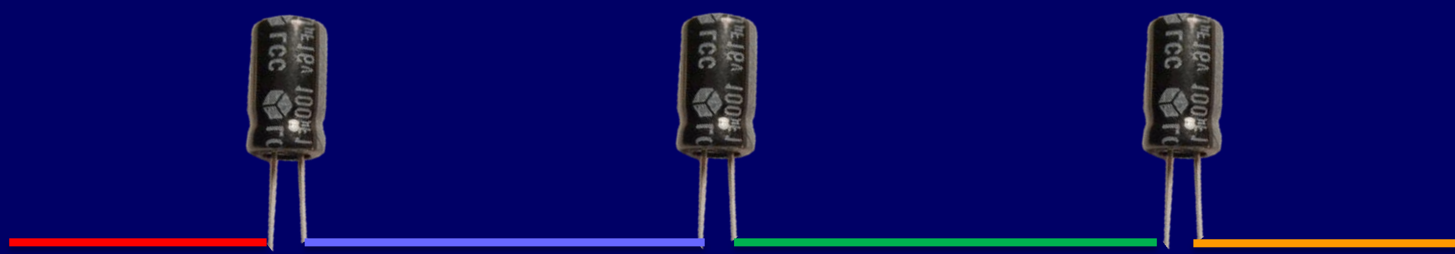
A) increases B) constant C) decreases

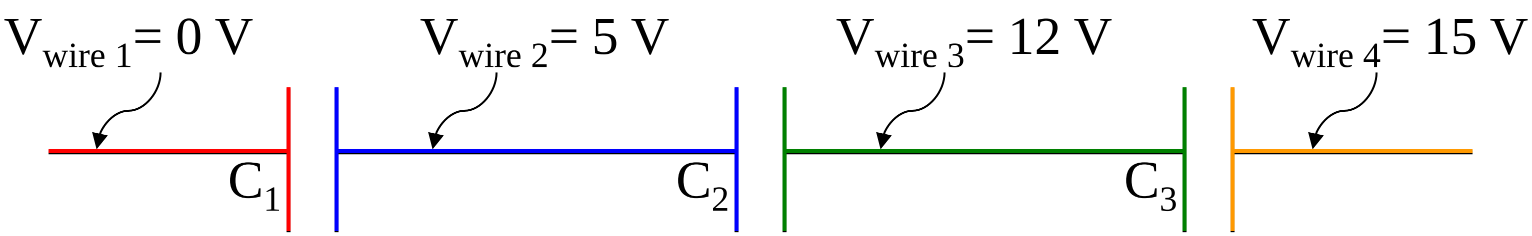
U= ½ QV Q constant, V increased

Plates are attracted to each other, you must pull them apart, so the potential energy of the plates increases.

Capacitors are used in circuits!

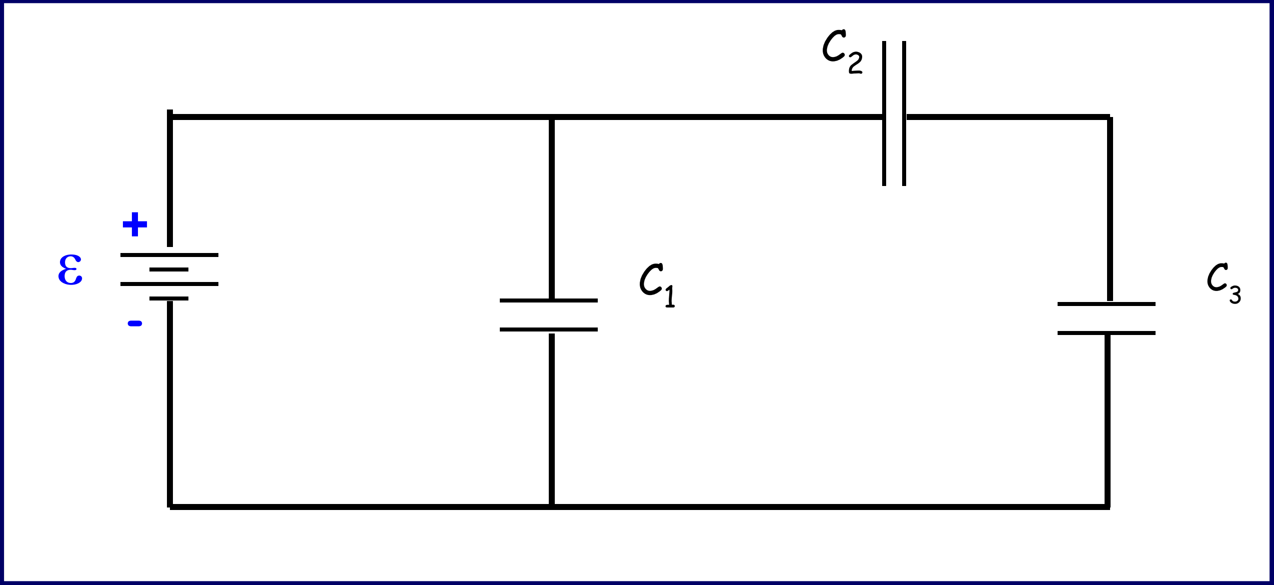
- In circuits, elements are connected by wires.
- Any connected region of wire has the same potential.
- The potential difference across an element is the *element's* "voltage."



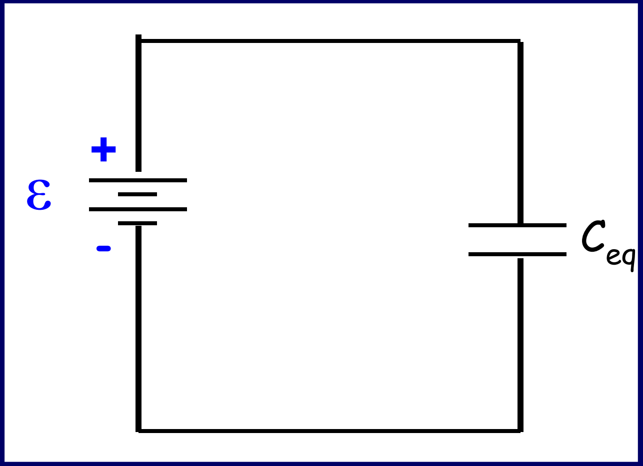


$V_{C_1} = 5-0$ V$= 5$ V $V_{C_2} = 12-5$ V$= 7$ V $V_{C_3} = 15-12$ V$= 3$ V

To understand complex circuits…

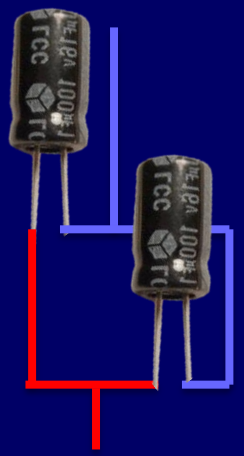


…treat capacitors in series and parallel as a fictitious equivalent capacitor!

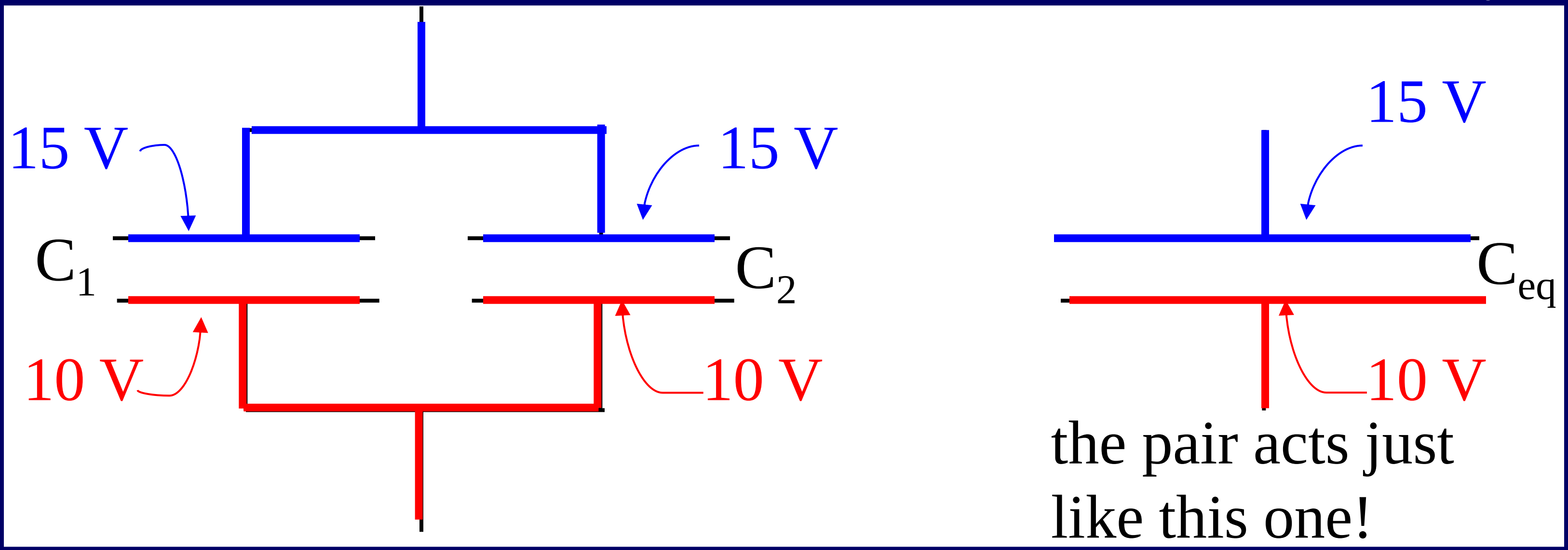


Capacitors in Parallel

- 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

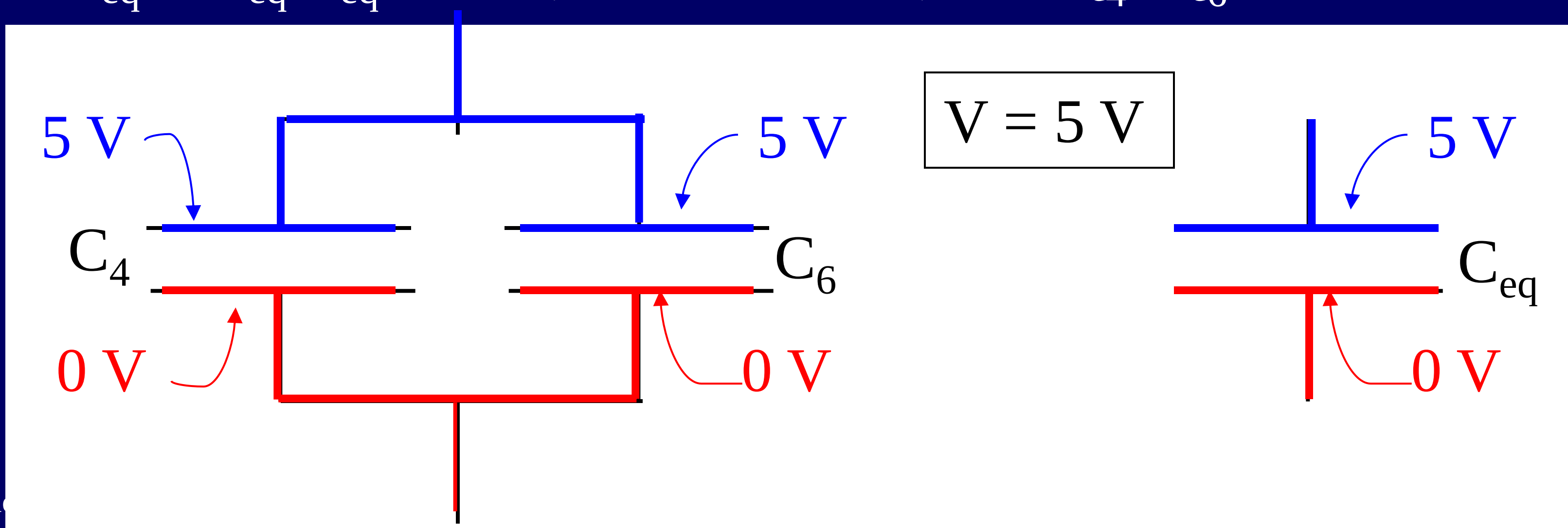
A 4 μF capacitor and 6 μF capacitor are connected in parallel and charged to 5 volts. Calculate C_{eq}, and the charge on each capacitor.

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

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

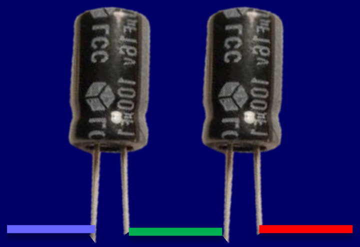
$$Q_6 = C_6 V_6 = (6\ \mu F)(5\ V) = 30\ \mu C$$

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

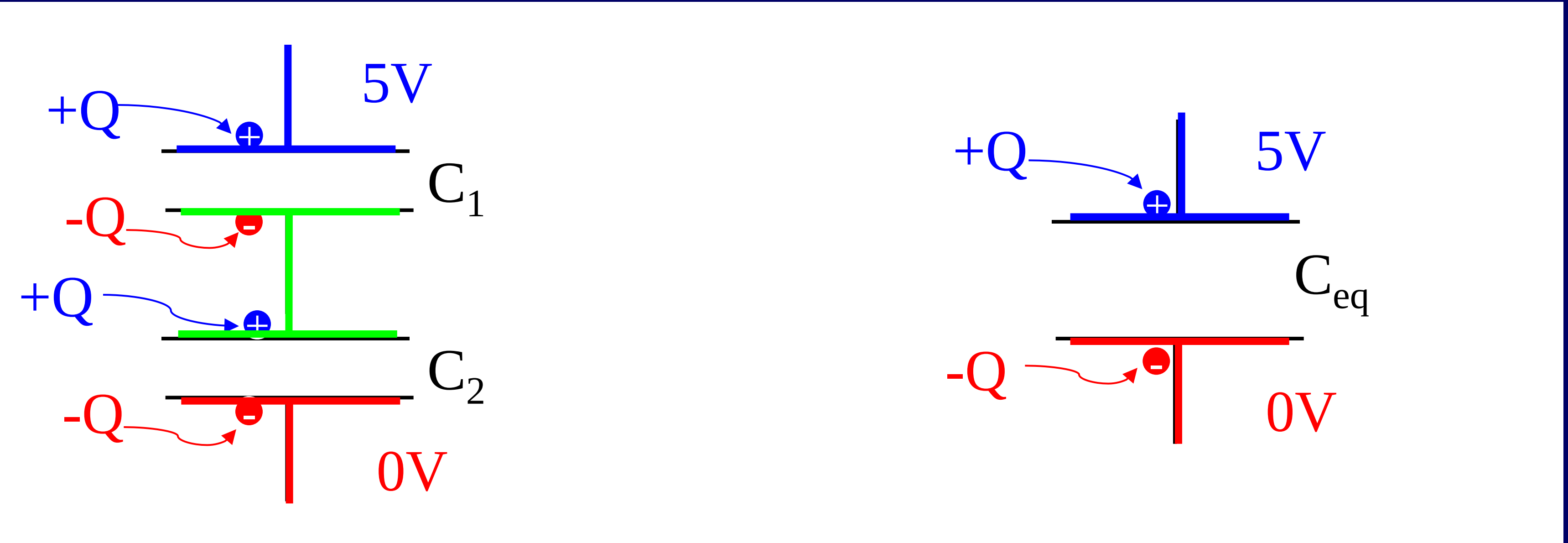


Capacitors in Series

- 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: $\dfrac{1}{C_{eq}} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$ Add d – remember $C=\varepsilon_0 A/d$



Series Practice

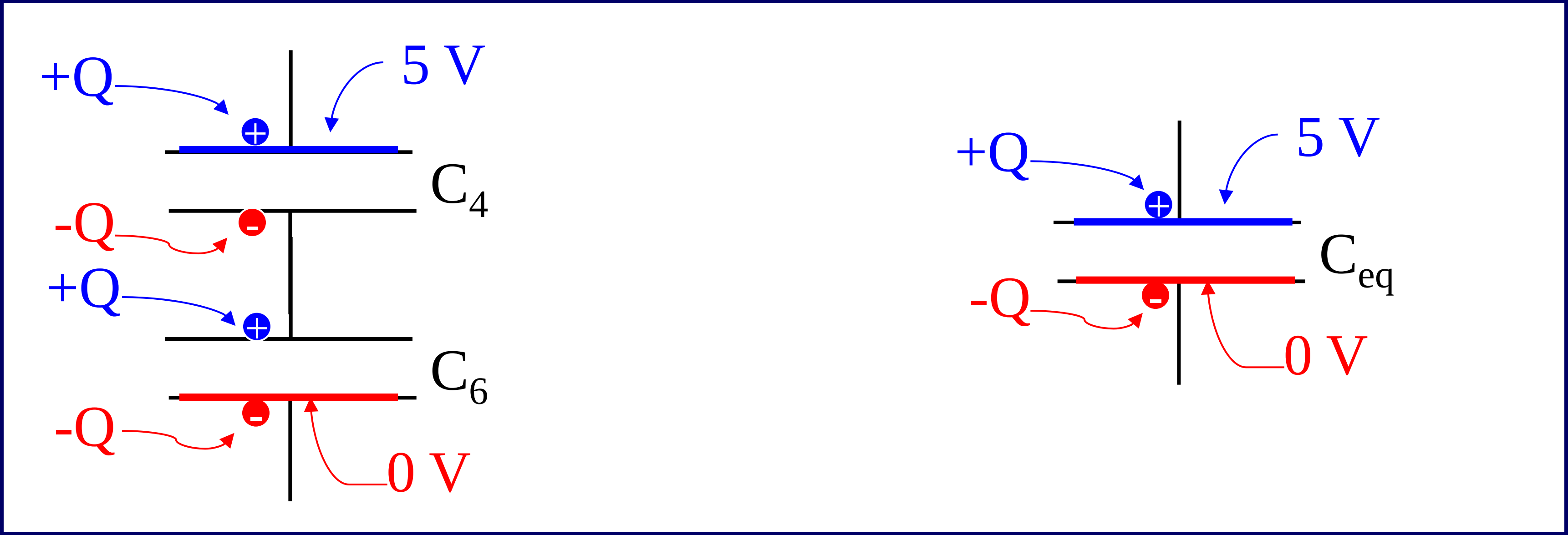
Example

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.

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

$Q = CV$

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



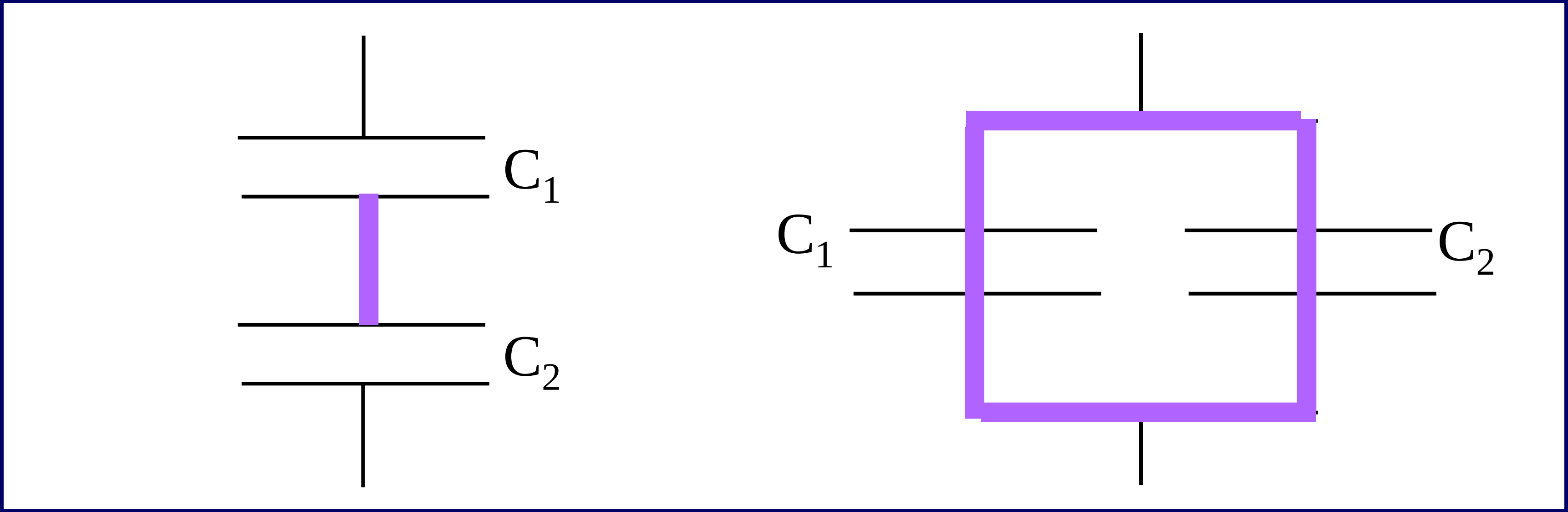
Comparison:
Series vs. *Parallel*

<u>Series</u>

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

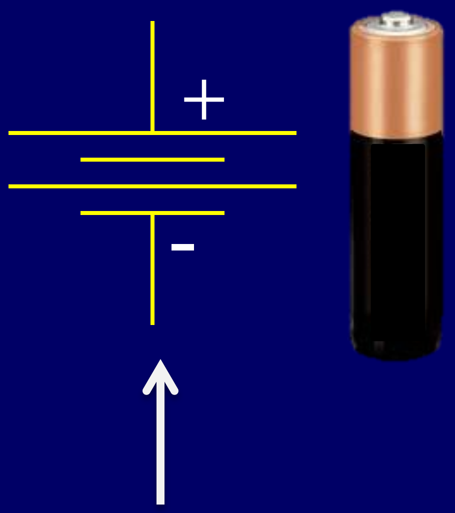
<u>Parallel</u>

- 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.



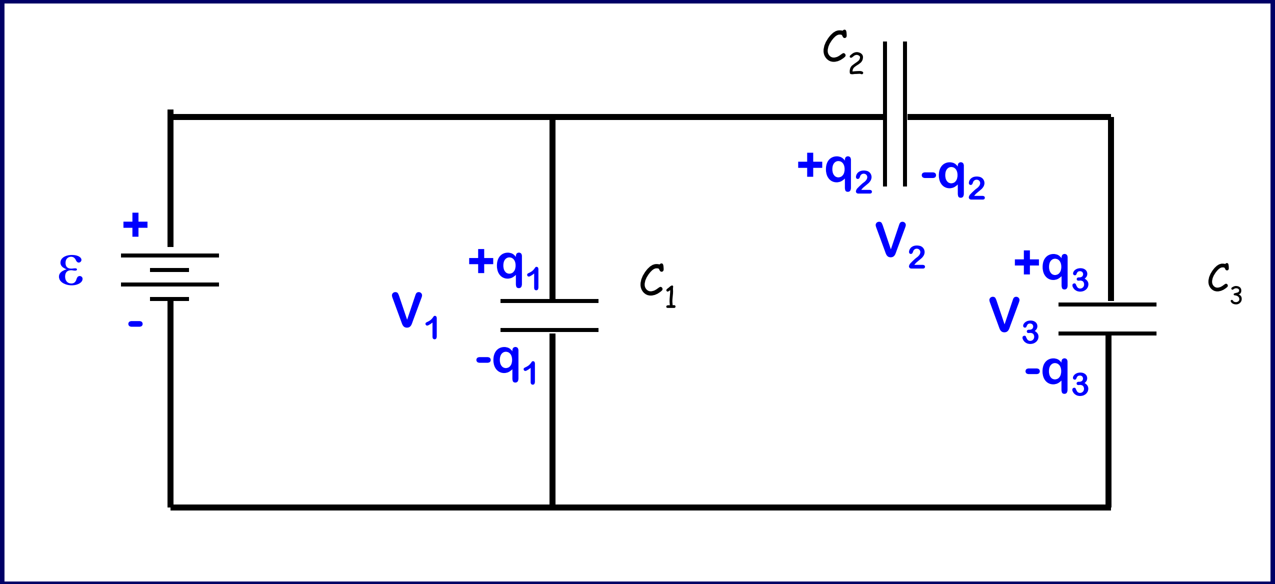
Like a pump for charge!

Usually "0V"
by convention

CheckPoint 4.4

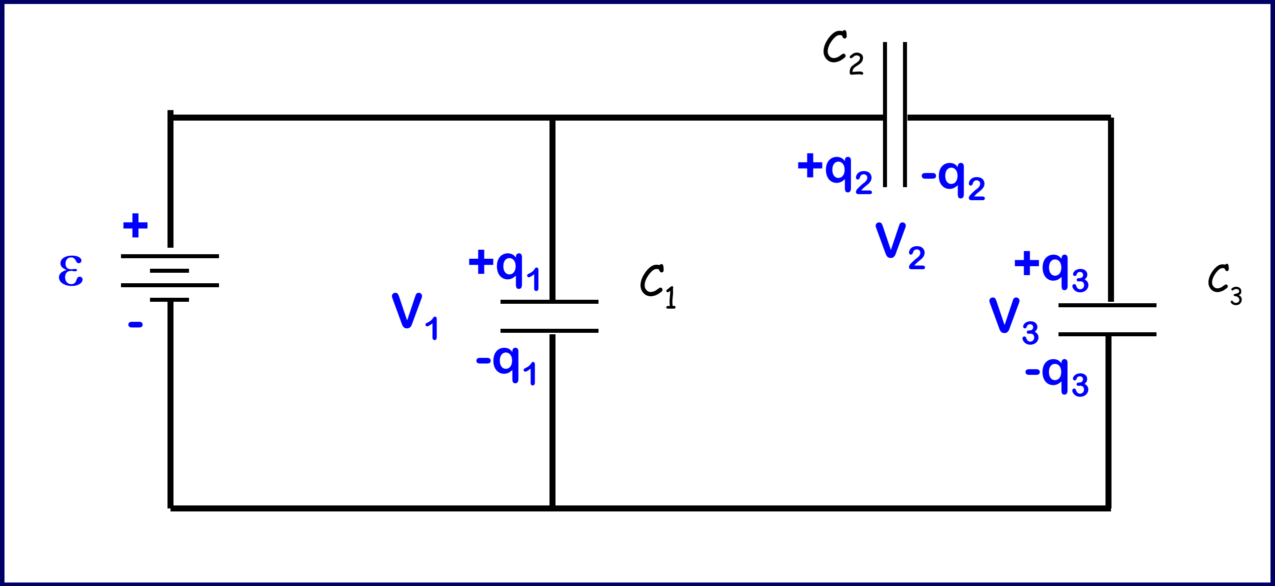
A circuit consists of three initially uncharged capacitors C_1, C_2, and C_3, which are then connected to a battery of emf ε. The capacitors obtain charges q_1, q_2, q_3, and have voltages across their plates V_1, V_2, and V_3. C_{eq} is the equivalent capacitance of the circuit. Which of these are true?

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.

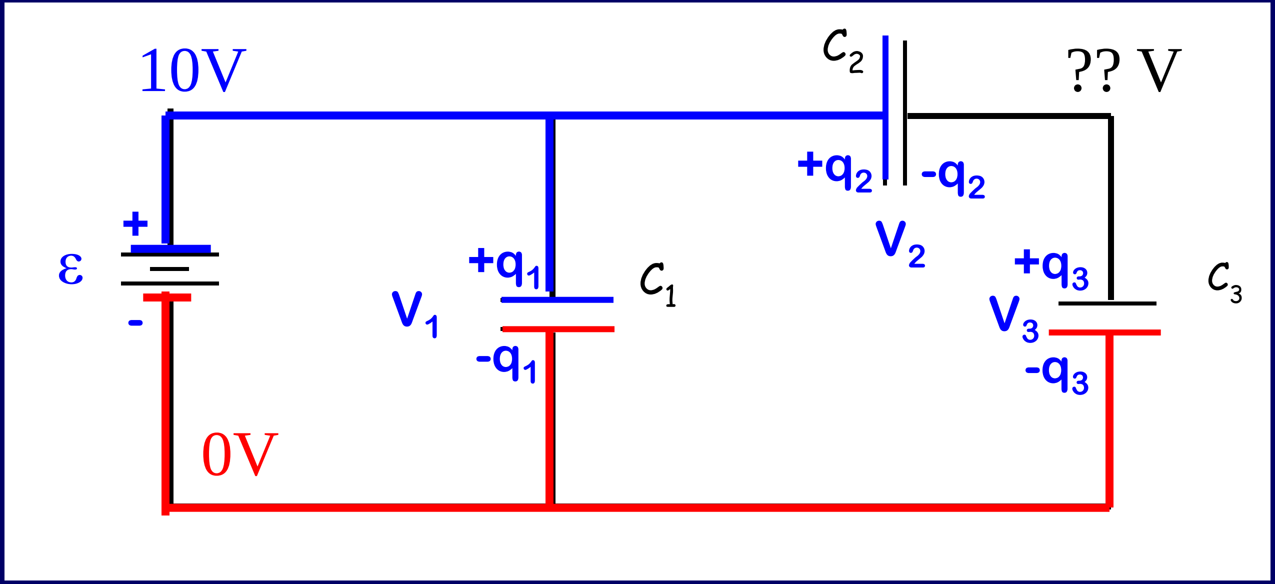


1) $q_1 = q_2$ Not necessarily. C_1 and C_2 are NOT in series.

2) $q_2 = q_3$ Yes! C_2 and C_3 are in series.

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) $V_2 = V_3$ Not necessarily, only if $C_2 = C_3$

2) $\varepsilon = V_1$ Yes! Both ends are connected by wires

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