Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

Announcements

- HW5 Due On Wiley Plus Tonight

Dielectrics (Insulators)

Easy rule to remember…

Everywhere there is an ε_o, change it to $\varepsilon = \kappa\varepsilon_o$.

$$|\vec{F}| = +\frac{1}{4\pi\kappa\varepsilon_0}\frac{QQ}{r^2}$$

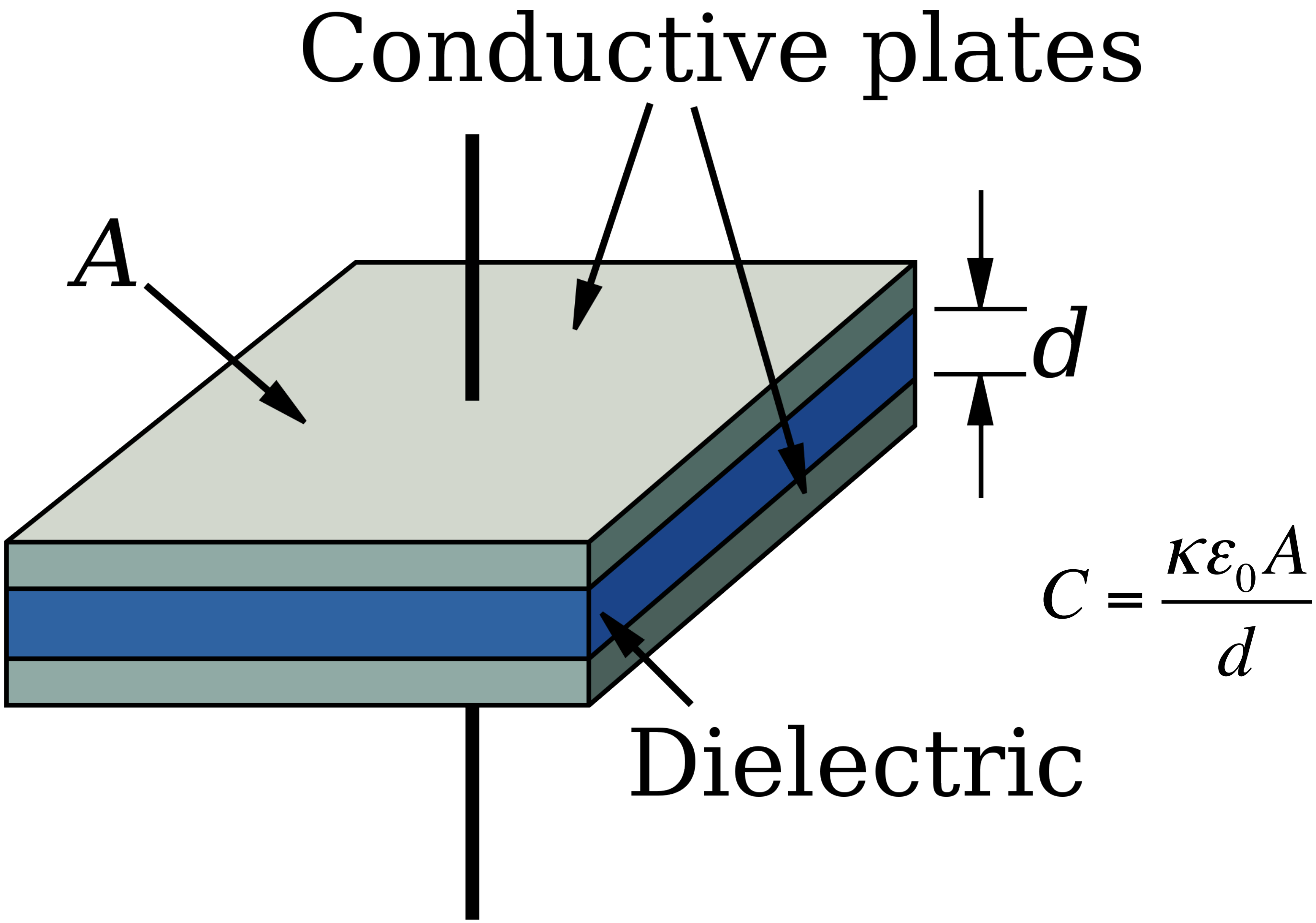
$$C = \frac{\varepsilon_0 A}{d} \Rightarrow \frac{\kappa\varepsilon_0 A}{d}$$

$$\oint \vec{E}\cdot d\vec{a} = \frac{Q_{enc}}{\kappa\varepsilon_0}$$

$$u_{ES} = \frac{1}{2}\varepsilon|\mathbf{E}|^2$$

Vacuum	$\kappa = 1.0000000$
Air	$\kappa = 1.00054$
Paper	$\kappa = 3.5$
Water	$\kappa = 80$
Titanium Ceramic	$\kappa = 130$
Perfect Conductor	$\kappa = \infty$

Capacitor



Conductive plates
A
d
Dielectric
$C = \frac{\kappa \varepsilon_0 A}{d}$

What About Conductors?

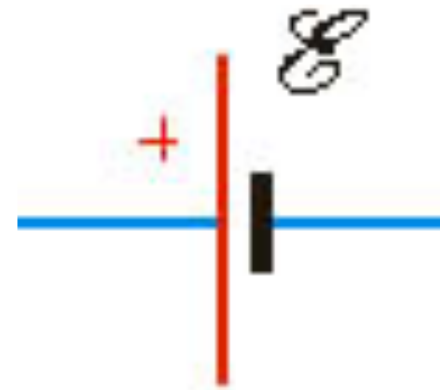
- Why can't you make an awesome capacitor with a conductor in the center?
- Given an infinite dielectric constant, you would think you could store an infinite amount of charge per voltage ($C = Q/V$)
- But, the voltage across a conductor is always zero
- So, the charge is $\infty \times 0$
  - Indeterminate, but in this case 0 wins

Conductors Make Bad Capacitors

- Even an almost-conductor makes a poor dielectric, because it conducts current
- This means that any charge stored on the capacitor will leak through
- This can happen gradually, or very suddenly, in the form of a breakdown

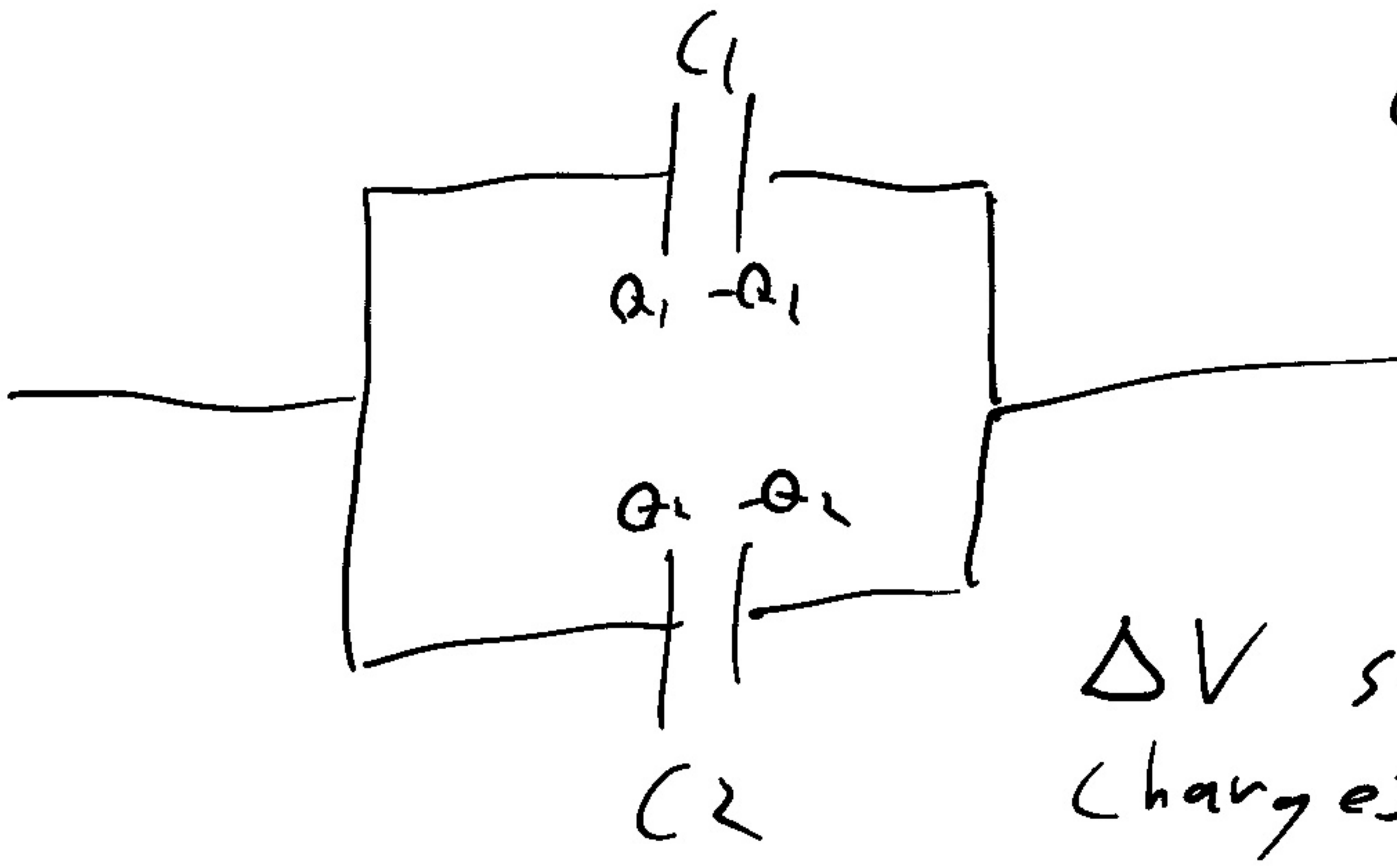
EMF

- EMF = ElectroMotive Force
  - Not actually a force!



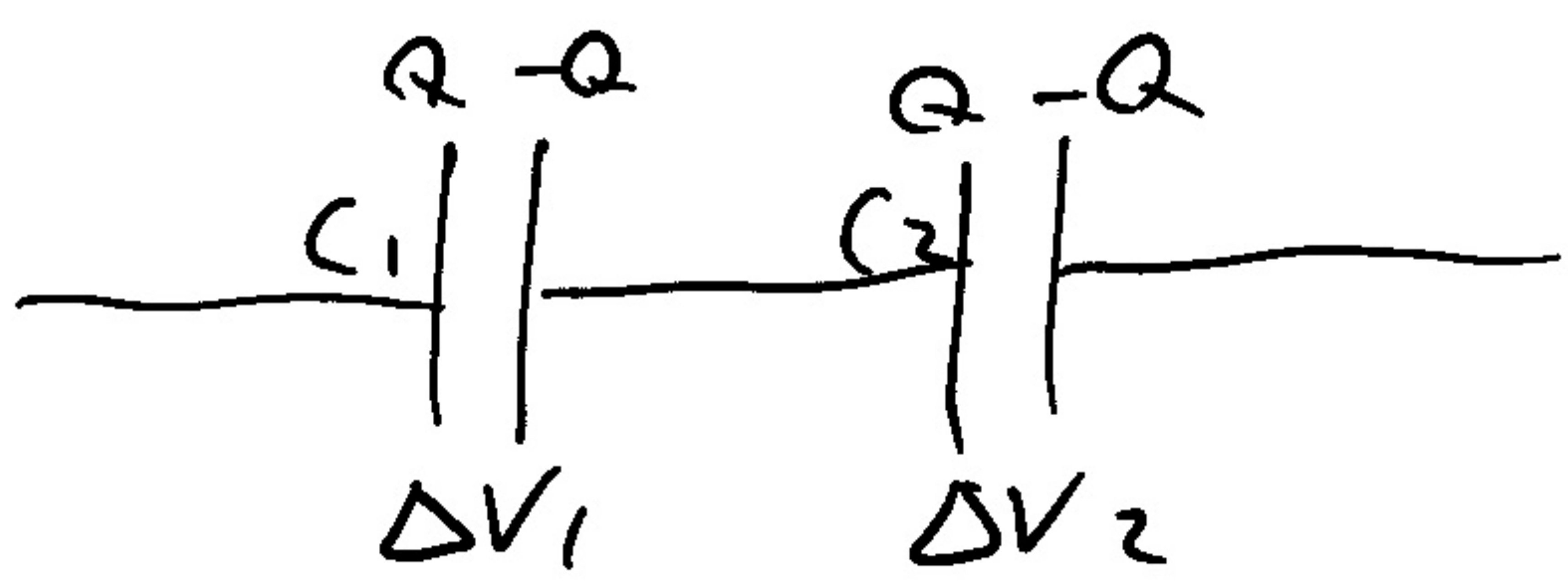
- Think of the EMF as something that produces a voltage difference
  - Could be a battery
  - Could be an electromagnetic power supply
  - Could be a changing magnetic field

$C = Q/V$



ΔV same
charges add

$$Q_{total} = Q_1 + Q_2$$
$$C_{total}\Delta V = C_1 \Delta V + C_2 \Delta V$$
$$C_{total} = C_1 + C_2$$

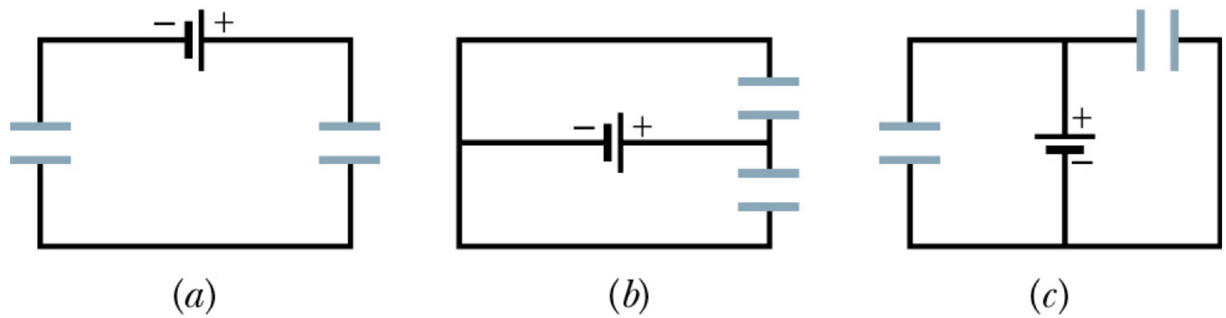


Q same
ΔV's add

$$\Delta V_{total} = \Delta V_1 + \Delta V_2$$
$$Q/C_{total} = Q/C_1 + Q/C_2$$
$$C_{total} = 1/(1/C_1 + 1/C_2)$$

Concept Check

Q16) For each circuit in the figure, are the capacitors connected in series, parallel, or neither?



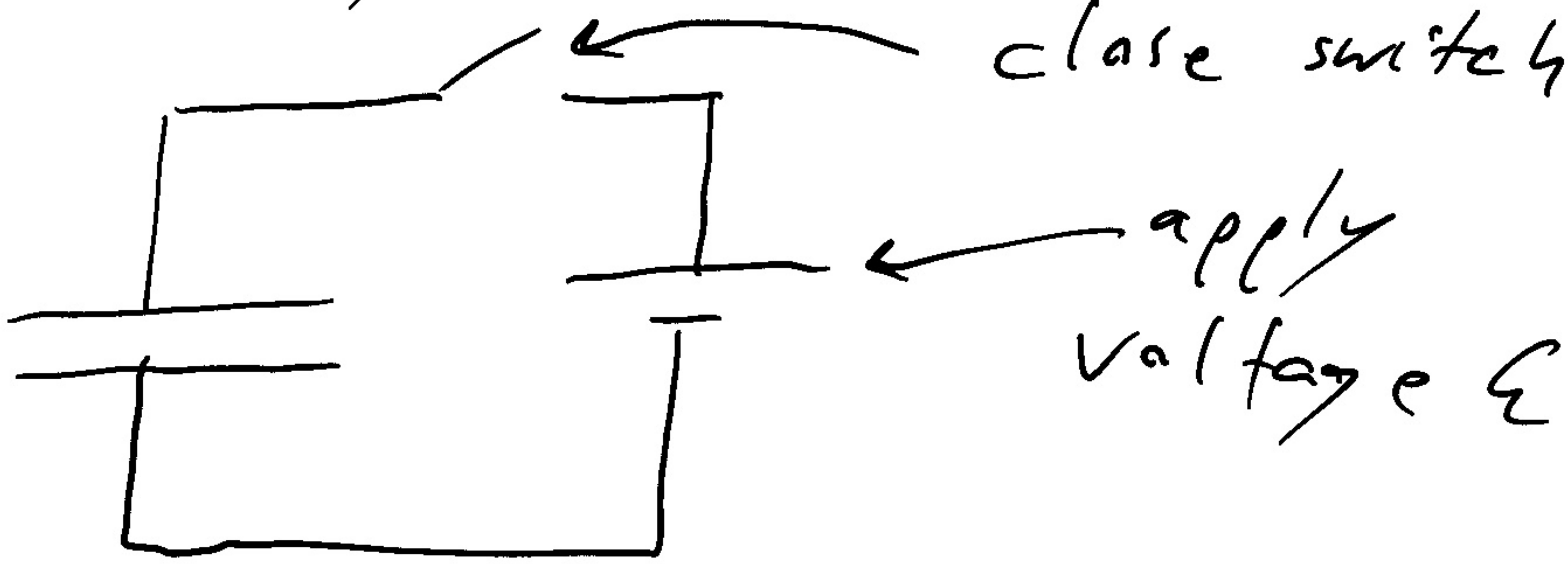
1) (a) series (b) parallel (c) parallel
2) (a) series (b) parallel (c) neither
3) (a) series (b) neither (c) parallel
4) (a) series (b) neither (c) neither
5) (a) parallel (b) parallel (c) parallel

How Do You Charge a Capacitor?

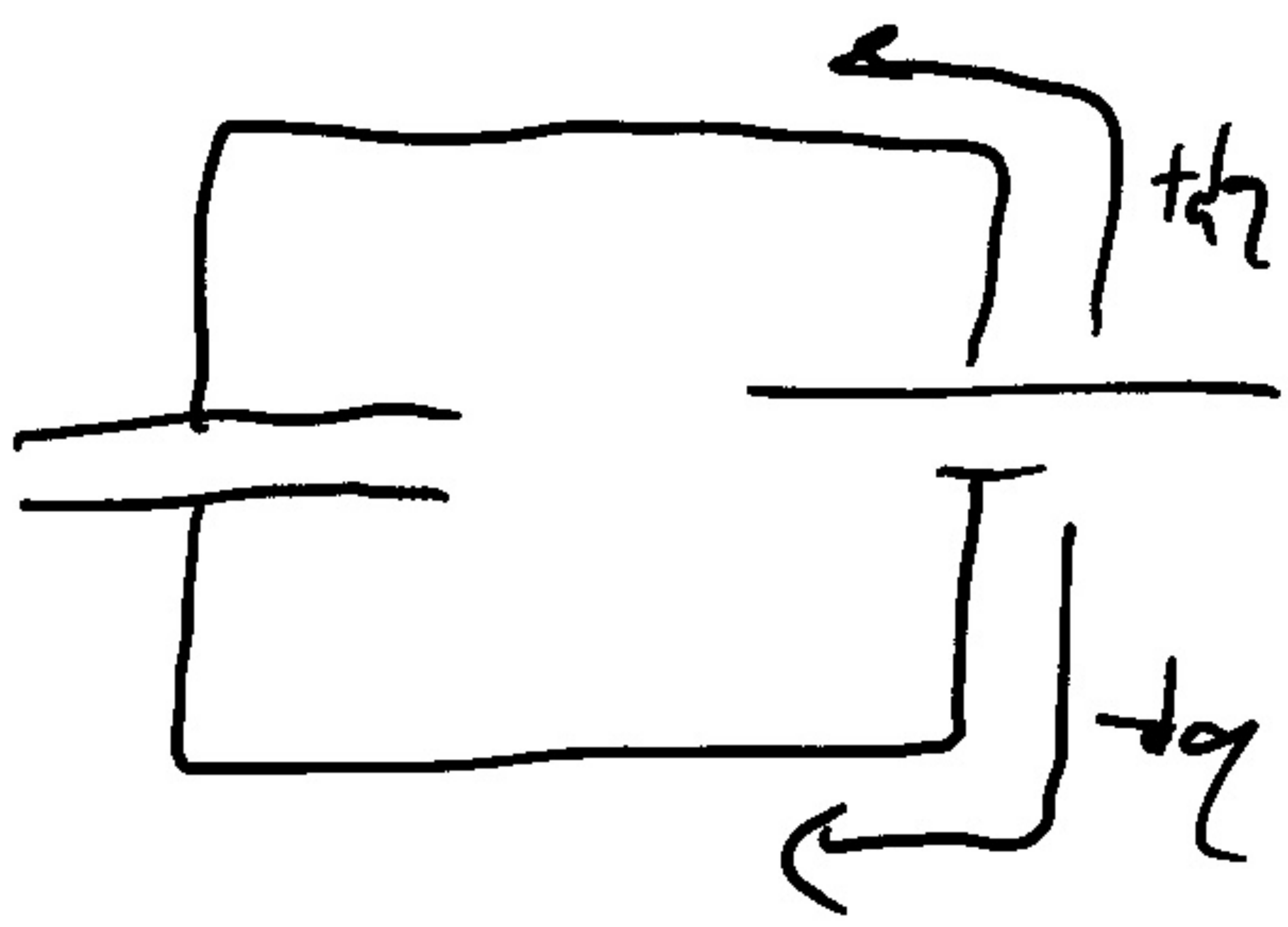
1. Apply a voltage across the capacitor
2. Causes charge to flow to the terminals of the capacitor until it is "fully charged"

- How long does this take?
- How do we represent the flow of charge?

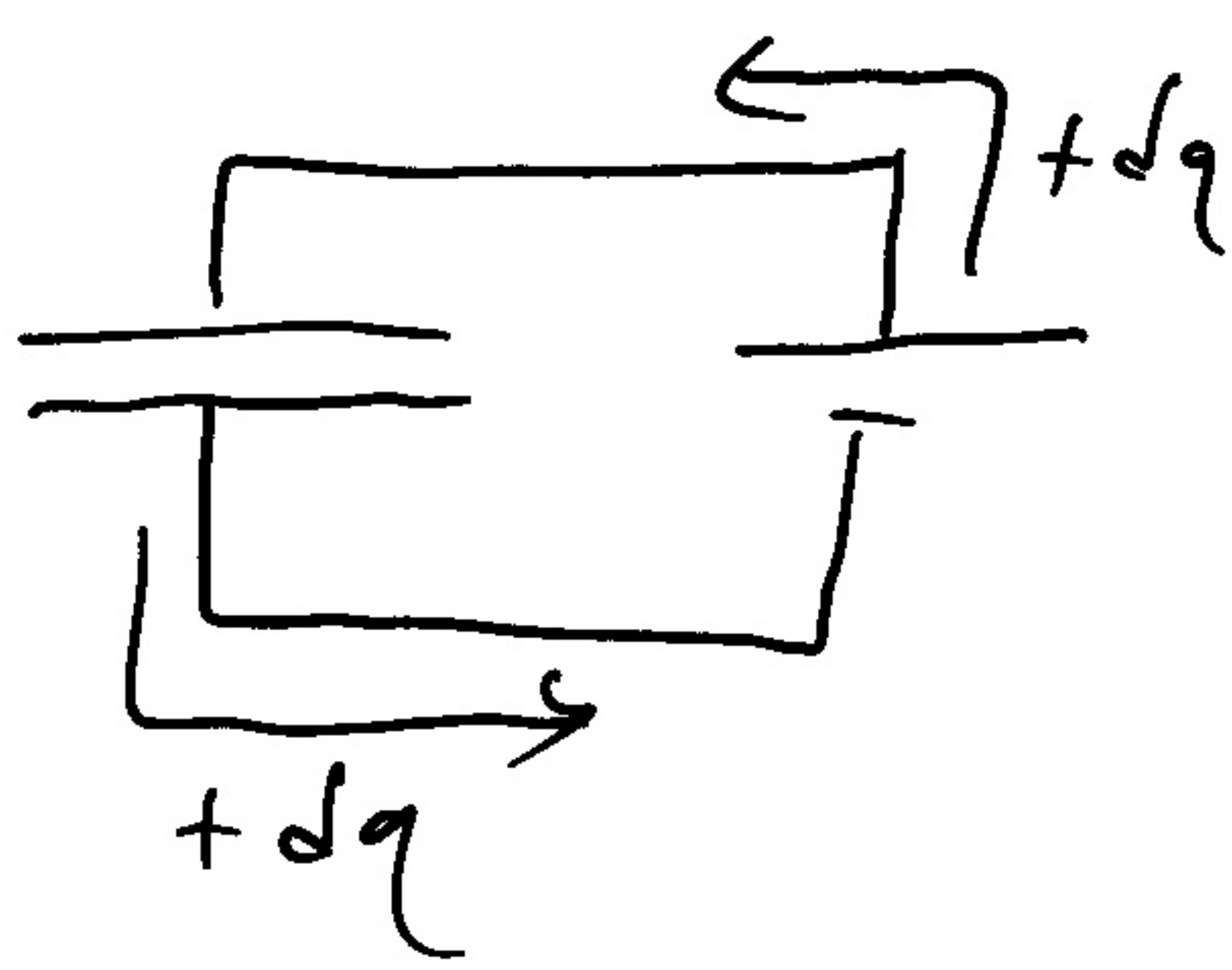
Charging a Capacitor



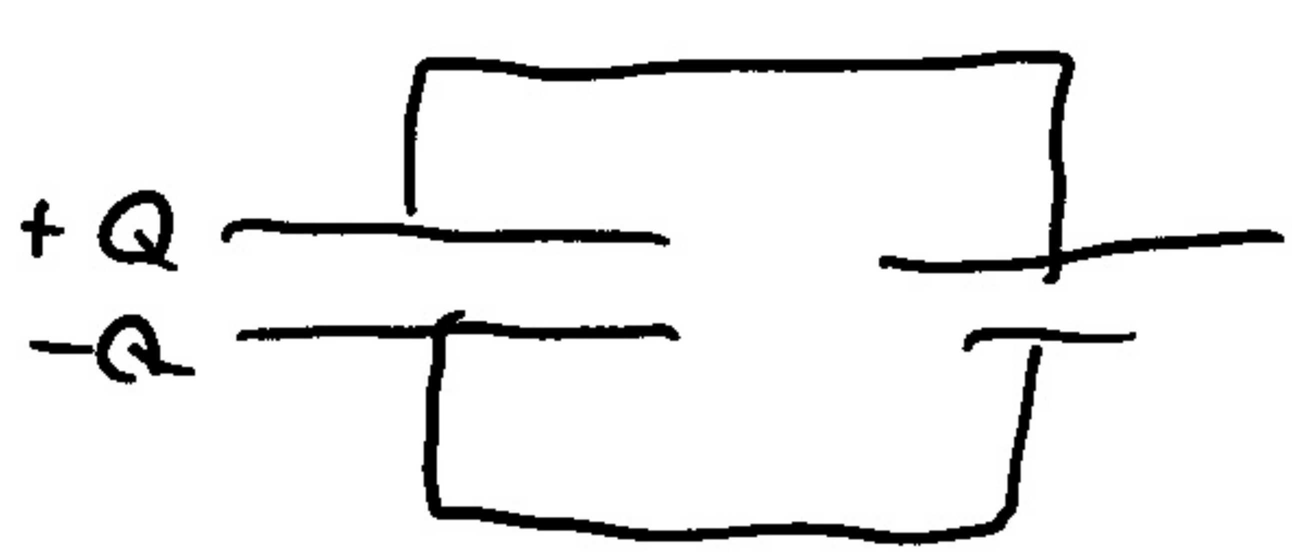
charge flows



or



until



$$Q = CV$$
$$= C\mathcal{E}$$

- very fast unless C is big.
- can slow this down with a resistor

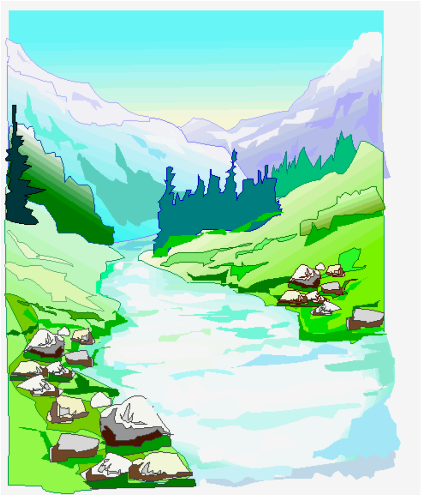
Current

Electric Current

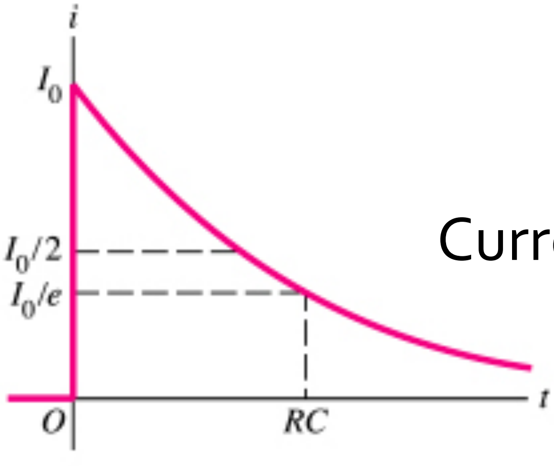
$$I = i \equiv \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt} =$$ Rate of flow of net charge past a point

Units [i] = Coulombs/second = Ampere (A) or "Amp"

- Note that having a finite current does not imply that the net charge at a given point has to change – it just means there is a net charge flowing past that point.

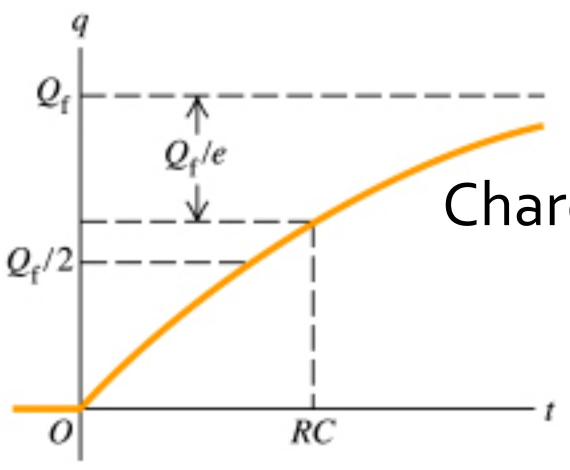


Current Charging Up a Capacitor



(a)

Current



(b)

Charge on Capacitor

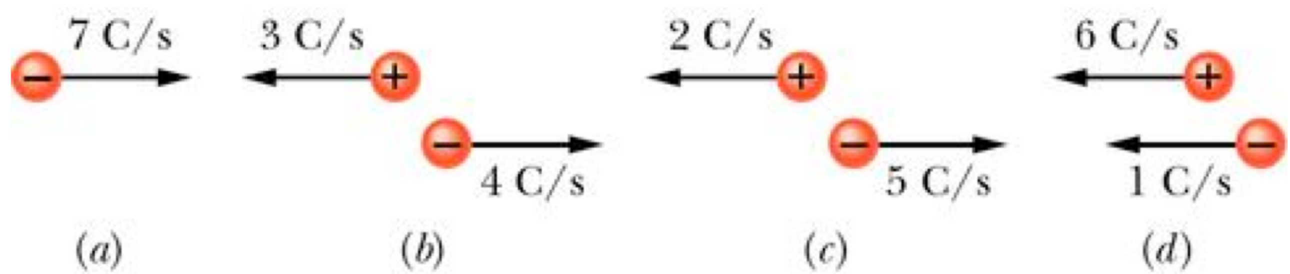
Current Flow

- Current through a capacitor stops once you finish charging it
  - No charge can flow "through" the capacitor – unless it breaks down
- However, there are other electrical components that can support a constant flow of charge through them
  - Example 1: Wire (really easy to make charge flow)
  - Example 2: Resistor (hard to make charge flow)

Concept Check

Q1) The figure below shows four situations in which positive and negative charges move horizontally through a region and gives the rate at which each charge moves. Rank the situations according to the effective current through the regions, greatest first.

1) a = d , c, b
2) a, d, b, c
3) a = b = c, d
4) all tie
5) none of the above



Current

Electrons flow in materials, not the protons, so the negative electric charges are moving.

$$\vec{F} = q\vec{E} = -e\vec{E}$$

Electrons go "upstream" against the electric field vector.

Resistors

Resistance R of a material

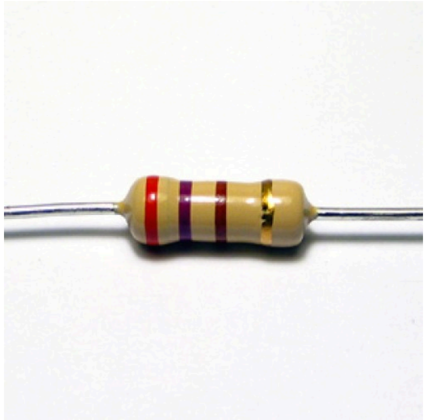
$$R \equiv \frac{V}{i} = \text{constant}$$

Definition of R

"Ohm's Law" $$V = iR$$

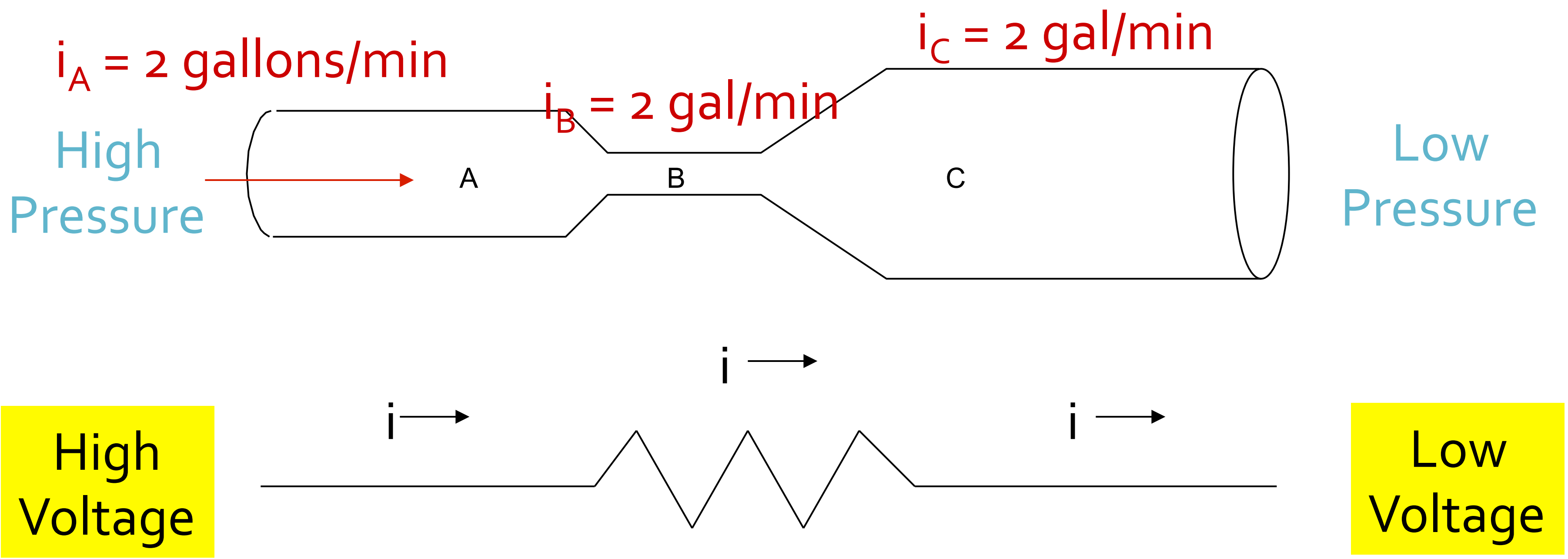
This is not really a physical law.
It is true for perfectly Ohmic materials.

Resistance has units of Ohms = Ω = Volts/Amp

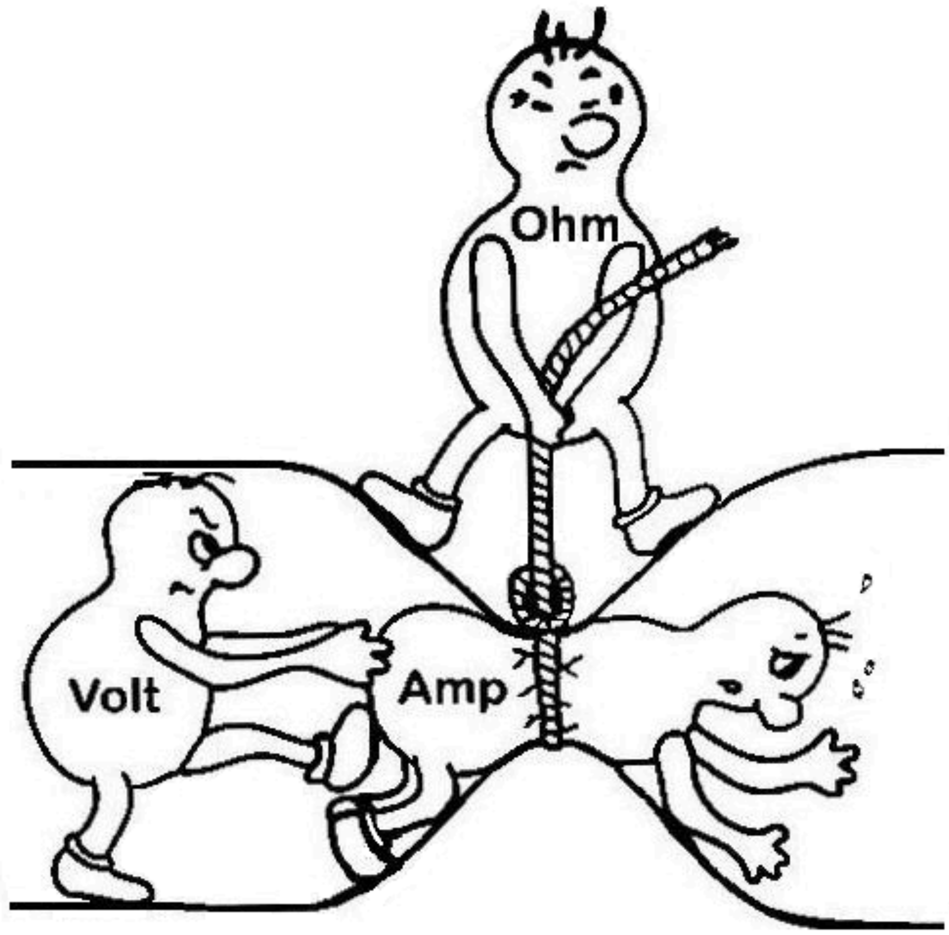


Resistor Analogy

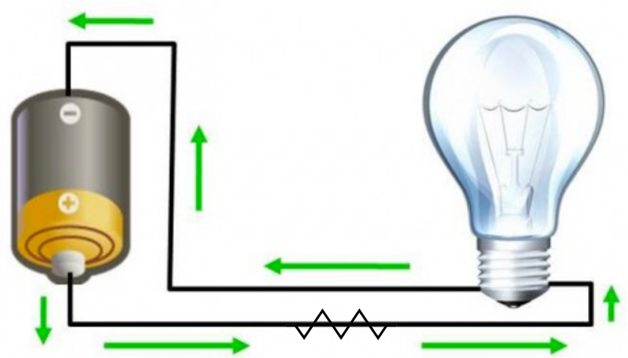
Flow of electrons in wire or resistor is like flow of water in a full pipe (no bubbles or leaks).



Resistor Analogy: Version 2



Concept Check



What if I put a resistor in series between the battery and the light bulb?

Does the light bulb:

A. Get brighter
B. Get dimmer
C. Stay the same
D. Go out
E. Blow Up!