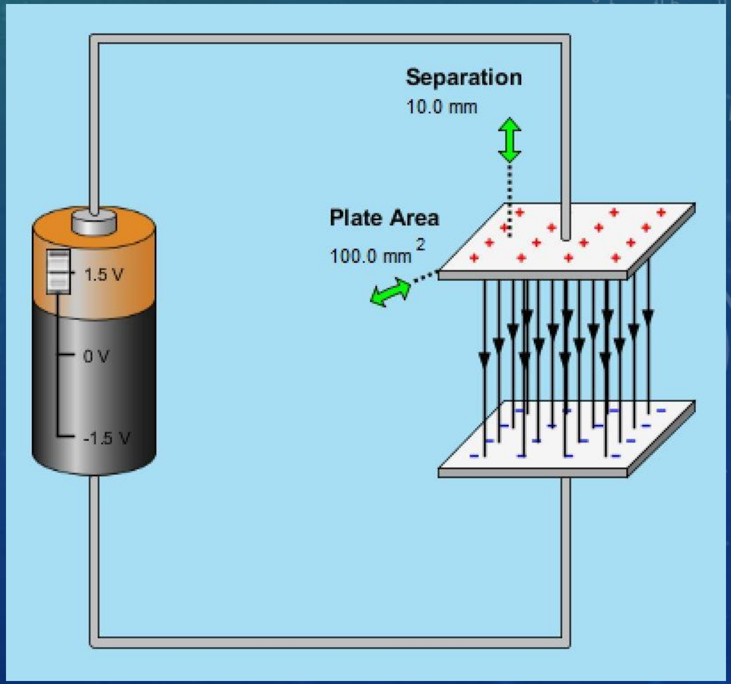
CAPACITORS

PES 1000 – PHYSICS IN EVERYDAY LIFE

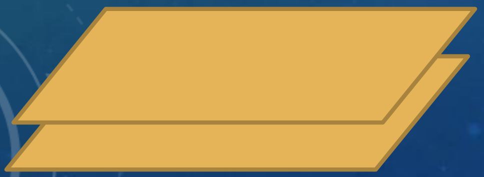
WHAT IS A CAPACITOR?

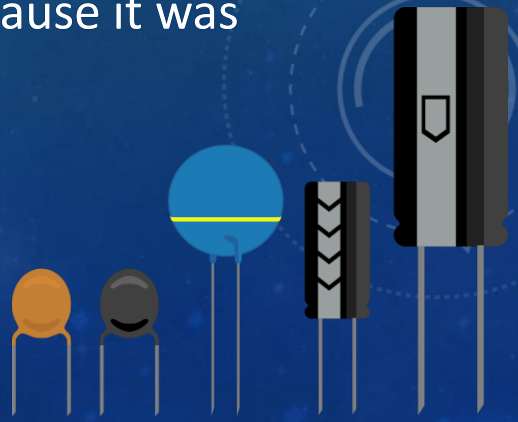
- A capacitor can be formed from any ungrounded conductor or pair of conductors.
  - A very common capacitor is made from two parallel plates of metal.
- Charging a capacitor consists of using a battery to move charge onto one of the conductors until the maximum potential of the battery is reached.
  - The charge usually is transferred from the other conductor, leaving it with an opposite charge.
- The charged capacitor is now storing energy because the separated charges have the potential to rejoin. The energy is being stored within the electric field that exists between the conductors.
- A capacitor is different from a battery because it can discharge (releasing the stored energy) in a very short time interval.
  - Batteries are designed <u>not</u> to do this, but to deliver their energy at a slow, constant rate.



CAPACITANCE

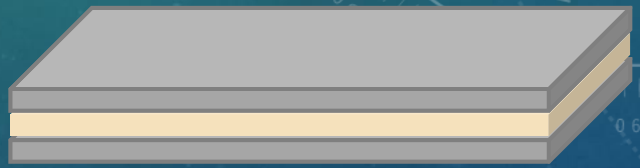
- The ability of a capacitor to store energy is characterized by its *capacitance*. The capacitance is defined as the amount of positive charge moved per unit voltage. $C = Q/V$
    - The capacitance is entirely dependent on the shape and relative positions of the conductors, and not how much or which sign of charge is on them at any particular time.
    - A battery with twice the voltage will move twice the charge, so the doubling cancels out.
- The variable used to measure capacitance is C (not to be confused with the abbreviation for the unit of charge, the Coulomb).
- Capacitance is measured in units of Farads (F). This name may sound familiar because it was named after Michael Faraday. 1 Farad = 1 Coulomb / 1 Volt
- Some common capacitor geometries:
    - Parallel plates, Nested spheres, parallel strips rolled into a cylinder, etc.



DIELECTRIC

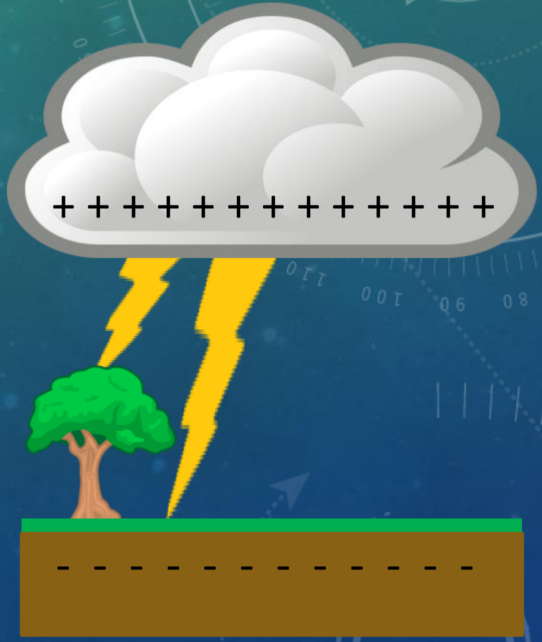
- The closer the plates, the greater the capacitance, BUT the separated charge can accidentally rejoin if any part of one conductor touches the other.
- One way to keep them separated is to put any insulating material between them. Many materials can be used.
  The general name for this material is *dielectric*.



- Not only does the dielectric make the capacitor less likely to accidentally discharge, it actually increases the capacitance in two ways.
  - It allows the conductors to be placed closer together, which increases capacitance.
  - It weakens the electric field, which allows more charge to be transferred to the conductor.
- If the voltage between the conductors is strong enough or if there is a flaw in the dielectric, then the charge will jump between the conductors. This is called *dielectric breakdown*.

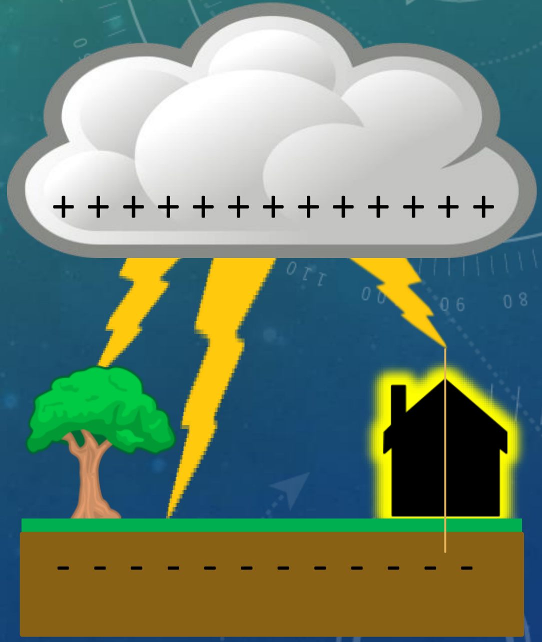
LIGHTNING

- Dielectric breakdown occurs during a lightning storm.
  - The friction between clouds and air transfers charge. One cloud could build up a large positive charge, and the ground below would build up a negative charge in response.
  - The charge is separated by air (an insulator), so the charge remains separate until the voltage reaches enough to cause the dielectric breakdown of the air.
  - The electric charge jumps from cloud to ground in the form of a lightning bolt.
  - The distance of air is less between tall structures and the cloud, so lightning tends to strike them first.



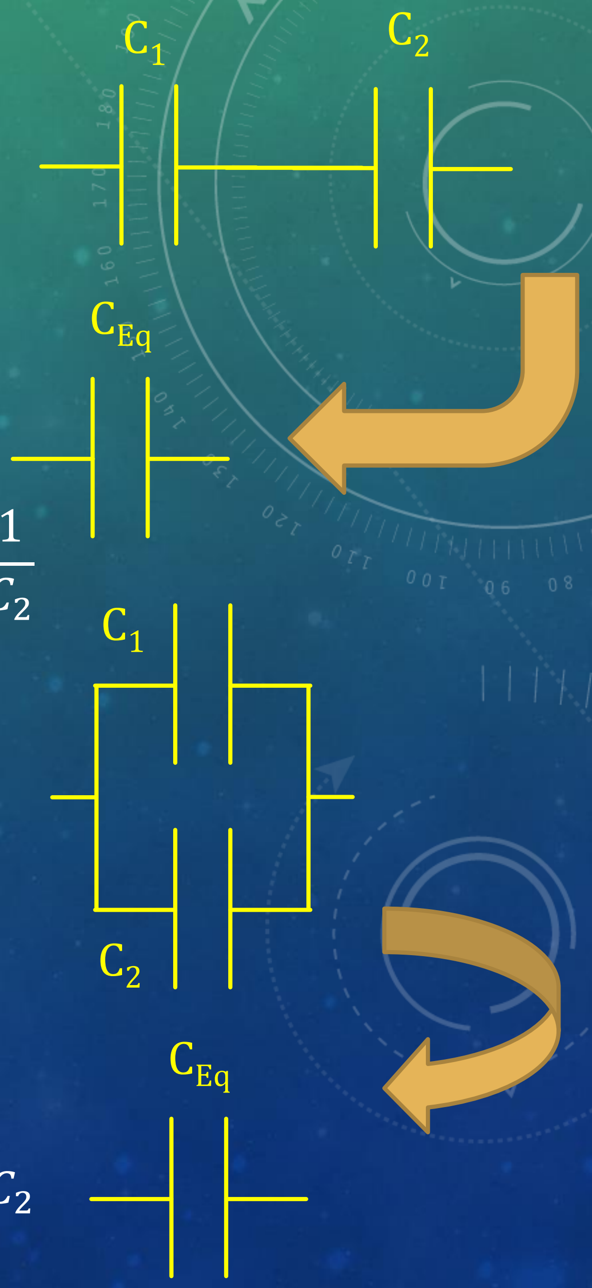
LIGHTNING

- Lightning rods protect the structures to which they are attached in two ways:
  - If lightning strikes, the grounded rod transfers it to the ground without passing through the structure, thus avoiding fire or electrical damage.
  - The rod lowers the chance of a strike to begin with. The charge from the ground tends to flow up to the tip of the rod, which is a sharp point. The charge then escapes from the rod onto nearby particles (*coronal discharge*), thus dissipating the charge, lowering the voltage, and reducing the chance of a strike.



CAPACITORS IN PARALLEL AND SERIES

- The symbol for a capacitor in a circuit looks like two parallel plates.
- As with resistors, collections of capacitors in a circuit can be replaced with a single capacitance for the system. Pairs of capacitors can be combined using the series and parallel rules:
  - Series – capacitance decreases
  - Parallel – capacitance accumulates
  - This is opposite of resistors: resistors in series collectively increase the overall resistance, but in parallel, the collective resistance drops.



$$\frac{1}{C_{Eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

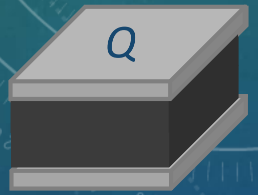
$$C_{Eq} = C_1 + C_2$$

USES FOR CAPACITORS

- In any system that needs energy delivered rapidly, a capacitor can be used.
  - The capacitor (or a bank of capacitors) is charged gradually over time from the power source.
  - The capacitor or capacitors can then be discharged all at once, supplying more energy in a short interval than the power source could have on its own.
  - Application: Flash for a camera – A capacitor is charged from the battery. Then the energy is dumped quickly through the bulb, creating a flash of light.
  - Application: High-power physics experiments – A bank of capacitors is charged from the city power lines. The energy is delivered quickly to the experiment.
- Banks of capacitors are used in an alternating current power delivery system.
  - Capacitors are used to regulate the oscillation of the alternating current to compensate for other components in the system and deliver power most efficiently.

CAPACITIVE SENSORS

- Since the capacitance of a pair of conductors depends on their geometry, then changes in their geometry can be detected by looking for a change in their capacitance.
  - Imagine two parallel plates separated by a distance with a flexible dielectric.
  - Using a battery, charge is transferred from one to the other, and the battery is disconnected.
  - The voltage between the plates is the same as the battery's original voltage.
  - Now imagine that the plates are moved closer together. This increases their capacitance.
  - Since the amount of charge hasn't changed, the voltage between them must decrease.
  - So detecting a voltage drop means the plates have been pushed together.
- This is the principle behind computer keys, for instance. The key press causes a voltage drop which the computer detects.



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

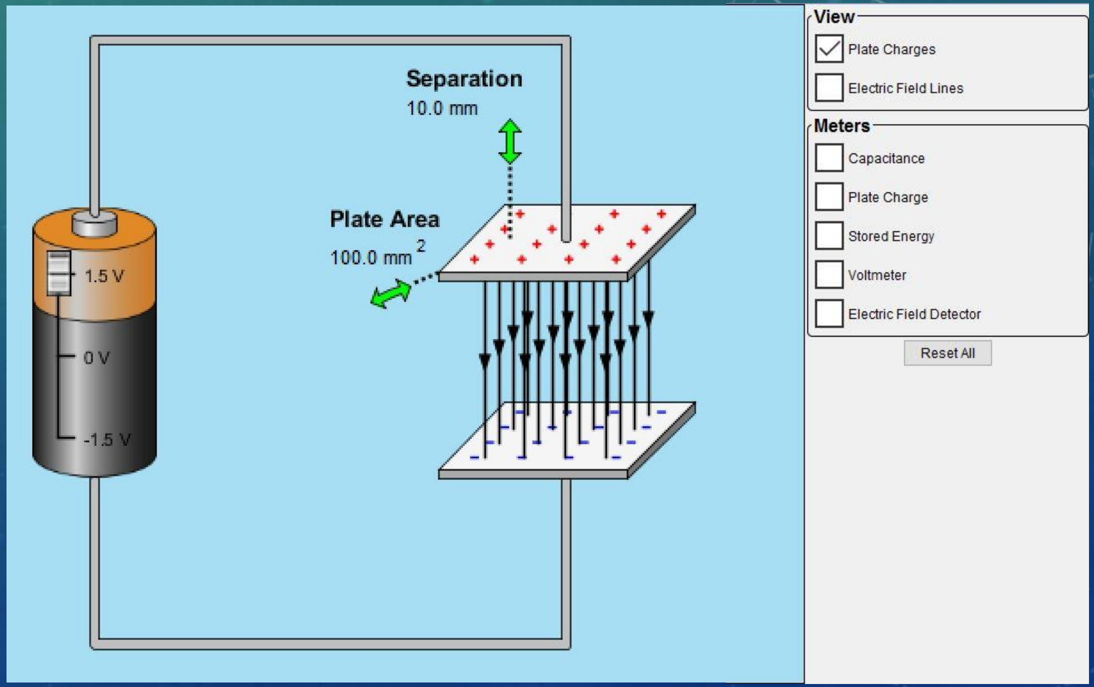
Or

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

CAPACITOR SIMULATION

- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/capacitor-lab

- Things to do:
  - On the 'Intro' tab:
    - Check the 'Capacitance' and 'Electric Field Lines' boxes.
    - Observe the capacitance change as the Separation distance changes and as the Plate Area changes.
  - On the 'Dielectric' tab:
    - Check the 'Capacitance' and 'Electric Field Lines'
    - Observe the capacitance change as you slide the Dielectric between the plates.
  - On the 'Multiple Capacitors'
    - Check the 'Total Capacitance' box.
    - Observe the capacitance of different circuits.



CONCLUSION

- A capacitor is composed of two conductors that can hold opposite charges, thereby storing electrical energy.
- Capacitance is the measure of the energy storage capacity. It is measured in Farads.
- Material placed between the conductors (a dielectric) increases both the structural strength and the capacitance.
- Capacitors can be connected in parallel and series, and they have combination rules similar but distinct to the rules for resistors.
- Capacitors are useful whenever a quick delivery of power is needed or to modulate AC systems.