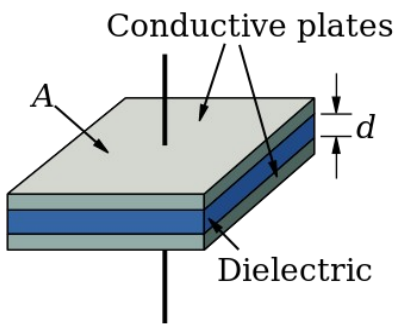
Prelab: Capacitors

A capacitor is a two-terminal device that stores electrical energy. Unlike a battery, which stores electro-chemical energy (energy stored in chemical bonds), a capacitor works by providing a way to separate positive and negative charges. Capacitors are extremely useful for a number of applications including energy storage, smoothing out voltage fluctuations or noise in electronic circuits, and for timing applications as we shall see.

A (normal) capacitor consists of three parts:

- Each terminal is connected to a conductor with large surface area, which is called a **plate**. (Even though it's usually not rigid).
- In between the two plates, there is a thin isolating layer called a **dielectric**. (It can be vacuum, but it is usually some non-conducting material like paper.)

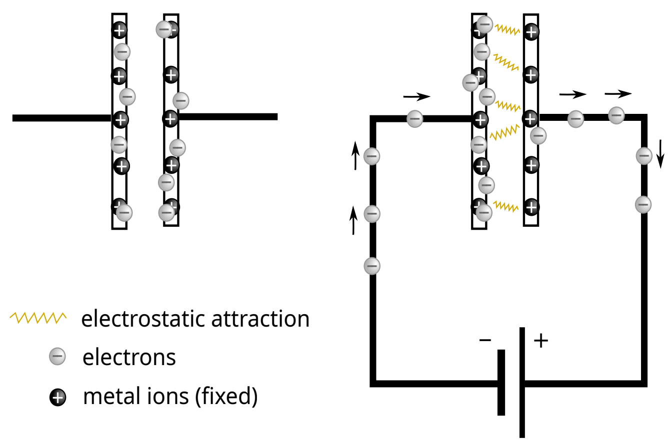


Because there is a "gap" between the two plates, it is important to note that **no electrons can move from one plate to the other**.

Even though no charges can move across the capacitor, once we connect it to a battery, something interesting happens (see right):

The electrons on the right side of the capacitor get **depleted**, i.e., start to move to the "+" terminal of the battery. At the same time electrons from the "–" terminal of the battery flow towards the left side of the capacitor.

However, electrons repel each other, so the electrons should be pushed right back into the battery, right? No, some of the electrons can stay on the left side of capacitor since they are held in place by the attraction to the "+" ions on the right of the capacitor.



Thus we have a current through the circuit (electrons moving towards one side of the capacitor and away from the other. This does not go on forever: once more and more electrons are building up on one side, they start repeling each other more and more strongly, and the current becomes smaller and smaller. Eventually, enough charge has built up such that the electric attraction across the capacitor is equal to the repulsion on either side. The capacitor is then fully charged and the current is zero.

The efficiency of a capacitor in storing charge is called its **capacitance** (***C***). Looking at the picture above, we realize that the capacitance should grow as we make the area *A* of the plates bigger, as more charges will "fit". It should also improve when me make the distance *d* between the plates smaller, as this increases the attraction between charges on both sides. Also it should improve if we find a dialectric that is particular good at "amplifying" the attraction between the opposite plates, given by a amplification factor κ ("kappa"). The formula for the capacitance of a plate capacitor is thus:

$$C = \epsilon_0 \kappa \frac{A}{d}$$

The constant $\epsilon_0 \approx 9\text{nF}/\text{m}$ ("epsilon naught") is just a constant of proportionality.

The SI unit of capacitance is **Farad** (**F**), which is a ridiculously large unit: if you see a capacitor with a capacitance of more than "1 F", back away, very slowly. Typical capacitors have a capacitance of nano-Farad (1 nF = 0.000 000 001 F) or micro-Farad (1 µF = 0.000 001 F).

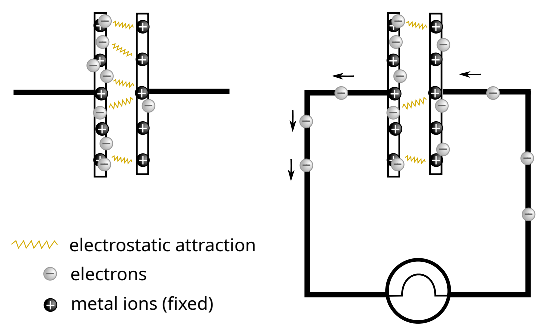
The charge Q than can be stored in a capacitor is related to the voltage (V) of the charging source and the capacitance of the capacitor. One finds:

$$\text{(charge)} = \text{(capacitance)} \times \text{(voltage)}$$

$$Q = CV$$

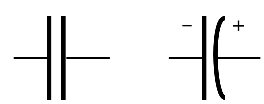
Once all the charge is stored inside of the capacitor, the voltage across the capacitor will be equal to the voltage of the battery that was used to charge it.

Now we can disconnect the capacitor from the battery and we have a charged capacitor. We can now use the energy stored in the capacitor to do something useful[1], like powering a light bulb: once we connect the capacitor to a light bulb, the electrons will flow into the **opposite** direction in an effort to equilibrate charge on the two sides.



In this case, the capacitor provides large current and large voltage at the beginning, which quickly drops until the last charge is drained from the capacitor.

The circuit symbols for a capacitor are shown on the right. A plate capacitor can be used in either direction, while an electrolyte capacitor must be used in the proper polarity, or it will get hot and potentially break (and making an unbelievable mess, if I might add).



1 *One also can do something decisively not useful, like charging all the capacitors we can find and putting them in drawer such that next person who needs one gets horribly zapped.*