AP Physics - Capacitance

We've already looked at capacitors when we talked about Leyden jars. The Leyden jar being, as mentioned before, the very first capacitor. Capacitor technology has evolved quite a bit since the days of Ben Franklin and they are no longer made with jars and metal foil.

A capacitor is simply two conductors separated by an insulator. The insulator is given a fancy name - ***dielectric***.

The dielectric can be almost anything that doesn't conduct electricity – paper, plastic, rubber, wax, air, &tc.

Capacitors can be very small or very large. Most of them are made up from metal foils separated by thin plastic or paper sheets. These things are then rolled up and put into little metal cans (for the bigger ones) or covered with a glob of plastic or ceramic if they are small.

Capacitors store charge and are very useful in electronics. They are rated on their ***capacitance***, which is the ratio of stored charge to the potential difference.

$$C = \frac{Q}{V}$$ Equation for capacitance.

C is the capacitance, ***Q*** is the stored charge, and ***V*** is the potential difference across the two plates.

The unit for capacitance is the ***farad*** whose symbol is ***F***. The farad is named after a famous electricity physicist (whose discoveries we have not yet gotten to, but, have no fear, we will), Michael Faraday.

A farad is a Coulomb per volt.

$$1\,F = 1\frac{C}{V}$$

The farad is a very large amount of capacitance, so when you look at a capacitor, you don't see farads listed, mostly you see μF and pF.

$$1\,\mu F = 10^{-6} F \qquad 1\,pF = 10^{-12}\,F$$

- A 3.0 pF capacitor is connected to a 12 V battery. What is the charge on the capacitor?

$$C = \frac{Q}{V} \qquad Q = CV = \left(3.0\,x\,10^{-12} F\right)\left(12\,V\right) = \boxed{3.6\,x\,10^{-11} C}$$

Finding Capacitance:

The equation for capacitance when the two plates are separated by air is:

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

Where **C** is the capacitance, ϵ_0 is the permittivity of free space, **A** is the area of the capacitor's plates, and **d** is the distance between the plates. The value for the permittivity of free space, which has to do with how well lines of force travel through air is:

$$\epsilon_0 = 8.85 \, x \, 10^{-12} \frac{C^2}{N \cdot m^2}$$

- A parallel plate capacitor has an area of 2.00 cm^2. Plate separation is 0.100 mm. capacitance?

First we will convert the area to square meters:

$$2.00 \, \cancel{cm}^2 \left(\frac{1 \, m}{10^2 \, \cancel{cm}} \right)^2 = 2.00 \, x \, 10^{-4} \, m^2$$

Next we will convert the plate separation to meters.

$$1.00 \, \cancel{mm} \left(\frac{1 \, m}{10^3 \, \cancel{mm}} \right) = 1.00 \, x \, 10^{-3} \, m$$

Now we can use the capacitance equation to figure out the answer.

$$C = \frac{\epsilon_0 A}{d} = \left(8.85 \, x \, 10^{-12} \frac{C^2}{N \cdot \cancel{m}^2} \right) \frac{\left(2.00 \, x \, 10^{-4} \, \cancel{m}^2\right)}{\left(1.00 \, x \, 10^{-3} \, m\right)}$$

$$C = 17.7 \, x \, 10^{-13} F = 1.77 \, x \, 10^{-12} F = \boxed{1.77 \, pF}$$

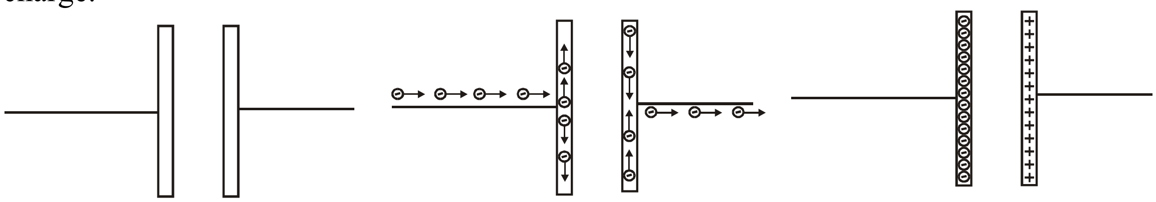
Equations are very powerful things. We can look at them and make predictions and figure out what is really going on. We can do this with the capacitance equation.

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

What happens to capacitance if the area of the plates increases or gets smaller? What happens if the plates are moved closer together? Moved farther apart?

Energy Stored in Capacitor: Capacitors store energy. We can think of them as potential energy devices.

When you first put a capacitor into a circuit, the device has no charge. If electricity is allowed to flow, electrons will begin to charge up the capacitor. It takes time for the charge to build up. Eventually the capacitor will have all the charge that it can hold and electricity will stop flowing. The capacitor will have maximum potential energy at this point and store its maximum amount of charge.



Uncharged capacitor | *Capacitor charging Electricity flows* | *Charged capacitor no electricity flows*

When electrons first begin to flow, they pile up on one of the plates. This plate becomes more and more negative as the electrons collect. The electrons on the plate across the dielectric are repelled by the strong negative charge on the oppostite plate, so they begin to flow. The current direction is the same on either side of the capacitor. As more and more electrons collect on the negative plate, fewer and fewer free electrons remain on the other plate. It has a positive charge that gets bigger and bigger as time goes by. As the negative charge increases, the flow of electrons slows down. The flow of electrons on the other side of the capacitor slows down as well as there ain't many electrons left on the postive plate to flow. Eventually the negative plate has as many electrons as it can possibly hold and the flow of electrons stops. The capacitor is completely charged. This is exactly what happened with the Leyden jar.

The charged capacitor has a large amount of charge. If we give the thing a path for the electrons to flow, all the charge will immediately go rushing out. Remember the spark when the Leyden jar discharged? Capacitors are used to deliver big amounts of sudden charge. They are used in flash units for camera. A small little battery puts charge into a large capacitor. When you take a picture, all the stored charge is immediately released to a high voltage xenon bulb that makes a very bright flash of light.

The potential energy stored in the capacitor is the product of the charge and the voltage (potential difference). The average potential energy in the capacitor is half of the total amount of energy it will have when fully charged, so we can write:

$$U = \frac{1}{2}QV$$ Average potential energy stored in capacitor.

We know that the charge is related to the capacitance by:

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

We can plug this into the potential energy equation:

$$U = \frac{1}{2}QV \qquad = \frac{1}{2}(CV)V \qquad = \qquad \frac{1}{2}CV^2$$

So we have two equations we can use for potential energy stored in a capacitor:

$$U = \frac{1}{2}QV \qquad = \frac{1}{2}CV^2$$

This is the form of the equations that you will see on the equation sheets for the AP Physics Test.

- A 12.5 μF capacitor is connected across a 9.0 V battery. Find the potential energy stored in the thing.

$$U = \frac{1}{2}CV^2 \qquad = \frac{1}{2}\left(12.5\,x\,10^{-12}\,F\right)\left(9.0\,V\right)^2 \qquad = \qquad \boxed{5.1\,x\,10^{-10}\,J}$$