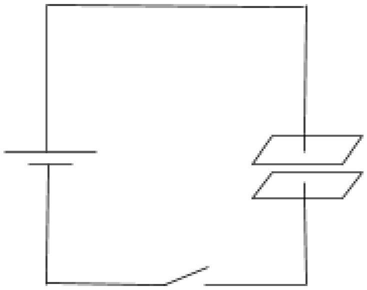
Capacitor Structure

For this discussion, we are going to concentrate on the most conventional arrangement of conductors called the *parallel-plate capacitor.* It is given this name because it is made of two conducting plates of equal area (*A*) that are separated by a constant distance (*d*). At the beginning, we are going to assume there is only air between the plates, but will later look at what would happen if we place different insulating materials in the gap.



Note: This is not a proper circuit diagram since I have used pictures of parallel plates instead of the symbol for a capacitor.

In the arrangement shown, we are going to consider the plates of the capacitor to be uncharged initially. This does not mean there are no charges on the plates, simply there is not a *net* charge on the plates. When the switch is closed, the positive side of the battery will begin to pull electrons from the top plate and the negative side of the battery will push electrons to the bottom plate. For our purposes, we will assume no charges can pass through the air gap between the plates. As we discussed in previous units, this will make the top plate positive and the bottom plate negative.

The separation of charges will establish an electric field between the plates. If we assume the size of the plates is large compared to the distance between them, we can show the electric field between the plates is a constant $E = \frac{q}{\varepsilon_0 A}$ where ε_0 is the permittivity of free space and *q* is the amount of charge on a plate. As the amount of charge on each plate increases, the electric field between them also increases. The potential difference between two points in a constant electric field can be calculated by multiplying the distance along the field line by the value of the field. This means the potential difference (*V*) between the plates is $V = Ed = (\frac{q}{\varepsilon_0 A})d = \frac{qd}{\varepsilon_0 A}$. As you can see, there is a constant ratio between the net charge on a plate and the potential difference across the plates. ***This ratio is called the capacitance of the object (*** $C = \frac{q}{V}$ ***).*** If we do a bit of manipulation, we can show the capacitance is determined by the geometry of the arrangement $C = \frac{q}{V} = \frac{q}{\frac{qd}{\varepsilon_0 A}} = \frac{\varepsilon_0 A}{d}$.

From the equation, you can see that you can change the capacitance by either changing the area of the plates or the distance between them. The permittivity of free space describes the ability of the electric field to permeate a vacuum. If we don't have a vacuum between the plates, we must use a modification of this constant. Dielectric materials are materials that are poor conductors, but will become polar in an electric field. The ratio of the permittivity of the material to that of free space is called the **dielectric constant** $\kappa = \frac{\varepsilon}{\varepsilon_0}$. Taking this into account, the capacitance equation can be written as $C = \frac{\varepsilon A}{d}$ where $\varepsilon = \kappa\varepsilon_0$.

Since the capacitor is separating positive and negative charges, it is a way of storing electrical energy. The energy stored is based on the amount of work that must be done to separate the charges. As the charges build, the potential difference also increases, making it more difficult to separate the charges. The resulting equation for calculating this energy is $E = \frac{1}{2}CV^2$.