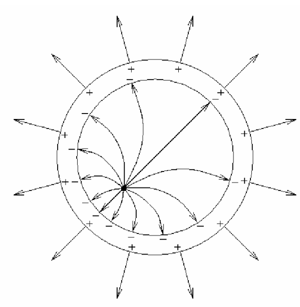
Topics: Capacitors & Dielectrics
Related Reading:
Course Notes (Liao et al.): Sections 4.3-4.4; Chapter 5
Serway and Jewett: Chapter 26
Giancoli: Chapter 22
Experiments: (3) Faraday Ice Pail

Topic Introduction

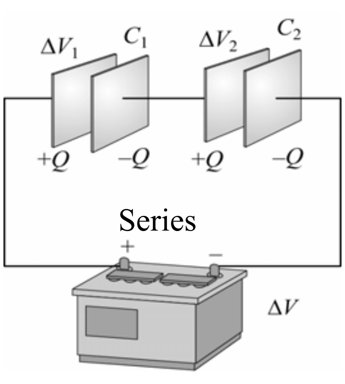
Today we continue our discussion of conductors & capacitors, including an introduction to dielectrics, which are materials which when put into a capacitor decrease the electric field and hence increase the capacitance of the capacitor.

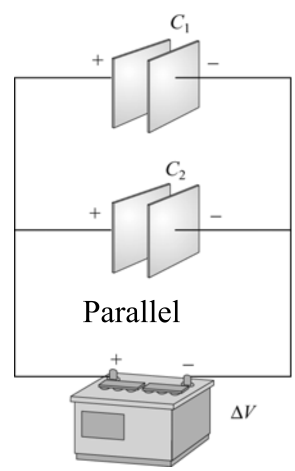
Conductors & Shielding



Last time we noted that conductors were equipotential surfaces, and that all charge moves to the surface of a conductor so that the electric field remains zero inside. Because of this, a hollow conductor very effectively separates its inside from its outside. For example, when charge is placed inside of a hollow conductor an equal and opposite charge moves to the inside of the conductor to shield it. This leaves an equal amount of charge on the outer surface of the conductor (in order to maintain neutrality). How does it arrange itself? As shown in the picture at left, the charges on the outside don't know anything about what is going on inside the conductor. The fact that the electric field is zero in the conductor cuts off communication between these two regions. The same would happen if you placed a charge outside of a conductive shield – the region inside the shield wouldn't know about it. Such a conducting enclosure is called a Faraday Cage, and is commonly used in science and industry in order to eliminate the electromagnetic noise ever-present in the environment (outside the cage) in order to make sensitive measurements inside the cage.

Capacitance





Last time we introduced the idea of a capacitor as a device to store charge. This time we will discuss what happens when multiple capacitors are put together. There are two distinct ways of putting circuit elements (such as capacitors) together: in *series* and in *parallel*. Elements in series (such as the capacitors and battery at left) are connected one after another. As shown, the charge on each capacitor must be the same, as long as everything is initially uncharged when the capacitors are connected (which is always the case unless otherwise stated). In parallel, the capacitors have the same potential drop across them (their bottoms and tops are at the same potential). From these setups we will calculate the equivalent capacitance of the system – what one capacitor could replace the two capacitors and store the same amount of charge when hooked to the same battery. It turns out that in parallel capacitors add ($C_{equivalent} \equiv C_1 + C_2$) while in series they add inversely ($C^{-1}_{equivalent} \equiv C_1^{-1} + C_2^{-1}$).

Dielectrics
A dielectric is a piece of material that, when inserted into an electric field, has a reduced electric field in its interior. Thus, if a dielectric is placed into a capacitor, the electric field in that capacitor is reduced, as is hence the potential difference between the plates, thus increasing the capacitor's capacitance (remember, $C \equiv Q / |\Delta V|$). The effectiveness of a dielectric is summarized in its "dielectric constant" κ. The larger the dielectric constant, the more the field is reduced (paper has κ=3.7, Pyrex κ=5.6). Why do we use dielectrics? Dielectrics increase capacitance, which is something we frequently want to do, and can also prevent breakdown inside a capacitor, allowing more charge to be pushed onto the plates before the capacitor "shorts out" (before charge jumps from one plate to the other).

Important Equations

Capacitors in Series: $C^{-1}_{equivalent} \equiv C_1^{-1} + C_2^{-1}$

Capacitors in Parallel: $C_{equivalent} \equiv C_1 + C_2$

Gauss's Law in Dielectric: $\oiint_S \kappa \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0}$

Experiment 3: Faraday Ice Pail

Preparation: Read lab write-up.

In this lab we will study electrostatic shielding, and how charges move on conductors when other charges are brought near them. We will also learn how to use Data Studio, software for collecting and presenting data that we will use for most of the remaining experiments this semester. The idea of the experiment is quite simple. We will have two concentric cylindrical cages, and can measure the potential difference between them. We can bring charges (positive or negative) into any of the three regions created by these two cylindrical cages. And finally, we can connect either cage to "ground" (e.g. the Earth), meaning that it can pull on as much charge as it wants to respond to your moving around charges. The point of the lab is to get a good understanding of what the responses are to you moving around charges, and how the potential difference changes due to these responses.