

**Topics:** Capacitors

**Related Reading:**

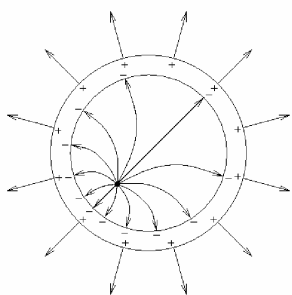
Course Notes (Liao et al.): Sections 4.3-4.4; Chapter 5

**Experiments:** (2) 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. We will define *current*, *current density*, and *resistance*.

### 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.

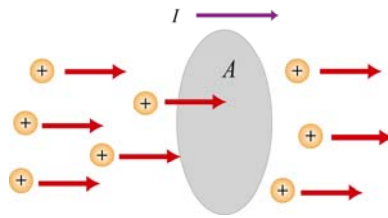
### Experiment 2: Faraday Ice Pail

**Preparation:** Read pre-lab reading and answer pre-lab questions

In this lab we will study electrostatic shielding, and how charges move on conductors when other charges are brought near them. 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 charges around. The point of the lab is to get a good understanding of what the responses are to you moving charges around, and how the potential difference changes due to these responses.

### Current and Current Density

Electric currents are flows of electric charge. Suppose a collection of charges is moving perpendicular to a surface of area  $A$ , as shown in the figure



The electric current  $I$  is defined to be the rate at which charges flow across the area  $A$ . If an amount of charge  $\Delta Q$  passes through a surface in a time interval  $\Delta t$ , then the current  $I$  is given by  $I = \frac{\Delta Q}{\Delta t}$  (coulombs per second, or amps). The current density  $\vec{J}$  (amps per square

meter) is a concept closely related to current. The magnitude of the current density  $\vec{J}$  at any point in space is the amount of charge per unit time *per unit area* flowing pass that point.

That is,  $|\vec{J}| = \frac{\Delta Q}{\Delta t \Delta A}$ . The current  $I$  is a scalar, but  $\vec{J}$  is a vector, the direction of which is the direction of the current flow.

### Microscopic Picture of Current Density

If charge carriers in a conductor have number density  $n$ , charge  $q$ , and a drift velocity  $\vec{v}_d$ , then the current density  $\vec{J}$  is the product of  $n$ ,  $q$ , and  $\vec{v}_d$ . In *Ohmic* conductors, the drift velocity  $\vec{v}_d$  of the charge carriers is proportional to the electric field  $\vec{E}$  in the conductor. This proportionality arises from a balance between the acceleration due the electric field and the deceleration due to collisions between the charge carriers and the “lattice.” In steady state these two terms balance each other, leading to a steady drift velocity (a “terminal” velocity) proportional to  $\vec{E}$ . This proportionality leads directly to the “microscopic” Ohm’s Law, which states that the current density  $\vec{J}$  is equal to the electric field  $\vec{E}$  times the conductivity  $\sigma$ . The conductivity  $\sigma$  of a material is equal to the inverse of its resistivity  $\rho$ .

### Important Equations

Relation between  $\vec{J}$  and  $I$ :

$$I = \iint \vec{J} \cdot d\vec{A}$$

Microscopic Ohm’s Law:

$$\vec{J} = \sigma \vec{E} = \vec{E} / \rho$$

Macroscopic Ohm’s Law:

$$V = IR$$

Resistance of a conductor with resistivity  $\rho$ ,  
cross-sectional area  $A$ , and length  $l$ :

$$R = \rho l / A$$