

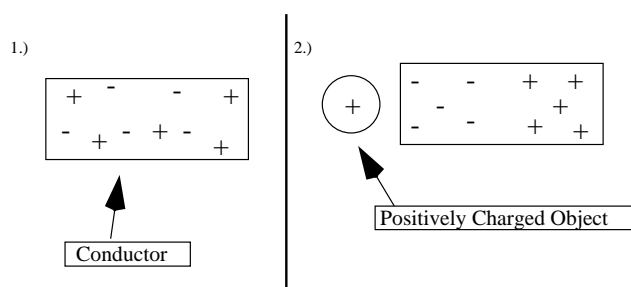
# Electrostatic Induction and the Faraday Ice Pail

Adapted from 8.02T Fall 2001 writeup by Peter Fisher and Jason Cahoon

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## 1 Introduction

When a positively charged object like a glass rod is placed near a conductor, electric fields inside the conductor exert forces on the free charge carriers in the conductor (electrons in metallic conductors), which cause them to move. Some of those negative charges redistribute themselves near the glass rod leaving the parts of the conductor furthest from the glass rod positively charged. This process occurs rapidly, and it ends when there is no longer any electric field inside the conductor. The surface of the conductor ends up with regions where there is an excess of one type of charge over the other. This charge distribution is called an induced charge distribution. The process of separating positive from negative charges on a conductor by the presence of a charged object is called electrostatic induction.



**Figure 1: Electrostatic Induction**

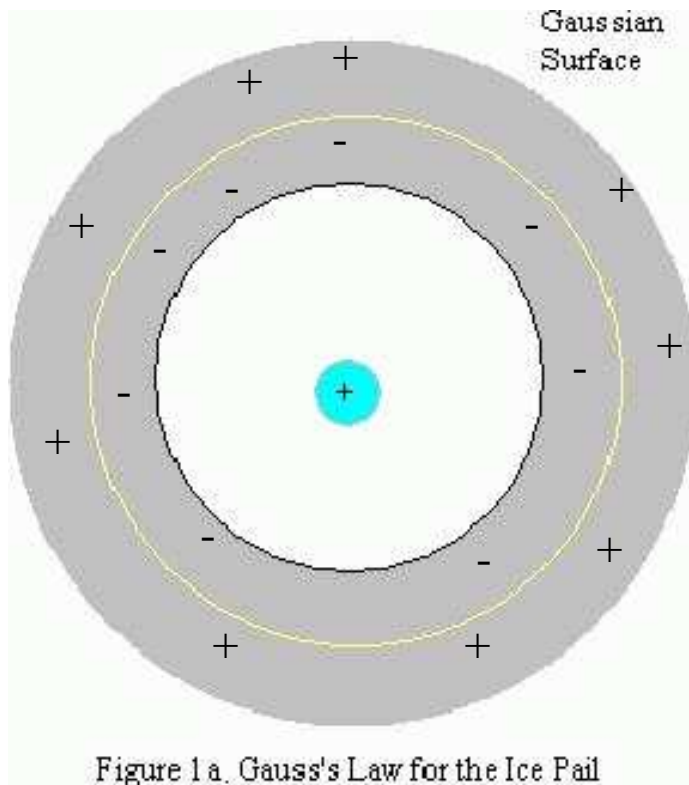
Michael Faraday used a metal ice pail as a conducting object to study how charges distributed themselves when a charged object was brought inside the pail. The ice pail had a lid with a small opening through which he lowered a positively-charged metal ball into the pail without touching it to the pail. Negative charges in the pail moved to the inner surface of the pail leaving positive charges on the outside. Faraday observed the charge on the outer surface by using an electroscope, a device that measures the presence of charge. (An electroscope with a scale to indicate the amount of charge is called an electrometer.)

If the charged ball touches the inside of the ice pail, electrons flow into the ball exactly neutralizing the ball. This leaves the pail with a net positive charge residing on the outer surface of the pail. The outer surface charge can be sensed by touching a small, uncharged metal conductor to the outer surface of the pail. In that case conductor becomes positively charged. But if the uncharged conductor touches the inner surface of the pail, it does not pick up any charge.

The fact that the excess charge on the ice pail resides entirely on the surface is a consequence of Gauss's Law. Gauss's Law states that the electric flux through any closed surface is proportional to the charge enclosed inside that surface,

$$\oint E \cdot dA = 4\pi q_{in}$$

Consider a mathematical, closed Gaussian surface that is inside the surface of the ice pail (Figure 1a). Once static equilibrium has been reached, the electric field inside the metal walls of the ice pail is zero. Note that the electric field in the hollow region inside the ice pail is not zero due to the presence of the charged ball. Since the Gaussian surface is in a conducting region where there is zero electric field, the electric flux through the Gaussian surface is also zero. Therefore by Gauss's Law, the net charge inside the Gaussian surface must be zero. For the Faraday ice pail, the positively charged ball is inside the Gaussian surface. Therefore there must be an additional induced negative charge on the inner surface of the ice pail that exactly cancels the positive charge on the ball. Since the pail is uncharged, by charge conservation, there must be an equal amount of positive induced charge on the pail as the negative induced charge. This positive charge must reside outside the Gaussian surface, hence on the outer surface of the ice pail.



Now suppose the Ice Pail is connected to a large conducting object (“ground”) as in Figure 1b. When a positively charged object is inserted into the pail, negative charge carriers will flow from the ground onto the outer surface of the pail. If the wire to ground is then disconnected, the pail will have an overall negative charge. Once the positively charged ball is removed, this negative charge will redistribute itself over the surfaces of the pail, i.e. it is charged negatively.

## 2 Equipment

- 1 Laptop
- 1 750 Interface
- 1 Wire Mesh 'ice pail'

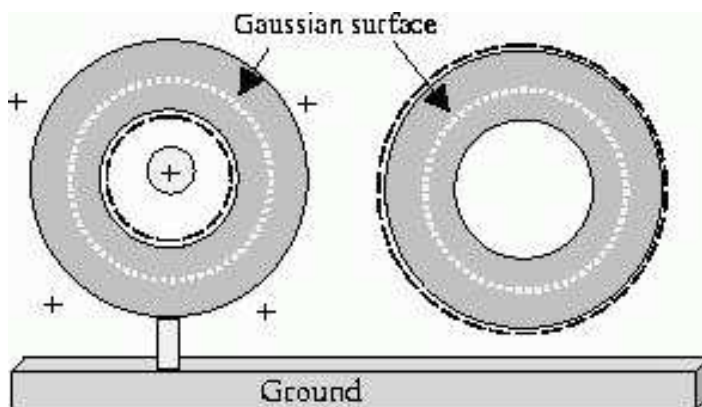


Figure 1: Charge distribution

- 1 Charge Sensor
- 1 Interface wire for Charge Sensor and ice pail (has 2 alligator clips)
- 1 Interface wire for the Charge Sensor and the 750 (has an 8 pin connector on one end)

### 3 Apparatus

The Faraday Ice Pail in our experiment consists of two, wire-mesh cylinders (Figure 2). The inner cylinder (the Ice Pail) has a diameter of 10 cm and is 15 cm deep. Three insulating rods support the bottom of the inner wire cylinder above a plastic support stand. The outer wire mesh cylinder is also mounted on the support and acts as a screen to eliminate the effect of any external charges and other external fields. The outer cylinder has no bottom wire mesh. It will be connected to a common ground. This means that electrons can flow to or from the shield as necessary to keep the electric field outside the entire apparatus zero.

We are making two approximations in this experiment. The wire mesh has many openings, so the actual induced charge distributions are quite complicated. Also our “Ice Pail” does not have a lid, so technically there is no “inner” and “outer” surface on the inner wire mesh cylinder. Assume that the effects of these two complications are small and proceed as if our ice pail surface was solid and covered.



Figure 2: Faraday “Ice Pail”

In experiments using the Faraday “Ice Pail”, a charged rod (Figure 3) will be inserted inside the inner wire mesh cylinder. This will cause the inner wire mesh cylinder to develop an inner charge distribution and an outer charge distribution. We will measure this outer charge distribution using a Charge Sensor.

### Charge Sensor

The Charge Sensor is a device that can detect charges on objects by measuring the voltage between them. It has a very high input resistance, which



Figure 3: Charge Producer

means that it does not draw off significant amounts of charge. The Charge Sensor has two leads (Figure 4). The negative (black) lead of the Charge Sensor is connected to the outer wire shield, which acts as ground. The positive lead (red on the clip lead) is connected to the inner wire mesh cylinder.



Figure 4: Charge Sensor

Your measurements will be primarily qualitative, so the following details about the Charge Sensor are mentioned only for general interest. The Charge Sensor actually measures the voltage difference between the inner wire mesh and the shield. This voltage arises from the charges on the outer surface of the inner wire mesh; positive voltage measurements correspond to positive

charge on that surface. The voltage measurements can be converted into charge measurements by a calibration. The Charge Sensor is designed to minimally affect the actual charges on the inner wire mesh.

The Charge Sensor has a built-in amplifier with a gain  $G$ , which multiplies the measured voltage difference by a factor  $G$  to give an output voltage

$$V_{out} = GV_{in}$$

There are three gain settings: 1, 5, and 20. (Figure 5). The amplifier can only read a maximum voltage input of  $\pm 10V$  on the 1x setting,  $\pm 2V$  on the 5x setting, and  $\pm 0.5V$  on the 20x setting. The ZERO switch on the Charge Sensor brings the input voltage to ground.

**Your amplifier should be set on the 1x setting.**



Figure 5: Gain and Zero Settings for the Charge Sensor

When the Charge Sensor is used on the most sensitive range (x20), it may display a small “offset” voltage. That is, pressing the ZERO switch may not cause the voltage to go exactly to zero. Although this residual voltage is typically quite small (less than 0.1 volt), it will be constant for any particular GAIN setting and can be subtracted from the final measurement to give a more accurate reading.

The extremely high input resistance of the sensor also makes it sensitive to stray electrostatic fields in its immediate vicinity. You may want to experiment with the sensor by bringing a variety of different objects that you have charged near the meter and see what happens.

## 4 Preparation

The purpose of the following experiments is to investigate and compare charging an object by contact to charging by induction.

### Computer Setup

1. With your computer turned OFF, install the Adaptec 1460D SCSI adapter card into an available PCI expansion slot.
2. Connect the Science Workshop 750 Interface to the computer using the SCSI cable.
3. Connect the power supply to the 750 Interface and turn on the interface power. Remember: Always turn on the interface before powering up the computer.
4. Turn on your computer.



### Charge Sensor Setup

1. Using the cable provided, connect the Charge Sensor to the Analog Channel A on the 750 Interface. The cable runs from the right end of the sensor as shown in Figure 5 to Channel A.



2. Connect the cable assembly on the BNC port on the Charge Sensor (see left end of the sensor in Figure 5). Line up the connector on the end of the cable with the pin on the BNC port. Push the connector onto the port and then twist the connector clockwise about one-quarter turn until it clicks into place.
3. Download the file 8.022Lab1.ds from the web site, <http://cyclotron.mit.edu/~fisherp/8.022Labs>. Save the file to your desktop. To start Data Studio with this file, either double click on this file or drag the icon for 8.022Lab1.ds onto the Data Studio Icon on the desktop of the computer.

### **Data Studio File**

1. The data studio file has a Voltage Graph, a Charge Graph, and a Meter Display.
2. The data recording is set at 10 samples per second (10 Hz), for a duration of 20 seconds.

### **Charge Sensor Calibration and Equipment Setup**

Connect the Charge Sensor input lead (red alligator clip) to the inner wire mesh cylinder. The Charge Sensor ground lead (black alligator clip) attaches to the shield. (See Figure 1). Set the charge sensor gain to 1x.

### **Preparing to Record Data**

Before starting any experiment using the “Faraday Ice Pail”, the pail must be momentarily grounded. To ground the pail, touch both the inner wire mesh and the outer wire shield at the same time with a conductor such as the finger of one hand.

## 5 Experimentation

### 5.1 Experiment 1: Data Recording- Determine the Polarity of the Charge Producers

1. Ground the “Ice Pail” and press the “ZERO” button on the Charge Sensor to discharge the sensor.
2. Start recording data. (The start button is located on the menu bar).
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.
  - Without touching the “Ice Pail”, lower the white Charge Producer into the “Ice Pail”. Watch the Meter and Graph displays.
  - Remove the white Charge Producer and then lower the blue Charge Producer into the “Ice Pail”. Watch the results.
4. After a few moments, stop recording data.

#### Questions

1. What polarity is the white Charge Producer? What polarity is the blue Charge Producer?

### 5.2 Experiment 2: Data Recording- Charge on the White Charge Producer

1. Ground the “Ice Pail” and press the “ZERO” button on the Charge Sensor to discharge the sensor.
2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.
  - Lower the white Charge Producer into the “Ice Pail”. Rub the surface of the white Charge Producer against the inner wire mesh cylinder and then remove the Charge Producer. Watch the Meter and Graph displays.

4. After a few moments, stop recording data.

**Questions:**

1. What happens to the charge on the “Ice Pail” when you rub the inner pail with the white Charge Producer and then remove the Charge Producer?

**5.3 Experiment 3: Data Recording- Charge on the Blue Charge Producer**

1. Ground the “Ice Pail” and press the “ZERO” button on the Charge Sensor to discharge the sensor.
2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.
  - Lower the blue Charge Producer into the “Ice Pail”. Rub the surface of the blue Charge Producer against the inner wire mesh cylinder and then remove the Charge Producer. Watch the Meter and Graph displays.
4. After a few moments, stop recording data.

**Questions:**

1. What happens to the charge on the “Ice Pail” when you rub the inner pail with the blue Charge Producer and then remove the Charge Producer?

**5.4 Experiment 4: Data Recording- Charge by Induction**

1. Ground the “Ice Pail” and press the “ZERO” button on the Charge Sensor to discharge the sensor.
2. Start recording data.

3. Briskly rub the blue and white surfaces of the Charge Producers together several times.
  - Without touching the “Ice Pail” with the Charge Producer, lower the white Charge Producer into the “Ice Pail”.
  - While the Charge Producer is still inside the inner wire mesh cylinder, use the finger of one hand to momentarily ground the “Ice Pail”. Remember, to ground the pail, touch both the inner wire mesh and the outer wire shield at the same time with a conductor such as the finger of one hand. Watch the Meter and Graph displays.
  - After you ground the “Ice Pail”, remove your hand and then remove the Charge Producer.
4. After a few moments, stop recording data.
5. Ground the “Ice Pail” and zero the Charge Sensor. Repeat the procedure using the blue Charge Producer.

**Questions:**

1. What happens to the charge on the “Ice Pail” when the white Charge Producer is lowered into the pail without touching the inner wire mesh cylinder?
2. What happens to the charge on the “Ice Pail” when the “Ice Pail” is momentarily grounded while the Charge Producer is still inside the inner wire mesh cylinder?
3. What happens to the charge on the “Ice Pail” after the Charge Producer is removed from the inner wire mesh cylinder?
4. How does the charging of an object by contact compare to charging of an object by induction?

**5.5 Experiment 5: Data Recording- Testing the Shield**

1. Ground the “Ice Pail” and press the “ZERO” button on the Charge Sensor to discharge the sensor.

2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.
  - Bring the white Charge Producer just outside the shield without touching the shield. Watch the Meter and Graph displays.
4. After a few moments, stop recording data.

**Questions:**

1. What happens to the charge on the “Ice Pail” when the white Charge Producer is placed just outside the outer wire mesh shield? Will an induced charge distribution appear on the inner wire mesh cylinder? Explain your reasoning.
2. Why does the shielding work only if the electric force between charged point like objects varies according to the inverse square of the distance?