Experiment 0
An Introduction to the Equipment

Objectives

After completing Experiment 0, you should be able to:

- Use basic electronic instruments
- Determine the precision of a measurement
- Select the scale that gives the most accurate reading
- Give a qualitative description of electric potential (voltage), current, and resistance
- Describe the uses of an electrometer, voltmeter, ammeter, ohmmeter, and multimeter
- Use an electrometer and digital multimeter properly
- Describe the precautions required to protect meters from damage.

Introduction

In Physics 116L, you will investigate the properties of electricity and magnetism with a variety of laboratory instruments. Unlike mechanics, for which the basic measurements of length, time, and mass are familiar, common quantities, electricity and magnetism involve unfamiliar quantities and require special instruments for their study. Some of the measurements are quite simple, for example the circuits of Experiments 5 and 6, but others are more subtle. Although you are certainly familiar with certain aspects of basic electricity -- shocks upon touching metal objects on dry days, the quantitative experiments are not trivial. You must understand a number of physical processes and phenomena to form a conceptual picture of what is happening in these experiments. We cannot explore electrostatics one step at a time as in the lectures; understanding even the simplest experiments requires the complete framework of electrostatics. These first three experiments, which introduce you to electrical instruments and the basic properties of electric charge, require considerable thought and care.

If you are unfamiliar with these instruments, you may find them slightly intimidating at first. However, they are not really difficult to use. This first "experiment" is merely a set of exercises to enable you to experiment with the basic instruments and become comfortable with using them. Since few of you have had the opportunity to play with electrical or electronic apparatus and instruments, this will give you a chance to explore the use of some simple instruments that are essential to most modern laboratory work. Most modern laboratories use a combination of individual instruments and computer-controlled instrumentation. You will use both kinds in this lab.

The purpose of this first lab is to familiarize you with some of the instruments commonly used in 116L (and other laboratories). You should not be too concerned with trying to understand the internal functioning of the instruments in this <u>first</u> lab. Regard the instruments as computers or television sets, apparatus to be used without full understanding of the mechanism. Instead, concentrate on the measuring process itself. Try to understand the proper procedures for using each piece of equipment. In particular, you should know how each instrument is prepared prior to making a measurement and how the measurement is actually made. You should also be aware of the precautions required to safeguard the equipment from serious damage. Gaining an early familiarity with these concepts will make it easier to distinguish between the physical principles you are studying and the measurements used to illustrate those principles.

To use an instrument, you must first have some idea of what that instrument measures. In this lab, you will frequently measure the following quantities[*]:

- Electric potential (measured with an electrometer or voltmeter)
- Electric current (measured with an ammeter)
- Resistance (measured with an ohmmeter)

Although you may not know the precise definitions and meanings of these terms and will not reach them in lectures for a few weeks, you should be familiar with the terms from the prerequisite (high school) physics course. The following qualitative descriptions should assist you in the laboratory.

Electric potential is measured in units of volts and often called "voltage"; it is a subtle concept. As the name suggests, the electric potential is closely related to potential energy. Just as for potential energy, only the electric potential difference between two points is really defined. A large electric potential difference between two points means that a large amount of energy could be released if a charge moved from one to the other. [High voltages must therefore be treated with caution; the release of substantial amounts of energy by charges moving within your body is inimical to your health. Fortunately, misapplication of the voltages present in this experiment poses a hazard only to the equipment. Voltages exceeding 100 volts in later experiments can deliver very unpleasant shocks.] All points on a conductor (e.g. a metal object) are typically at the same potential; connecting two metal objects by a wire will reduce their potential difference to zero. Potential difference is generally measured by connecting the two points with wires to the two terminals of the measuring instrument.

Although only potential differences are fundamentally defined, the planet Earth, being a large conductor at constant potential, is often used as a reference (a potential of zero). In the laboratory, you will most often cite the potential of an object as its potential difference from "earth" or "ground." Whenever the potential of single object is given without an explicit difference, the implication is that the value used ground as the reference. For the corresponding measurement, one terminal of the instrument must always be connected to ground.

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[*] Note that charge does not appear on this list. Although charge is a fundamental concept in electricity, it is not susceptible to direct measurement, and it is not a fundamental measured quantity. This fact is responsible for the conceptual complexity of electrostatic experiments.

Electric current is a measure of the flow of electric charge through an object such as a wire. The units of current are amperes, colloquially "amps". The concept of an electric current flowing in a wire is very similar to the concept of water flowing in a pipe. The greater the flow of water through the pipe (mass or volume/unit time), the greater the current of water. The electric current through a wire is the rate at which charge flows through the wire. The electric current is more easily and directly measured than is the electric charge itself.

Resistance is also related to the idea of flow. Resistance is a property of the wire or material in which the current flows and measures the opposition the medium presents to the flow. It is the ratio of the "force" applied to the current driven. For electric current, the electric potential is the force. The unit of resistance is the Ohm. An object with a very high resistance permits very little current to flow at a given applied voltage, whereas an object with low resistance carries a high current under the same conditions. A superconductor permits current to flow with no driving force.

The instruments you will use in this experiment are described in the following section.

Equipment

Electrometers are used to measure electric potential or voltage. Figure 1 shows the electrometer used in this lab.. Although they may look rather simple and crude, they employ very sophisticated semi-conductor electronics. These electrometers make routine measurements that were not possible fifty years ago; even twenty-five years ago, such measurements required expensive, bulky apparatus.. On the front of the instrument is a meter with a pointer (needle) positioned near zero at the center. The meter is inscribed with two scales; the setting of the switch on the front left of the box determines which is to be used, and the green LEDs on the lower left of the front face indicate the choice. With the switch set to 10 or 100, the upper scale is used reading from -10 to +10 volts at 10 position and -100 to +100 at the 100 setting. Similarly, the positions of 3 and 30 use the lower scale, to be read as ±3 and ±30 volts.

The unit is turned on and off with a button on the right front of the box. This instrument is powered by batteries and should always be turned **Off** when not in use.

After turning the instrument **On**, press the Zero button to confirm that the needle reads 0 at the center of the scale. You may find that the needle does not return precisely to 0. (You will explore this in the experiment.) If the meter is not set to zero, it will read some value even in the absence of an applied voltage. This value will be added algebraically to the true value and thus introduce a systematic error in the observations.

Although this instrument can be used by itself, connecting it to a computer is advantageous for some future experiments. The connection uses a special cable from the left side of the box to the Science Workshop Interface. Operation of this unit with the computers is described in Appendix E and in the experiments where it is used, as it will be here.

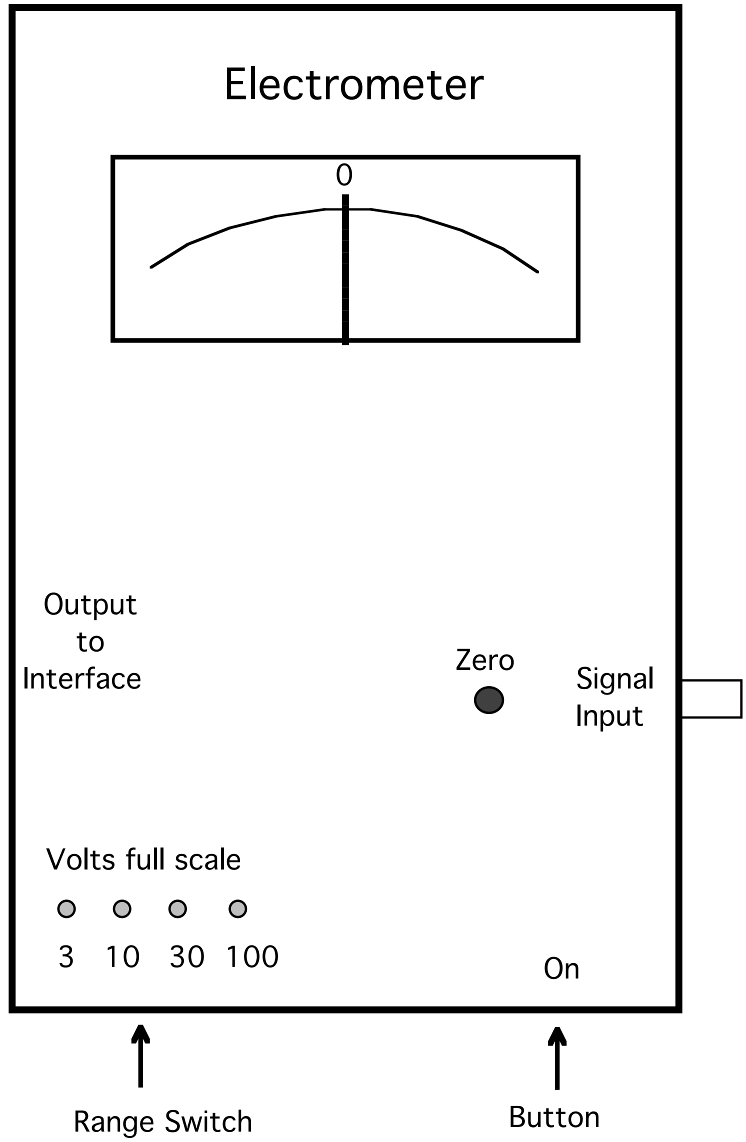


Figure 1

On the right side of the box is the input terminal for connecting to the voltage to be measured. The terminal uses a standard connector that locks in place. (These are called BNC connectors and widely used for quality cable connections. The connector and cable are coaxial: there is a central insulated wire surrounded by a conducting tube. The outer conductor is a shield and is variously termed the shield or common.) You will use a cable that connects to the electrometer and has red and black clip-leads at the other end. Conventionally, red is positive and connected to the center conductor and black is negative, connected to the outer conductor of the cable. The clips are attached to the two points between which you wish to measure the electric potential (voltage). The **Zero** button connects the two inputs together. When the clip leads are connected to an experiment, do not press the **Zero** button unless you intend to connect the red and black connection points. For example, never press the **Zero** button while the leads are connected to a voltage source like a battery or power supply.

The operation of the **Zero** button is shown in Fig. 2. (The input represents the center conductor; the common is the shield.) The electrometer is wired as shown on the left, whereas most instruments with zero-check buttons or switches (oscilloscopes, for example), use the arrangement on the right, which does not affect the circuit connected to the instrument during the zero check. On the electrometer, the zero switch is normally open; it closes when pushed.

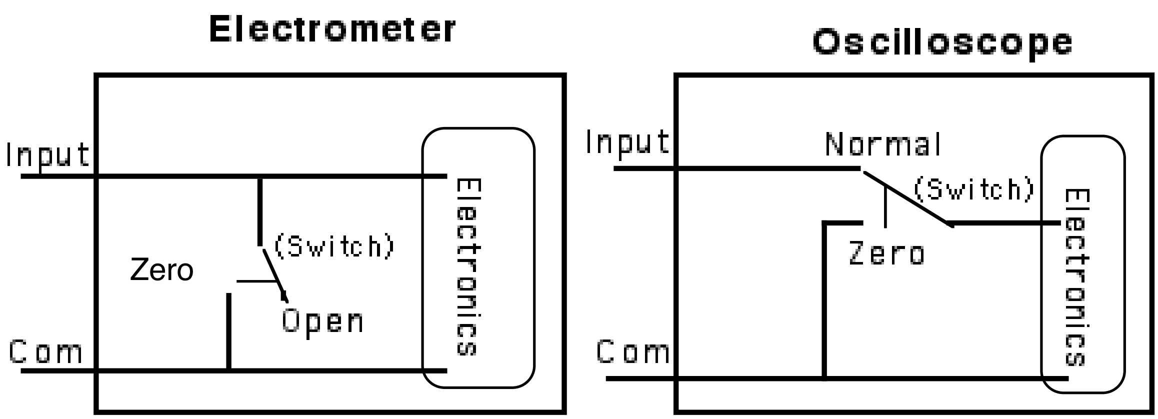


Fig. 2 Alternative Zeroing Configurations

Before measuring an unknown quantity with any instrument, set the instrument to its highest range, the 100 volt scale in this case. (If the unknown quantity is much greater than the range selected, the instrument could be damaged. Every instrument has its limits.) If the reading is less than the full scale of the next lower range, you can then switch to the lower range, proceeding until the needle indicates a significant fraction of the full scale. For example, if the unknown voltage were 2 volts, you would see a small deflection on the 30 scale, turn the switch down to the 10 scale, note a reading of 2, and proceed to the 3 scale.

To make a reading, face the instrument directly so that your line of sight is perpendicular to the face of the meter. Note the range and the needle position on the scale. If the needle lies between markings, interpolate its position. Adjacent marks on the scale denote the divisions. Depending upon the value of the division, you will interpolate to some fraction of a division, seldom less than 1/5. If the division represented 0.1 volts, you might record 1.34 volts, 1.30 volts or 1.32 volts, but not 1.305 volts; if the division represented 0.3 volts, you might record only 4.1 volts or 4.2 volts, but not 4.05 volts. There is seldom any reason to strain for accurate interpolation of an analog meter reading; one can generally read the scale to much greater precision than the true accuracy of the result considering the systematic errors in the instrument. When the instrument is connected to the computer, you can also view the reading on the computer.

Using the Meter display, similar techniques may be employed, although viewing angle is irrelevant, and you have much more flexibility in setting the scale.

Near the **Input** terminal on the right side of the box is a **Ground** banana socket. The **Ground** terminal is connected internally to the negative side of the **Input**, the shield and black clip lead. Ground (or earth) denotes a common reference point, that of the surface of the conducting earth, widely used as the zero reference point with respect to which potential measurements are made.* It is accessible in a laboratory as the third (ground) prong on a power outlet, at most cold water pipes, which are continuous metal back into the ground, and sometimes as special wires in a laboratory, often heavy bare copper cable. In this laboratory, ground is provided by aluminum angles mounted on the top shelf of each bench. If an instrument is connected to one of these points, it is said to be "grounded." If the device has no connection to a ground, it is said to "float." If you ground the electrometer by connecting a wire from the **Ground** terminal to a laboratory ground, the black clip-lead becomes grounded. Whatever you connect to the black lead will be brought to ground potential. If the electrometer is grounded, do not connect the black lead to an object unless you want that object connected to ground.

To extend the battery life and protect the instrument, please turn the electrometer **Off** at the end of period.

Digital Multimeters are ubiquitous instruments for making various electrical measurements. They measure both ac and dc voltages and resistances over a wide range of values; many, like the ones in this laboratory, also measure current; they are digital voltmeters, ohmmeters, and ammeters. A digital meter is one that displays integer numbers as contrasted with the analog meter of the electrometer. Analog multimeters are also common. The Fluke multimeters used in this lab are shown in Fig. 3. Connections are made to the multimeter using two probes that are plugged into sockets on the front of the instrument. The black probe is always attached to the terminal labeled "com" (common). For voltage and resistance measurements, the red probe is connected to the "V-Ω" terminal. For current measurements, the red probe is attached to the terminal labeled "10A" or "300 mA." **Always be sure that the red probe is connected to the proper terminal.** Connect the red probe to the current terminals **only** when measuring current. Always return the probe to the "V-Ω" terminal when finished measuring current. These precautions are necessary to protect the meter. Attempting to measure a voltage with the multimeter set for current measurements will usually destroy the meter.

* Although **Ground** properly means the potential of Earth, its use is sometimes broadened by analogy to a common reference point for all measurements in a circuit, not necessarily connected to Earth. Such a point is more correctly called a **common**, but this precision in usage is not always adhered to. An example is the **Ground** socket on the electrometer, which is an internal shield and common point for the electronic circuit. It *could* be usefully connected to a true ground, but absent such a connection, it is not at ground potential.

The front panel of the multimeter has a digital display and a rotary switch to control operation. The switch selects whether the meter measures ac or dc voltage, ac or dc current, or resistance. (They are mutually exclusive.) The switch should be set for **DC** in this experiment. Since this is also a battery-powered device, it should be turned **On** only when being used and turned **Off** otherwise.. For voltage and current, the display shows both magnitude and sign of the quantity. The instrument automatically chooses the best range among those possible. The units follow the usual MKS convention:

V = volts

mV = millivolts = 10^{-3} volts

mA = milliamps = 10^{-3} amps

μA = microamps = 10^{-6} amps

Ω = ohms KΩ = kilo ohms = 10^3 ohms MΩ = megohms = 10^6 ohms

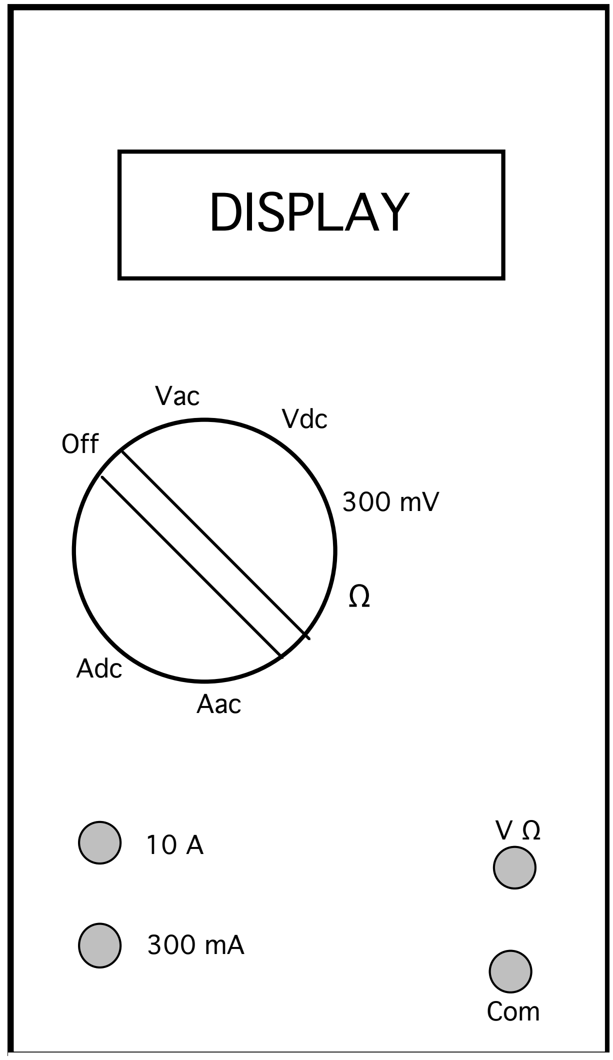


Figure 3 Fluke Digital Multimeter

The display will usually give four digits. However, the accuracy is generally much less than the precision suggested by the number of significant digits. The accuracy advertised on the case is ±0.3% for voltage, ±1.5% for current, and ±0.5% for resistance. The uncertainty is therefore the larger of

- ±1 in the last digit
- ± the percentage uncertainty given on the instrument.

A current reading of 952 mA is therefore accurate to ±1.5% (because 1.5% of 952 mA is greater than 1 mA), whereas a voltage reading of 98 mV is accurate to ±1 mV (because 1 mV is greater than 0.3% of 98 mV).

To measure voltage with the multimeter, switch to V(dc) and connect the red probe to the "V-Ω" terminal. Connect the leads as with the electrometer. (Since you are measuring voltage with both instruments, the procedures are the same.)

To measure resistance with the multimeter, switch to "Ω" and connect the red probe to the "V-Ω" terminal. Connect the probes across the object whose resistance you wish to measure. The result is independent of which probe (red or black) is connected to which point on an object. (You can check this by interchanging the probe connections on the object.) **Caution:** Do not attempt to measure the resistance of an object that is part of a live circuit -- an object connected to batteries or a power supply. This can easily damage the meter. Resistance measurements are best done on objects not connected to anything except the multimeter. Keep your fingers on the plastic probe holders when making resistance measurements, especially on the high resistance ranges. If you touch both metal probes, the multimeter may measure your resistance, not that of the object. (You can check this simply by gripping one probe in each hand or pressing both probes against your skin.)

To measure current with the multimeter, switch to the 10A position and connect the red probe to the "10A" terminal. Connect the instrument. The measured current will flow through the instrument. Since excess current can damage the instrument, it is very important to proceed carefully. Always begin on the maximum range and only proceed to the more sensitive range if necessary. (The meters do have some internal protection. Currents moderately above the range will merely blow a fuse, making the instrument inoperable until the fuse can be replaced. However, a current greatly above the limit will damage electronic components before the fuse can blow. This entails expensive repairs.) A positive current reading means that current is flowing into the meter through the red lead.

To protect the instrument, always connect the red probe to the "V-Ω" terminal and turn the multimeter **Off** for storage. (These are the "normal" settings and provide a margin of safety. Even if the next user connects the instrument without checking the settings, the meter is unlikely to be damaged.)

Power supplies, like batteries, generate a potential difference or voltage. The power supplies that you will use in this course plug into a standard electrical outlet and provide an adjustable voltage. They have an On-Off switch, a knob with which to control the voltage, and a meter to indicate the output voltage. The power supply that you will use in this experiment provides up to 30 V. This is a sophisticated power supply that can also supply a controlled current. Note that although the power supply has a three-pronged plug with a ground connection, none of the output terminals is connected to ground. If you want a ground connection, you must provide it directly.

Experimental Procedure

For this experiment, you will need the following apparatus:

- Electrometer (in Instrument Kit)
- Digital Multimeter (in Instrument Kit)
- Faraday cup and cage (in cabinet)
- Power Supply (30V) (in cabinet)
- Decade Resistor Box (in cabinet)
- Dry cell (in cabinet)
- Light bulb (on Component board -- Appendix A -- in cabinet)
- Wires (on Racks at end of benches)

The electrometers, multimeters, and several other parts that you will use regularly are in plastic boxes in a cabinet. Each group should collect one at the beginning of the period and return it in good order with all items in their original compartments to your instructor for inspection at the end.

Before starting experiments, you should log in to your laboratory computer and copy the Excel 116L folder to your USB device. You will need the Excel Workbooks in that folder to prepare for several later experiments, and there is no other way to access them outside the laboratory.

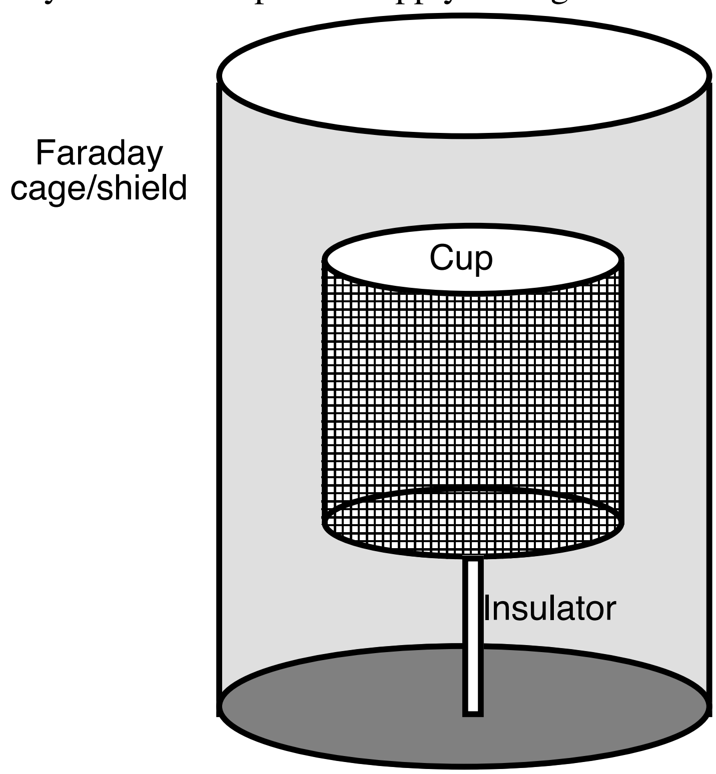
First, a comment on parallax error, which affects all analog mechanical meters. Parallax is easily demonstrated. Hold your thumb up at arm's length and view its apparent position on a wall with just one eye. Now view your thumb with the other eye, noting the shift in its apparent position. This shift in apparent position with viewing angle can introduce errors in reading a meter. The apparent position of the needle on the scale behind it varies with the view. To minimize parallax errors, one should always view the meter perpendicularly when reading it.

The following eight exercises illustrate the use of electrometers and multimeters:

1. First you will check the zero adjustment. Set the switch to 100 V and measure the value with the Zero button depressed. Repeat for each of the ranges. Comment on the result. Is this a systematic or random error? Explain.

2. For this exercise, you will use the electrometer to measure voltage on a Faraday cup and cage that will be used in later experiments. The Faraday apparatus consists of two concentric cylindrical wire cages that are not electrically connected. You will also use a power supply, a device for producing voltages. For this experiment, use the 30 V regulated power supply. Connect a wire between the red (positive) terminal of the power supply and the Faraday cup (inner cage). Connect another wire from the black (negative) terminal to the Faraday shield (outer cage). When the power supply is turned on, it will apply a voltage of up to 30V between the two terminals and hence between the Faraday cup and shield.

Connect the red lead of the electrometer to the Faraday cup and the black lead to the Faraday shield. Do not connect anything to the **Ground** terminal of the electrometer. Set the switch of the electrometer to 10 V and zero it. Now turn on the power supply and slowly turn up the voltage to approximately 5 volts. Record the reading on the electrometer, including uncertainty. Next, change the switch to 30 V. Again, record the reading and uncertainty. Which reading is the more accurate? Why? Turn the power supply voltage back to zero.



3. Next you will use the computer to measure how a voltage changes with time. Connect the electrometer using the special cable to the Interface Analog Channel A. Following instructions in Appendix E, select Electrometer from the input list. Choose Graph from the Display list. Be sure that data acquisition is Stopped and clear the display of other traces if they are present. Start data acquisition. The trace should begin across the screen. Slowly increase the power supply voltage and watch the trace rise. If the result is not clearly visible, change the scales on the graph and repeat. This is a good opportunity to explore the behavior of Capstone for acquiring data. You could test the various options and menu choices to see what is possible. Turn the power supply voltage back to zero. <u>Disconnect the electrometer from the computer interface.</u>

4. Next you will see that the electrometer measures the voltage applied <u>across its leads.</u> Disconnect the electrometer leads from the Faraday cup, set the electrometer to 30 V, and zero the electrometer. Connect <u>both</u> red and black electrometer leads to the Faraday <u>cup</u>. Turn on the power supply and increase the voltage to 17 V as shown on the power supply meter. Record the electrometer reading and its uncertainty. Turn off the power supply. Reconnect the electrometer leads as indicated for b. in the table below, turn on the power supply, record the reading, and turn off the power supply, repeating the procedure until you have readings for each of the following sets of electrometer connections:

	Red	Black
a	Cup	cup
b	Shield	Shield
c	Cup	Shield
d	Shield	Cup

Explain why your readings make sense. You are now finished with the electrometer. Don't forget to turn the electrometer **Off**.

5. Consider the following hypothetical experiment. The electrometer is grounded in the sense that a wire is connected from its **Ground** terminal to the black power supply terminal. If the procedures of part **4** were repeated, what would be the difference in results? Explain your reasoning. Why is this experiment not done? (Careful drawings of all the connections in each case should reveal the reason.)

6. Next you will use the digital multimeter for voltage measurements. Select the dc voltage mode of the multimeter. Repeat the measurements of part **4** using the digital multimeter instead of the electrometer. Include the uncertainties as given in the description of the multimeter.

7. Now measure the voltage of a dry cell battery – an AA battery in a holder. Make one measurement with the red probe connected to the red battery lead and the other connected to the black battery lead. Repeat with the probes reversed. Explain the difference in the two readings. Record your data and uncertainties, and also determine the percentage difference between the measured voltage and the value given on the battery label: 1.5 V.

8. Now you will make resistance measurements. Select the ohmmeter mode of the multimeter and connect the probes to the multimeter as required. Connect the probes to the two terminals on a decade resistance box. Make resistance measurements at each of the following settings on the decade resistance box: 100 Ω, 1000 Ω, 10,000 Ω, and 100,000 Ω. Record the range along with the reading and uncertainty. Find the percentage difference between the measured value and the nominal value from the box setting. If you were to repeat these resistance measurements with the ohmmeter probes reversed, what differences would you expect in your measurements?

Proceed to parts 9 and 10 only if you have sufficient time after completing all of the previous exercises, including writing the report.

9. Use the ohmmeter function of the digital multimeter to measure the resistance of the light bulb provided. Reverse the probes and repeat the measurement. Record the values and uncertainties.

10. For the final exercise, you will measure the resistance of the light bulb in a simple circuit. You will use the 30 V regulated power supply. The following (underlined) procedure should be followed whenever you use power supplies:

Begin with the power supply turned off and the voltage control knob set to zero, fully counterclockwise. Connect a wire from one of the light bulb terminals to the black power supply terminal (labeled "-"). Connect the red power supply terminal ("+") to the other light bulb terminal. Turn the power supply on and slowly increase the voltage until the light bulb filament just begins to shine. Record the voltage and current readings from the meters on the power supply. Calculate the resistance and its uncertainty. How does the value compare with that measured by the multimeter? Comment on any significant difference. Return the voltage to zero and turn off the power supply.

Please turn all instruments off and return equipment to its proper place. The Instrument Kit must be presented to your instructor for checking before returning it to its cabinet.

GENERAL NOTE: The scales and ranges of most instruments are clear and simple. Like the electrometer, they are labeled by the full-scale value, 10V, 30V, etc. or like oscilloscopes, 1V/div, 10V/div, etc. on the display. However, some usage can be ambiguous, and you must know the instrument to understand its meaning. For example, the probes commonly used with oscilloscopes are marked x10. In this case, the probe attenuates, divides the signal by 10, and the instrument scale must be multiplied by 10 to measure correctly, e.g. the normal range of 1V/div must be read as 10V/div to obtain the correct value. In other contexts, particularly in a phrase like gain x10, the output would indeed be 10 times the input, the same usage as in optics for magnifiers. The magnetic field sensor that you will use in a later experiment requires this care.

References

Ohanian and Markert, **Physics** (Third edition), Chapters 22, 25, 28.6.

Pre-lab 0

1. For any meter, with which scale should you begin measurements?

2. To what fraction of a division (space between tick marks) should you be able to read an analog meter?

3. Suppose that the electrometer is grounded by connecting the ground socket to the laboratory ground. At what potential (relative to the conventional ground reference) is the black lead?

4. For the digital multimeter with specifications as described here, give the uncertainties in the following readings:

a) 1.515 volts

b) 22 millivolts

c) 1.918 volts

d) 568 Ω

e) 2 A

5. If you measured a current of 0.91 A through the light bulb filament when the power supply indicated that it was supplying 4.25 V, what was the resistance of the filament?