PHYS 1112L - Introductory Physics Laboratory II

Laboratory Advanced Sheet
Capacitors (IBEAM)

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1. Introduction.

When you need electricity, it is nice to be able to throw a switch and get it. If you have access to a

generator, you can always insure that you have electricity whenever you throw the switch by keeping the

generator moving by some means (steam driven turbine, windmill, etc.). However, if you do not have this,

you will have to rely on some method of storing the electricity so that you can use it when you need it.

There are two basic ways of storing electricity: chemically and mechanically.

The most common form of chemical storage is in batteries. Batteries store the charge by creating

chemical compounds that will react in an acidic or basic solution to release electrons. Batteries have done

a tremendous job over the years, but they have had problems. For one, they often use chemically toxic

compounds like lead, mercury, and cadmium that are dangerous when the batteries are disposed of. For

another, they can be problematic whenever there is a crack in their container or whenever they make a

hole in their container. Anyone who has ever opened the back of a toy or appliance to find the innards

eaten away by the acid or base by such a leak knows what kind of mess this can make.

Electricity can also be stored chemically in a fuel cell. This device does not require an acidic or basic solution, as the chemical species (hydrogen and oxygen are the optimal ones) react across a semipermeable membrane and release electrons in the process. The lone by-product from such a reaction is water if hydrogen and oxygen are used, which poses no problems to the environment. The biggest problem standing in the way of the widespread usage of fuel cells is size, as they are so large currently as to be limited to objects the size of small trucks and bigger.

Mechanical storage is achieved with the use of capacitors. Capacitors store the electricity without the need for chemical reactions, acids, or bases. They consist of two conductors that are placed near each other, but are not allowed to touch. As negative charge is placed on one of the conductors, positive charge begins to build up on the other, as electrostatic forces keep the unlike charges near each other. Whenever the electricity is needed, the electrons are allowed to flow to the positively-charged conductor through a circuit that connects both sides of the capacitor.

Capacitors are a mainstay in modern electrical circuits. The computer that you are using to read or print this file contains millions of them to perform various tasks that are required. But electrical instruments are not the only places that capacitors appear in your everyday life. Various parts of plant and animal bodies also act like capacitors. For example, the membrane of an cell keeps charge separated just like a capacitor. This occurs because the cell membrane contains channel proteins and ion pumps that

maintain a different concentration of sodium, potassium, and chlorine ions on both sides. These different

concentrations means that there is a charge difference (more negative ions inside of the cell than outside,

normally), which results in a potential difference across the membrane. In nerve cells, this electric

potential is about 70 millivolts. While this does not seem like a large potential difference, it must be

remembered that is being maintained across a membrane that is only a couple of nanometers thick. This

corresponds to an electric field that is thousands of volts per meter, which is far greater than one finds in

most electrical appliances.

All cells have some potential difference across the membrane due to ion concentration differences. This

is important, as the electric field maintained by this “capacitor” membrane is very important for biological

processes. It is responsible for driving amino acids and other molecules against the concentration

gradients that exist to provide these nutrients to the inside of the cells. If the potential difference was not

there, these nutrients would not be able to be “fed” to the cells, which would result in death. This potential

difference is also important in the transmission of signals by nerve cells. When a portion of the nerve cell

membrane is activated, channels open in the membrane and sodium ions are allowed to flow under the

influence of the electric potential, causing an increase of positive ions in the cell and lowering the charge difference. This change in potential triggers the membrane closes to this section, causing it to undergo

the same process. Thus, the signal will be sent down the cell membrane, as successive sections of the

membrane are triggered. Before the nerve cell can “fire” again, the ions must be pumped out of the

interior of the cell and the electric potential restored to its resting state.

In this week’s lab, we are going to investigate some of the factors that affect how much electricity a

capacitor can store.

2. Objectives. The objectives of this laboratory are

a. to verify the dependence of capacitance on plate spacing for a parallel plate capacitor, and

b. to measure the dielectric constant of paper.

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3. Theory.

a. The capacitance of a parallel plate capacitor with no material between its plates is given by

$$\mathbf{C_0 = \varepsilon_0 A/d} \qquad \textbf{(1)}$$

where

C_0 is the capacitance without any material between its plates,
ε_0 is the permittivity of free space ($8.8542 \times 10^{-12}\ C^2/(N\ m^2)$),
A is the surface area of a plate of the capacitor, and
d is the separation distance between the plates.

b. The capacitance of a parallel plate capacitor with a dielectric material filling the region between its plates is given by

$$C = \kappa C_0 = \kappa \varepsilon_0 A/d \quad (2)$$

where

κ is the dielectric constant for the material.

c. In this experiment the plate area, A, is constant, while the plate separation distance, d, will be varied by inserting different thicknesses of dielectric material between the plates. A graph of capacitance, C, versus the reciprocal of the plate spacing, 1/d, should be a straight line (objective 1a). From equation 2, the slope of this straight line is

$$m = \kappa \varepsilon_0 A \quad (3)$$

Using the measured value of the slope, the measured plate area and the known value of the permittivity of free space, ε_0, the dielectric constant, κ, can be calculated (objective 1b).

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4. Apparatus and experimental procedures.

a. Equipment.

1) Parallel plate capacitor with leads.

2) Card stock paper.

3) Clothes pins.

4) Multimeter.

5) Micrometer and vernier caliper.

6) Ruler

b. Experimental setup. To be provided by the student.

c. Capabilities. To be provided by the student.

d. Procedures. Detailed instructions are provided in paragraph 4 below.

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5. Requirements.

a. In the laboratory.

1) Your instructor will introduce you to the equipment to be used in the experiment.

2) Measurements to determine the plate area and thickness of a single sheet of the card stock will be made.

3) Measurements of capacitance versus plate separation will made.

4) Your instructor will discuss methods to be used to prepare your data for plotting using the Microsoft Excel™ spreadsheet program.

b. After the laboratory. The items listed below will be turned in at the beginning of the next laboratory period. A complete laboratory report is **not** required for this experiment.

Para 3. Apparatus and experimental procedures.

1) Provide a figure of the experimental apparatus (para 3b).

2) Provide descriptions of the capabilities of equipment used in the experiment (para 3c).

Para 4. Data. Data tables are included at Annex A for recording measurements taken in the laboratory. A copy of these tables must be included with the lab report. Provide the items listed below in your report in the form a Microsoft Excel™ spreadsheet showing data, calculations and graphs. The spreadsheet will include:

1) Plate dimensions and calculated plate area.

2) Paper thickness measurements and calculation of the thickness of a single sheet.

3) Multimeter zero reading.

4) A table with columns for number of sheets of paper, measured capacitance, calculations for plate separation distance, reciprocal of plate separation distance, and measured capacitance corrected for multimeter zero reading.

5) A graph of the measured capacitance corrected for multimeter zero reading versus reciprocal of plate separation distance showing data points and regression (trend) line. Include the equation of the trend line on your graph.

6) Calculation of the value of the dielectric constant of paper.

5. Results and Conclusions.

a. Results.

1) A statement regarding the agreement or disagreement between the predicted and measured dependence of capacitance on plate separation distance for a parallel plate capacitor.

2) A statement of the measured value for the dielectric constant of paper.

b. Conclusions.

1) An assessment of the accuracy of your experiment. Use the value for the dielectric constant of paper given in your text for comparison purposes. Do not calculate a percent discrepancy. The actual value of the dielectric constant depends on the specific type of paper being considered.

2) Description of the sources of error in the experiment.

Annex A
Data

1. Plate dimensions.

dimension	measurement (cm)
length	
width	

2. Paper thickness.

item	measurement
number of sheets in stack	
thickness of stack	cm

3. Multimeter zero reading.

nF

4.Capacitance versus number of sheets of paper.

# of sheets of paper	capacitance (nF) (uncorrected for zero)
6	
8	
10	
12	
14	
16	
18	

20	
22	
24	
26	
28	
30	

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