VL-E2: DETERMINATION OF DIELECTRIC CONSTANT OF A MATERIAL USING A PARALLEL PLATE CAPACITOR

Objectives:

- To explore the relationship between charge and voltage for a capacitor.
- To explore the behavior of capacitors with and without dielectrics.

System Requirements:

Computer (Desktop/Laptop), Operating system: Windows with latest version of Java, capacitor-lab_en" (Zipped) File.

Advise:

Students are advised to follow the **procedures written in this manual very strictly** while performing the experiment. D**o not try to explore anything else during the experiment.**

Theory:

A dielectric is a material which has poor electrical conductivity but inherits an ability to store an electrical charge (due to Dielectric polarization). Dielectric constant, also called relative permittivity, property of an electrical insulating material (a dielectric) equal to the ratio of the capacitance of a capacitor filled with the dielectric material and without the dielectric material.

The electric flux through a closed surface area in vacuum is given by Gauss's law:

$$\oiint_s \bar{E}.d\bar{A} = \frac{Q}{\varepsilon_0} \qquad (1)$$

Where $\bar{E}$ is the electric field intensity, Q is the charge enclosed by the closed surface *A*, ε_0 is the permittivity constant in free space and *s* is a closed surface area.

If a voltage *V* is applied between the capacitor plates as shown in Fig. 1, an electric field $\bar{E}$ will prevail between the plates defined by: $V = \int_1^2 \bar{E}.d\bar{r} = E.d$

If **E** is constant Eq. (1) gives

$$\frac{Q}{\varepsilon_0} = E.A = V.A.\frac{1}{d} \qquad (2)$$

The charge *Q* of the capacitor in terms of the capacitance of the capacitor is given by

$$Q = CV = \varepsilon_0 \frac{A}{d}.V \qquad (3)$$

Where the capacitance *C* of the capacitor is given as

$$C = \varepsilon_0 \frac{A}{d} \qquad (4)$$

Thus, the dielectric constant in free space is ε_0:

$$\varepsilon_0 = \frac{d}{A}.\frac{Q}{V} \qquad (5)$$

Equations (3), (4) and (5) are valid only approximately for parallel field lines for a small and constant distance between the plates.

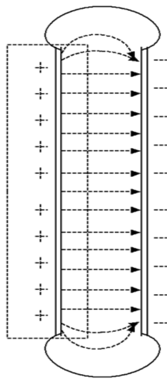

Fig. 1: Electric field of a parallel plate capacitor with small distance between the plates, as compared to the diameter of the plates.

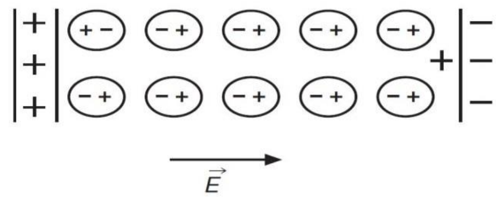

Fig. 2: Generation of free charges in a dielectric through polarization of the molecules in the electric field of a plate capacitor.

A dielectric material placed between the plates (Fig. 2) of a capacitor increases the capacitance of the capacitor and hence the voltage V will be reduced as

$$V = \frac{V_{Air}}{\kappa} \qquad (6)$$

Hence the capacitance and charge of the capacitor becomes,

$$C = \kappa . C_{Air} \qquad (7)$$

and $$Q = CV = \kappa . \varepsilon_0 . \frac{A}{d} . V \qquad (8)$$

For the same voltage, the amount of charge of the capacitor is significantly increased by the dielectric. The value of k, the ratio of the charges obtained with and without the dielectric materials (dividing equation [3] by [8]) is:

$$\kappa = \frac{Q_{dielectric}}{Q_{Air}} \qquad (9)$$

Procedures

1. Unzip "**capacitor-lab_en**" file and then install "**JavaSetup8u251**". Now click right button on the "**capacitor-lab_en.jar**" file and select open with "**Java Platform**".
2. To verify the properties of a capacitor with the area A, plate separation d and dielectric constant ε, click on 2nd tab **Dielectric** 

as shown in Fig. 3.
3. With the **Battery Connected** option, the applied potential can be changed upto ± 1.5 V.
4. Select the maximum plate separation (d = 10 mm = 10×10^{-3} m) and the minimum area of cross-section of the plates (A = 100 mm^2 = 1×10^{-4} m^2).

   [Students may select any fixed area and distance within the range].
5. With the **Battery Connected** option, measurement should be taken in air **without** and **with dielectric materials** (Teflon) simultaneously.
6. Click on the '**Plate Charge'** of the right top **View**. Click on '**Plate charge'**, and '**Voltmeter**' of **Meters**. To measure the applied voltage from battery, connect the two ports of voltmeter at the two plates of the capacitors and keep the dielectric block outside the capacitor as shown in Fig. 3.

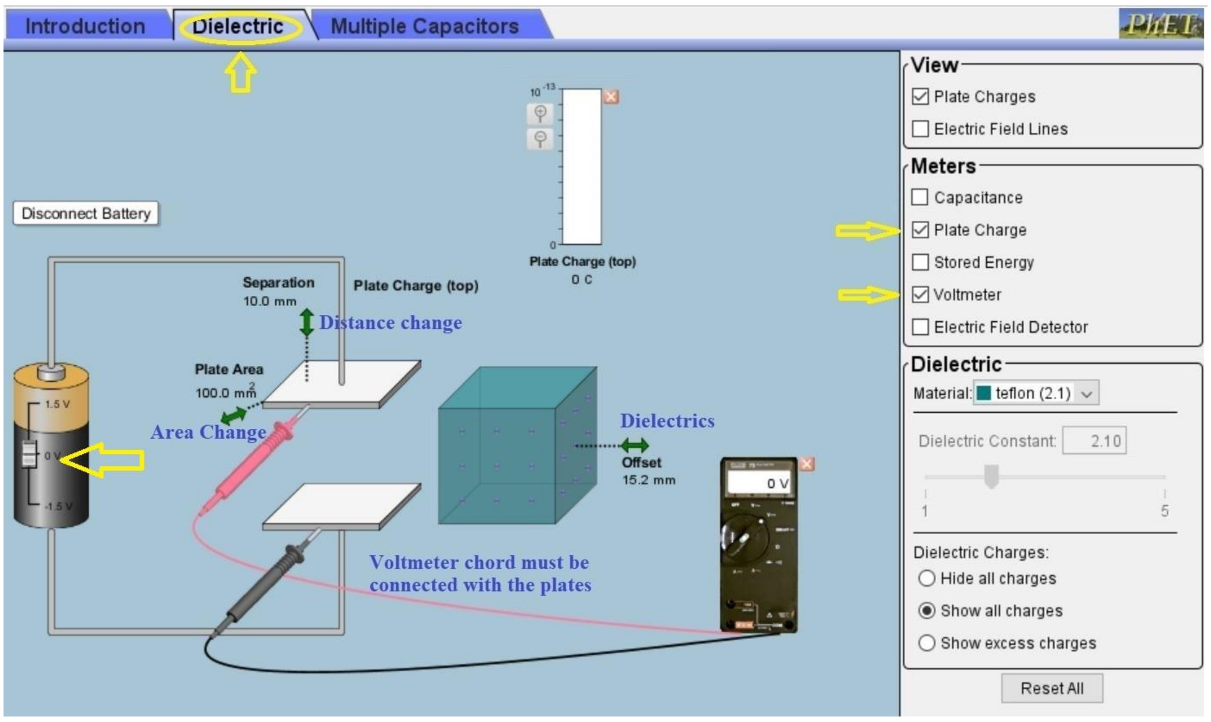

Fig. 3: Experimental setup.

7. (i) Fix the applied voltage (say 0.25 V) by varying the vertical knob in the battery and **measure the electrostatic charge** on the capacitor plates in **air** at the **constant distance** and **constant area** condition.

   (ii) Dragging the Teflon block in left direction and place it inside the capacitor. **Measure the corresponding electrostatic charge on the capacitor plates with Teflon.**

8. In a similar way, by applying different voltages of the Battery (viz. +0.25V, +0.5V, +0.75V, +1.0V, +1.25V and +1.5V), measure the electrostatic charge on the capacitor plates in **air** (without Teflon) and with the Teflon block as mentioned in procedure (6).

9. Draw the graphs with electrostatic charge vs applied voltage in air and with Teflon as shown in Fig. 4. Calculate the capacitance from graph in air (the slope value) and compare with the actual value (0.89×10^{-13} F).

10. Find the plate charges with air (Q_{Air}) and with the dielectric material ($Q_{dielectric}$) at a fixed applied voltage (say 1.5 V) from the graph and their ratio gives the dielectric constant κ of the material.

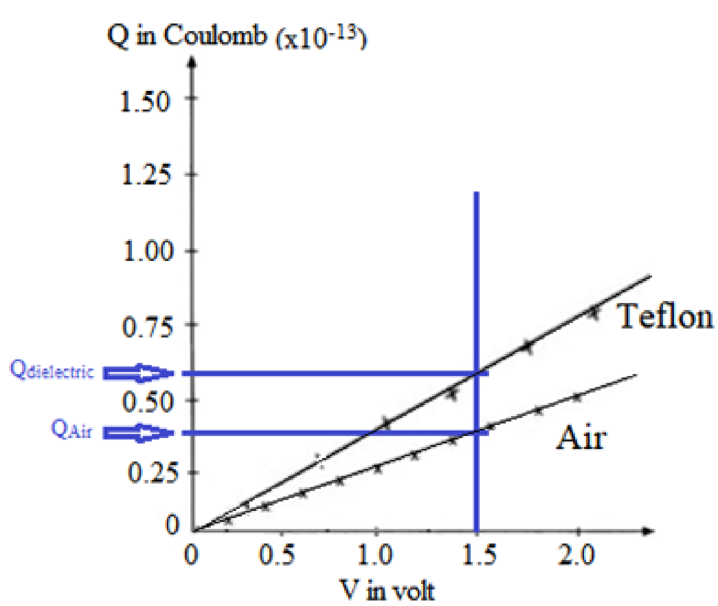

Fig. 4: Electrostatic charge Q of capacitor as a function of applied voltage *V*, in air and with Teflon as a dielectric material.

Data collections:

Table 1: Measurement of dielectric constant for Teflon

A = 100 mm^2 = 1×10^{-4} m^2, d = 10×10^{-3} m, Capacitance C_0 = 0.89×10^{-13} F

Sl No	Applied Voltage (V)	Plate Charge, Q (×10^{-12}) [Coul]	
		Air	Teflon
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Result:
Dielectric constant of Teflon ……

Error analysis:

Discussion:

Based on your understanding from this experiment, answer the following questions:

1) How Q, V and C of a capacitor vary with the plate separation and plate area?
2) Does the dielectric constant affect the amount of charge stored on the plate? If so, what is the relationship?
3) How does the dielectric material affect the capacitance?
4) As the dielectric constant increases how does the total stored energy change?
5) What is the relationship between free charge and induced charge?

