Experiment no.: E6

Name of the Experiment: Determination of dielectric constant of materials using parallel plate capacitor

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

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

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_c is applied between two capacitor plates as shown in fig. 1, an electric field $\bar{E}$ will prevail between the plates defined by: $V_c = \int_1^2 \bar{E}.d\bar{r} = E.d$

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

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

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

$$Q = CV_C = \varepsilon_0 \frac{A}{d}.V_C \qquad (3)$$

Where the capacitance C of the capacitor is given as

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

Thus, the dielectric constant is ε_0:

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

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

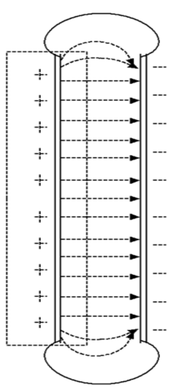

Fig. 1: Electric field of a plate capacitor with small distance between the plates, as compared to the diameter of the plates.

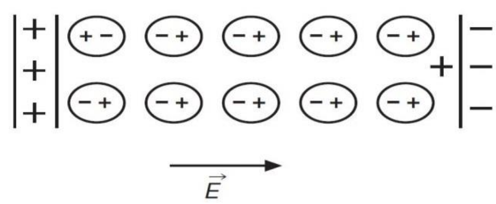

Fig. 2: Generation of free charges in a dielectric through polarization of the molecules in the electric field of a plate capacitor.

A dielectric material placed between the plates as shown in fig. 2 increases the capacitance of the capacitor. With the dielectric material of dielectric constant ε the voltage V_c will reduced as

$$V_c = \frac{V_{vac}}{\varepsilon} \qquad (6)$$

Hence the capacitance and charge of the capacitor becomes,

$$C = \varepsilon.C_{vac} \qquad (7)$$

and $$Q = CV_C = \varepsilon.\varepsilon_0.\frac{A}{d}.V_C \qquad (8)$$

For the same voltage, the amount of charge of the capacitor is significantly increased by the dielectric. If the charges obtained with and without plastic (equations [3] and [8]) are divided by each other:

$$\frac{Q_{plastic}}{Q_{vacuum}} = \varepsilon \qquad (9)$$

the obtained numerical value is the dielectric constant of the plastic.For the glass plates, a value of = 9.1 can be obtained similarly.

Material and Apparatus

Plate capacitor (d 260 mm), Plastic plate (283×283 mm), Glass plates f. current conductors, High-value resistor (10 MΩ), Universal measuring amplifier, High voltage supply unit (0-10 kV), PEK capacitor/case (1/0.22 μF), Voltmeter (0.3-300 VDC and 10-300 VAC), Green-yellow connecting cord (100 mm), Red connecting cord (500 mm), Blue connecting cord (500 mm), Connecting cord (50 KV, 500 mm), Screened BNC cable (750 mm), BNC adapter socket (4 mm plug), T type BNC connector, BNC-plug/socket adapter (4 mm)

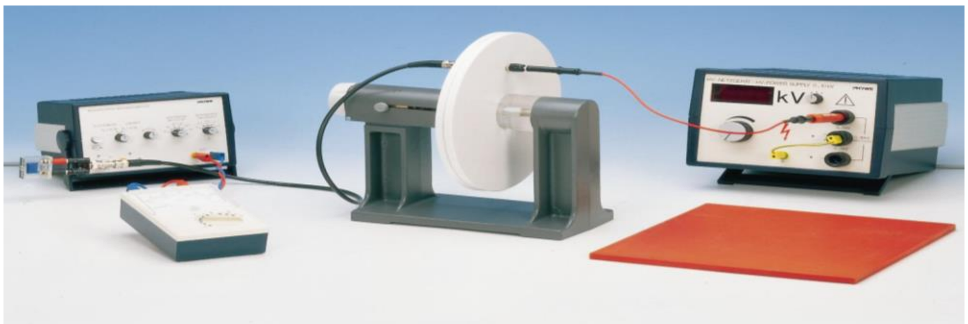

Fig. 3: Measurement set-up: Dielectric constant of different materials.

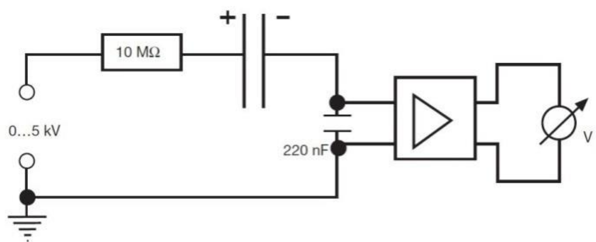

Fig. 4: Wiring diagram

Setup and procedure

1. Calculate the surface area of the capacitor plates by means of their radius.

2. Make the experimental setup and the corresponding wiring diagramas shown in fig. 3 and in fig. 4, respectively.The highly insulated capacitor plate should be connected to the upper connector of the high voltage power supply over the 10 MΩ protective resistors.

3. Make Ground both the middle connector of the high voltage power supply and the opposite capacitor plate over the 220 nF capacitor. Correct measurement of the initial voltage is to be assured by the corresponding adjustment of the toggle switch on the unit.

4. *The electrostatic induction charge on the plate capacitor can be measured over the voltage on the 220 nF capacitor, according to equation (4). Be sure not to be near the capacitor during measurements, as otherwise the electric field of the capacitor might distorted.*

5. The measurement amplifier is to be set to high input resistance, to amplification factor 1 and to time constant 0.

6. Measure the charge on the capacitor plates varying the voltage (0.5V, 1.0V, 2.0V, 2.5V, 3.V, 3.5V, 4.0V) between the plates of the plate capacitor at a constant distance (<0.5 cm). Draw the graph with electrostatic charge vs plate distance as shown in fig. 5.

7. Measure the charge on the capacitor plates varying the distance 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 at a constant voltage (1.5 kV) between the plates of the plate capacitor. Draw the graph as shown in fig. 6 to verify the linear relation between charge and plate capacitor voltage.

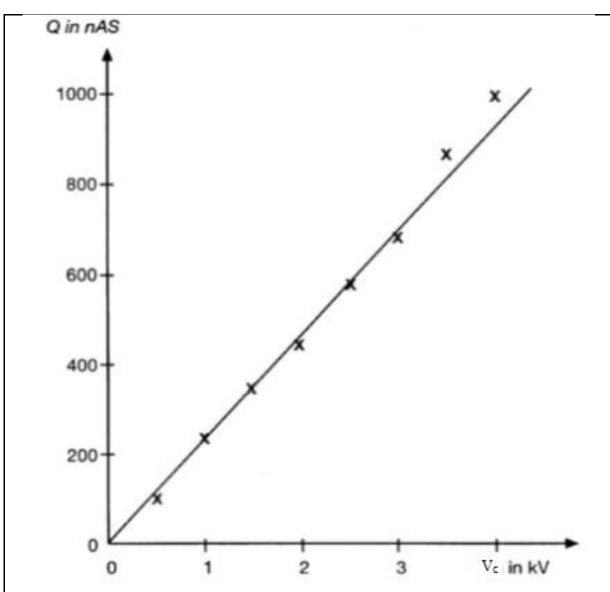

Fig.5: Electrostatic charge Q of a plate capacitor as a function of the applied voltage V_c (d = 0.2 cm)

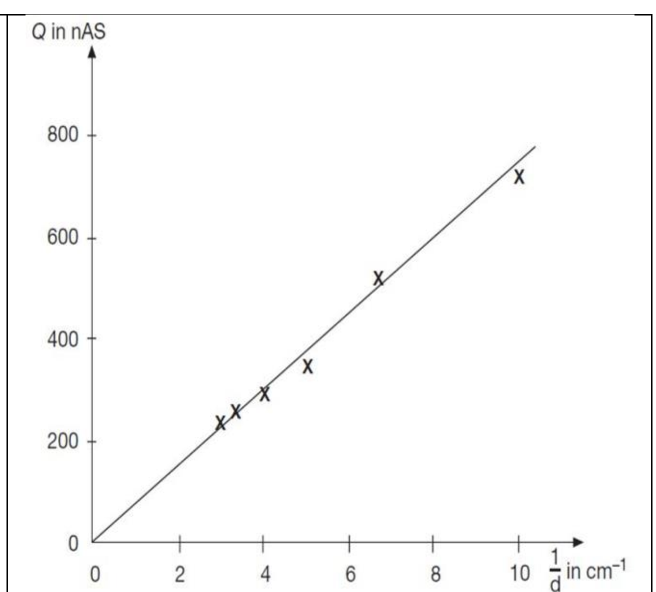

Fig. 6: Electrostatic charge Q of a plate capacitor as a function of the inverse distance between the capacitor plates d^{-1}(V_c= 1.5 kV).

8. Measure the electrostatic induction charge from varying voltage, with and without plastic plate placed in the space between the plates, with the same distance between the plates.

9. Draw the electrostatic induction charge Q of the plate capacitor as a function of the applied voltage V_c, with and without dielectric (plastic) between the plates as shown in fig. 7. The ratio between the electrostatic induction charges allows to determine the dielectric constant ε_0 of plastic.

10. The dielectric constant of the glass plate is determined in the same way.

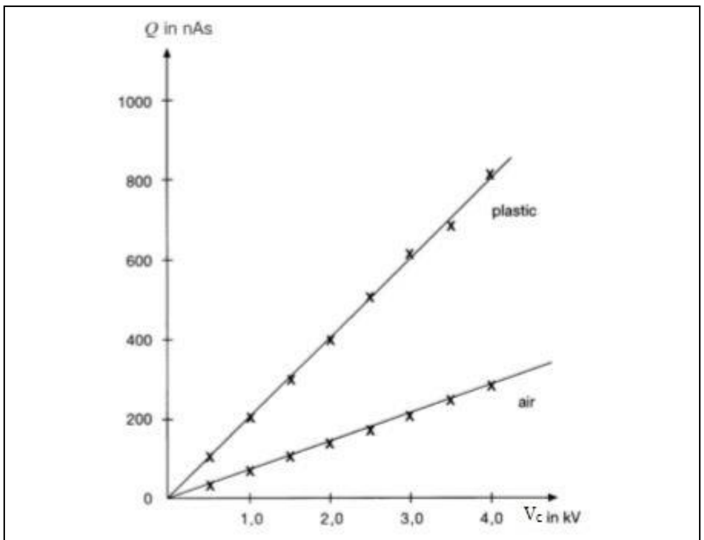

Fig. 7: Electrostatic charge Q of a plate capacitor as a function of the applied voltage V_c, with and without dielectric (plastic) between the plates (d = 0.98 cm)

Measurement results

Table 1: Measurement of the permittivity constant in constant applied voltage

$A = 0.0531\ \text{m}^2$ V_c= ___________ V $C = 220$ nF

Distance between the plates, d		Output voltage dropped in the opposite plate, V			Mean Voltage, V	Charge, Q	Permittivity constant, ε_0
[cm]	$1/d$ [cm^{-1}]	[V]			[V]	[nAs]	[pAs/Vm]

Table 2: Measurement of the electric constant at fixed separation

$A = 0.0531\ \text{m}^2$ d = _______________ cm $C = 220$ nF

Applied voltage, V_c	Output voltage dropped in the opposite plate, V			Mean Voltage, V	Charge, Q	Permittivity constant, ε_0
[V]	[V]			[V]	[nAs]	[pAs/Vm]

Table 3: Measurement of dielectric constant for Plastic

$A = 0.0531\ m^2$ $d =$ _______________ cm $C = 220$ nF

Applied voltage, V_c	Output voltage dropped in the opposite plate, V			Mean Voltage, V	Charge, Q		V_{vac}	Q_{vac}	Q/Q_{vac}
[V]	[V]			[V]	[nAs]	$[\frac{d}{A\epsilon_0}\frac{1}{V_c}]$	[V]	[nAs]	

Table 4: Measurement of dielectric constant for glass

$A = 0.0531\ m^2$ $d =$ _______________ cm $C = 220$ nF

Applied voltage, V_c	Output voltage dropped in the opposite plate, V			Mean Voltage, V	Charge, Q		V_{vac}	Q_{vac}	Q/Q_{vac}
[V]	[V]			[V]	[nAs]	$[\frac{d}{A\epsilon_0}\frac{1}{V_c}]$	[V]	[nAs]	

Glass: d = 0.17 cm, V_c = 0.5 kV, Output voltage, V = 5.8 V, Q = 1.264 μAs

$\varepsilon_{glass} = 9.1$