E6: 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.

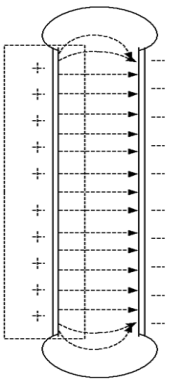


Fig. 1: Electric field of a plate capacitor with small distance between the plates, as compared to the diameter of the plates.

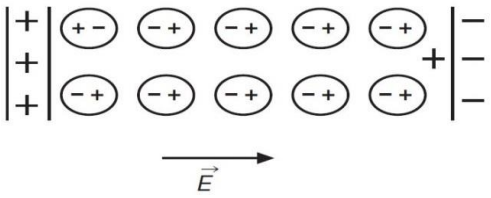


Fig. 2: Generation of free charges in a dielectric through polarization of the molecules in the electric field of a plate capacitor.

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

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

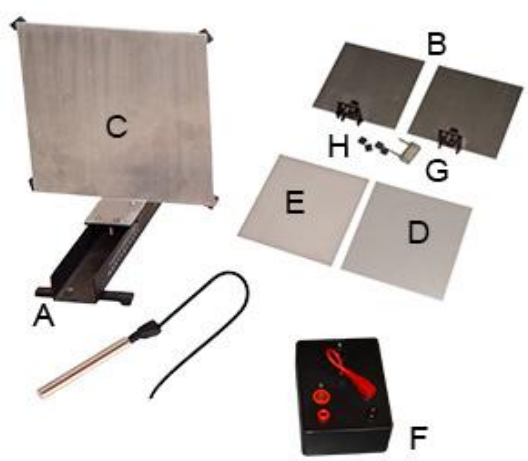
For the same voltage, the amount of charge of the capacitor is significantly increased by the dielectric. If the charges obtained with and without plastic (equations [3] and [8]) are divided by each other:

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

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

Apparatus

Dielectric constant kit, Electrometer amplifier, Digital multimeter, Power supply (2-12 V AC/DC), High voltage power supply (0-600V DC), Flexible plug leads (50 cm), black, Flexible plug leads (50 cm), red, Flexible plug leads (100 cm), yellow and earthing lead (100 cm), green. Way switch, Capacitor module 0.01mF and 100nF, 4.7 MΩ Resistance box.



A Metal Rail	: Metal sheet, L=350mm approx.
B Capacitor plate	: Aluminium, 20cm x 20cm (LxW)
C Capacitor plate	: Aluminium, 28cm x 28cm (LxW)
D Glass sheet	: 21cm x 21cm (LxW)
E Polystyrene sheet	: 21cm x 21cm (LxW)
F Two way switch	: 4mm socket, 3 nos.
G Capacitor	: 0.01μF & 0.001μF
H Spacer	: PVC (1,2,3,4,6 mm)

Scope of Supply : Complete with metal rail with scale printed 0-10 cm, pair of large and small capacitor plates, PVC spacers, two way switch , glass and polystyrene sheets, earthing rod, capacitor module.

Fig 3: Items in the dielectric constant kit.

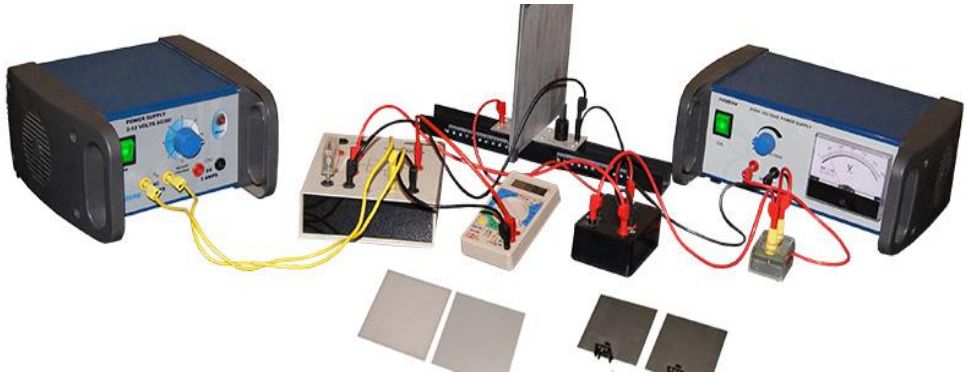


Fig. 4: Experimental setup.

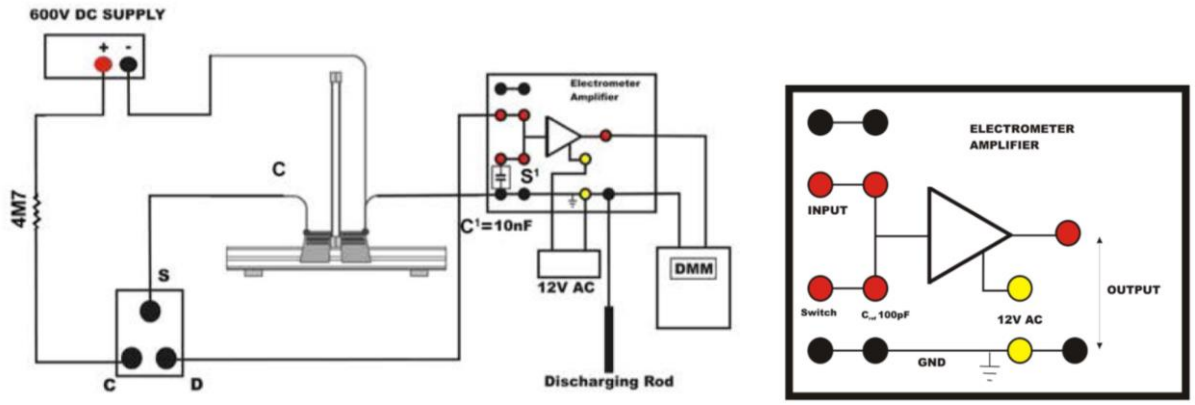


Fig. 5: Circuit diagram

Setup procedure:

1. Mount the pair of small plates; set the right plate at the 0 position with the indicator attached at the bottom of the plate and move the left plate to such a position that the two plates should touch each other, note the left plate position, this will be the initial position. (R_{plate} = 0, L_{plate} = ~4.7 cm)
   (Do not move the plate by grabbing it directly)
2. Keeping the R_{plate} at 0 position, move the left plate to set a distance'd' between the plates to 5 mm.
   (There should be a visible gap between the plates)
3. Connect the grounding from main electric socket with the grounding marked terminal of the electrometer amplifier (elec. amp.).
4. Ground all the instruments as well as yourself by touching with the earthing rod.
   (This must be done before each reading)
5. Connect negative terminal of the DC power supply to the right plate and to the ground of the amplifier, also connect the discharging rod.
6. Connect the positive side of the DC power supply to the socket C of the two-way switch.
7. Connect the socket S of the two-way switch to the left plate and the socket D to the positive input of elec. amp.
8. Connect the AC power supply to the yellow marked inlets of the elec. amp.
9. Connect the reference capacitor C_{ref} = 220 nF, push switch at the elec. amp. input terminals and connect the outputs of the elec. amp. to a digital multimeter, set the 20V DC position.

NEVER USE THE ELEC AMP IN DC OUTPUT

Experimental procedure:

1. Turn on the high voltage DC power supply and set the voltage value to around 50V.
2. Turn on the AC power supply and set the voltage value to 12V.
3. Before taking any reading, discharge the plates and C_{ref} capacitor by pressing the push switch for 5 sec, the output multimeter should show a value of 0V.
4. Then release the push switch and set the two-way switch at 'C' position for 5 sec, this position will charge the plates at the supplied DC voltage.
5. Afterwards, change the two-way switch at 'D' position for discharge the plates, note the multimeter reading.

Important instructions:

1. During experiment keep the discharging rod in your hand.
2. After setting the two-way switch at discharging position, take your hands away from the setup and wait till the reading is stable.
3. Any type of disturbance near the setup even the movement of the other persons near it must be avoided.

Use the plastic clips to grip the aluminum plates with polystyrene plates in between, while finding the dielectric constant of the polystyrene.

Procedure:

A Finding permittivity constant by changing distance between capacitor plates

1. Establish the connection set (S) to discharging (D) position with the two-way switch; discharge the plate capacitor with the discharging rod check the zero at output.

2. Keep the distance between the plates at 4 mm.

3. Hold the discharging rod in your hand (to store the charge), change the connection set (S) to charging (C) position with the two-way switch, and set the charging voltage E to 300 V

4. Change the connection back from S to D and note down the voltage reading displayed in multimeter (this is for charge measurement). *During discharging measurement, the output voltage of electrometer amplifier will vary, therefore wait for 30-60 sec to read out stable reading. Each measurement should be taken for same time interval. This reading should be taken three times for each distance and then average voltage used in calculations.*

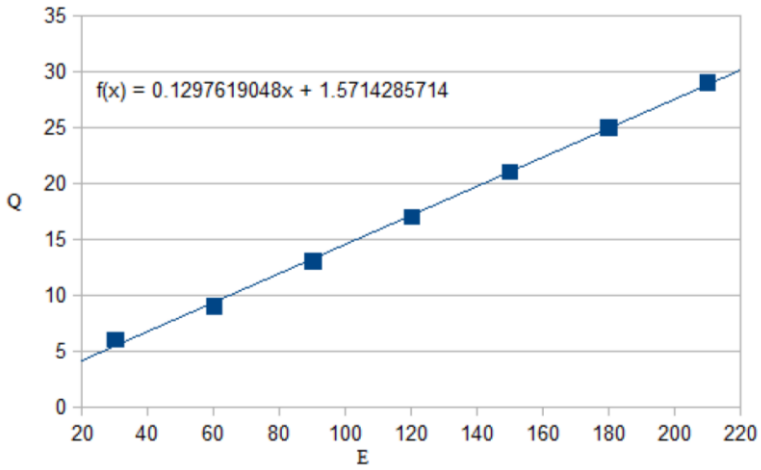
5. Repeat the procedure of discharging to discharge the plate charge.

4. Repeat the experiment by changing the distance between the plates 4 mm, 8mm, 12 mm…

5. Calculate charge from voltage measurements and draw a graph of Q against 1/d cm^{-1}. From the slope find the permittivity of air.

B Finding permittivity constant by changing applied voltage

Repeat procedure from part A, keeping distance between plates constant at 4 mm and $c_{ref} = 220\ nF$. Start with E = 30 V and note down voltage readings from multimeter. Repeat the experiment for E = 60 V, 90 V, 120 V, 150 V, 180 V, 210 V and 270 V. Calculate charge from voltage measurements. Plot a graph of charge against applied voltage E. Find the permittivity of air from the slope of the graph.



C. Measurement of dielectric constants of different materials (polystyrene and glass)

1. Place the polystyrene sheet between the pair of capacitor plates, and take care about the surfaces of plates are in complete touch with the sheet.

2. Establish the connection S to D in the two-way switch, and discharge the capacitor with the connection rods. Change back the connection to the S to C to charge to charge the

plates & change back to the S to D for discharge.

3. Hold the connection rod in your hand and measure the voltage V from multimeter (calculate charge) as a function of the voltage E (30 V, 60 V, 90 V…).

4. Now, replace the polystyrene plate with the glass plate, establish the connection S & D, and discharge the capacitor with the connection rod.

5. Hold the connection rod in your hand, charge the plate by making connection to S to C & S to D back to get charge reading and record the series of measurements with glass sheet as dielectric.

6. Draw graph of different dielectric materials together for comparison.

Data Collection

Table 1: Measurement of output voltage with varying distance between plates for constant applied voltage

A = 400 cm^2 V_c= 300 V $c_{ref} = 220\ nF$

Distance between the plates, d		Output voltage dropped in the opposite plate, [mV]			Mean Voltage, V	Charge, $Q = CV$ [nAs]
[mm]	1/d [m^{-1}]	V_1	V_2	V_3		
4						
8						
12						
16						
20						
24						
28						
32						

Table 2: Measurement of dielectric constant for plastic and air

A = 400 cm^2 d = 4 mm/6 mm/ 8 mm $c_{ref} = 220\ nF$

Applied voltage, E	Air				Polystyrene/Glass				Q/Q_{vac}
	Output voltage dropped in the opposite plate, V		Mean Voltage	Charge, Q	Output voltage dropped in the opposite plate, V		Mean Voltage	Charge, Q	
	V_1	V_2			V_1	V_2			

Calculations:

Error Analysis:

Results:
The permittivity of air is *(mention error)*
The dielectric constant of polystyrene is *(mention error)*
The dielectric constant of glass is *(mention error)*

Discussion:

Things to be careful about during the experiment:
1. The Earth terminal should be at zero potential. Check it before performing the experiment.

2. After making connections, touch the discharging rod, connected to earth terminal, with connecting wires, bodies of power supplies, table, bench of capacitor plate, electrometer amplifier, and your clothes to discharge all the stray charges to earth, in each trial.

3. During experiment keep the discharging rod in your hand.
4. After setting the two-way switch at discharging position, take your hands away from the setup and wait till the readings are stable.

5. Any type of disturbance near the setup even the movement of other persons near it must be avoided.

6. For quick stability of readings use capacitor of larger capacity.

7. Use plastic clips to grip the aluminum plates with polystyrene plate in between, while finding the dielectric constant of polystyrene.