Dielectrics in plate capacitors

DETERMINING THE RELATIVE PERMITTIVITY OF VARIOUS MATERIALS

- **Static measurement of voltage *U* across a plate capacitor with various dielectrics and a fixed plate separation *d*.**
- **Determination of relative permittivity ε_r for various dielectric materials.**

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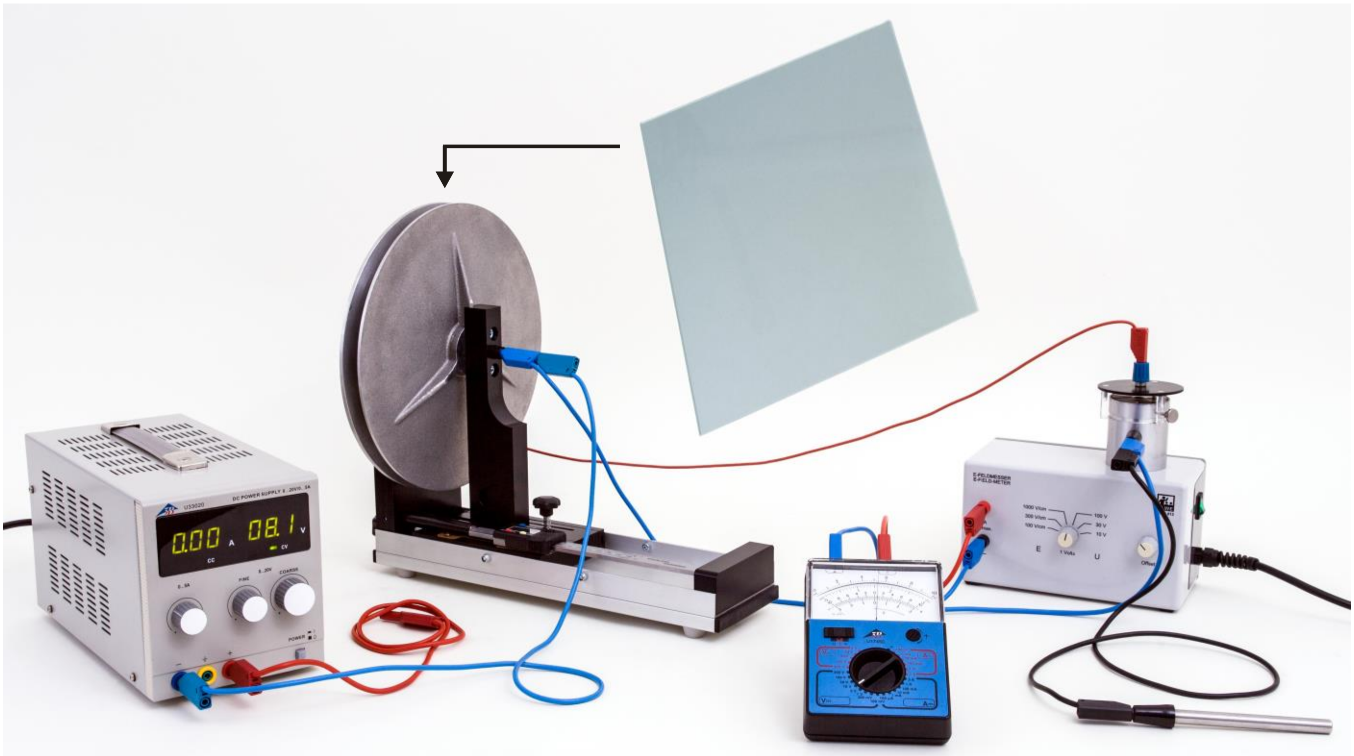

Fig. 1: Measurement set-up

BASIC PRINCIPLES

Any insulating or poorly conducting material lacking charge carriers which are free to move and situated inside an electric field will act as a dielectric. Such a material can be a gas, liquid or solid. The electric field causes the dielectric to become polarised. Firstly, electric dipoles can be induced due to shifts in charge within the atoms or molecules of the substance or between differently charged ions in the dielectric (displacement or induced polarisation). Secondly, any randomly oriented permanent dipoles within the dielectric can be moved into alignment with the electric field (orientational polarisation).

The relative permittivity, formerly also referred to as the dielectric constant ε_r of a dielectric, is defined by the relationship between the electric field *E* and dielectric displacement *D*:

(1) $D = \varepsilon_r \cdot \varepsilon_0 \cdot E$

$\varepsilon_0 = 8.85 \cdot 10^{-12} \frac{\text{V} \cdot \text{s}}{\text{A} \cdot \text{m}}$: Permittivity of free space.

If a dielectric is placed between the plates of a plate capacitor, the capacitance of the component increases by a factor of ε_r relative to the capacitance exhibited if the space between the plates is a vacuum:

$$(2) \quad C = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{d}.$$

A: Area of capacitor plates
d: Separation of capacitor plates

If the capacitor has been charged by a voltage U_0 prior to introduction of a dielectric, a charge Q gathers on the plates as given by the following equation:

$$(3) \quad Q = C_0 \cdot U_0 = \varepsilon_0 \cdot \frac{A}{d} \cdot U_0$$

This charge remains constant when the capacitor is disconnected from the voltage source.

When the dielectric is introduced, no current flows between the capacitor plates and, as given by equation (2), the voltage U_0 must decrease by a factor of ε_r if the charge Q remains constant:

$$(4) \quad Q = C \cdot U = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{d} \cdot \frac{U_0}{\varepsilon_r}$$

where

$$(5) \quad U = \frac{U_0}{\varepsilon_r} \Leftrightarrow \varepsilon_r = \frac{U_0}{U}.$$

$$(6) \quad U_0 = E_0 \cdot d \Leftrightarrow U = E \cdot d$$

Because of equation (6) above, the electric field E_0 must also decrease by a factor ε_r if the plate separation d remains constant

$$(7) \quad E = \frac{E_0}{\varepsilon_r} \Leftrightarrow \varepsilon_r = \frac{E_0}{E}$$

In this experiment an electric field meter is used as between the capacitor plates via the voltmeter and the charge Q on the plates remains constant.

LIST OF EQUIPMENT

1	Electric field meter	U8533015	1001029/30
1	Plate capacitor	U8492355	1006798
1	Cardboard plate	U8492341	1000936
1	Transparent acrylic plate	U8476371	1000880
1	DC power supply, 0-20 V, 0-5 A	U33020	1003311/2
1	Escola 100 analog multimeter	U8557380	1013527
1	Set of 15 experiment leads, 2.5 mm²	U13801	1002841

SET-UP

- Set up the experiment as shown in Fig. 2.

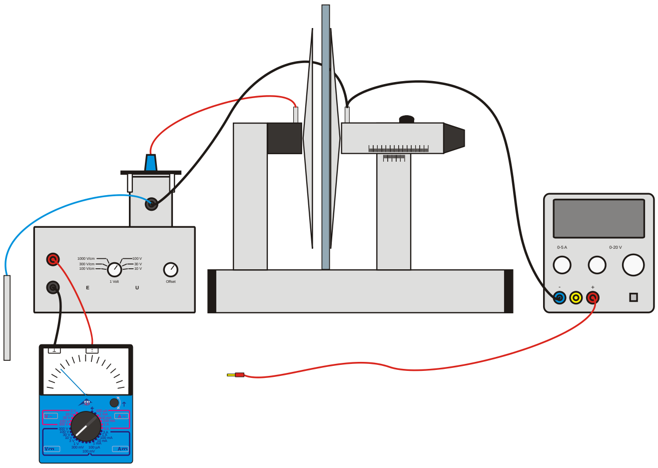

Fig. 2: Experiment set-up.

- Place the voltage measurement plate, with its range set to 1x, on the screening cylinder of the electric field meter in such a way that the distance between it and the screening plate is as small as possible. Secure the voltage measurement plate in place with the help of the knurled screw.
- Connect the fixed capacitor plate to the voltage measurement plate.
- Connect the movable capacitor plate to the ground socket of the electric field meter and the negative pole of the power supply.
- Connect the holding rod to the ground socket on the screening cylinder of the electric field meter.
- Connect one end of a lead to the positive pole of the power supply and put the other, loose end on the table without connecting it to anything.
- Connect the multimeter for measuring the voltage to the voltage output of the electric field meter.
- Set the range selector switch of the electric meter to 10 V, turn on the electric field meter and wait about three minutes for it to settle down.
- Turn on the power supply, setting the voltage on it to U_0 = 10 V.

PROCEDURE

- Set the plate separation d to 5 mm using the plate capacitor's fine adjustment mechanism.
- To discharge the plate capacitor, touch the fixed capacitor plate with the holding rod. This creates a short circuit between the plates. At the same time, use the offset knob on the electric field meter to calibrate its zero point.
- Remove the holding rod for the fixed capacitor plate and hold it in your own hand for the purpose of providing equipotential bonding.
- Do not let go of the holding rod for the full duration of the measurement.

- In order to charge the plate capacitor with the loose end of the wire connected to the positive terminal of the power supply, touch it to the fixed capacitor plate.
- When the capacitor is charged, take the wire away from the fixed capacitor plate again, thereby disconnecting it from the positive of the power supply.
- Read off the voltage U (= U_0) from the multimeter and make a note of it.
- Introduce the cardboard plate between the capacitor plates in such a way that it is flat against the moving capacitor plate connected to the ground terminal of the electric field meter and the negative pole of the power supply. Observe what happens to the voltage on the multimeter.
- Read off the voltage U after the cardboard dielectric has been introduced.
- Repeat the experiment with the acrylic plate.

SAMPLE MEASUREMENT

Voltage with no dielectric $U = U_0$:	10 V
Voltage with cardboard plate U:	2.2 V
Voltage with acrylic plate U:	2.9 V

EVALUATION

- Calculate the relative permittivities using equation (5).

With cardboard plate:

$$(8) \quad \varepsilon_r = \frac{U_0}{U} = \frac{10\ \text{V}}{2.2\ \text{V}} = 4.5$$

With acrylic plate:

$$(9) \quad \varepsilon_r = \frac{U_0}{U} = \frac{10\ \text{V}}{2.9\ \text{V}} = 3.4$$

The values measured are in very good agreement with values for cardboard (ε_r = 4.3 – 5.4) and acrylic (ε_r = 3.1 – 3.6) quoted in literature.