Measuring the potential inside a plate capacitor

Objects of the experiments

- To measure the potential in the plate-type capacitor in parallel to the capacitor plates: equipotential surfaces
- To measure the potential in the plate-type capacitor perpendicular to the capacitor plates: determination of the field strength *E*

Principles

In the experiment the potential in the plate capacitor is investigated. If the distance between the plates is significantly less than the dimensions of the plates, the electric field strength between the plates *E* can be regarded as homogeneous. The electric field lines run between the plates perpendicular to the plates. Therefore the equipotential surfaces run in parallel to the capacitor plates (see fig. 1).

In the two dimensional section through an electric field the points of equal potential form a line. The course of such equipotential lines is, just like the course of the field lines, determined by the spatial arrangement of the field-generating charges. The equipotential lines are always perpendicular to the electric field lines.

For measuring the potential between the capacitor plates a flame probe is used. In the metal tube of the flame probe a flammable gas flows to the tip and burns there with a small flame. Because of the flame at the tip, an ionisation current will flow until the ambient potential is reached. The resulting voltage is transmitted via the connection cable to the voltage measuring panel on the electric field meter S and there it is measured.

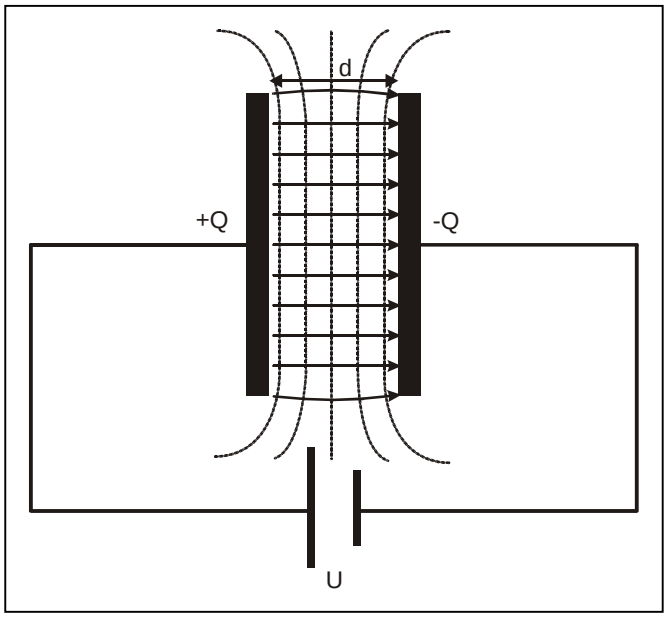

Fig. 1: Electric field and equipotential lines in the plate capacitor

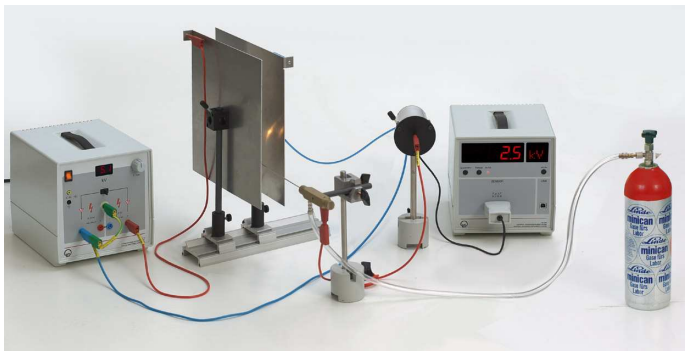

Fig. 2: Experimental setup

If the flame probe is moved in parallel to the capacitor plates, the equipotential surfaces between the plates are determined. If the flame probe is move perpendicular to the plates, the electric field can be determined from the changes in the potential.

In the experiment the potential is initially determined in parallel to the capacitor plates by shifting the flame probe to the desired distance *a* step by step in parallel to the capacitor plates and at each step measuring the resulting voltage *U*.

Then the flame probe is moved stepwise perpendicular to the capacitor plates and again the voltage *U* is measured for each step. The voltage values are plotted as a function of their location x. The gradient of the straight line which is fitted to the measured values corresponds directly to the electric field strength E in the plate capacitor. The value determined from the fit of a straight line to the measured values is compared to the value which is calculated using

$$E = \frac{U_C}{d}$$

from the applied voltage U_C and the distance *d* between the plates.

CS-0307

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Apparatus

1 electric field meter S..... 524 080
1 set of accessories for the electric field meter S... 540 540
1 universal measuring instrument P..... 531 835
1 high voltage power supply 10 kV 521 70

2 clamp riders with clamp 45/35..... 460 312
1 optical bench, S1 profile, 50 cm..... 460 317
2 saddle bases..... 300 11
2 stand rods, 25 cm 300 41
1 Leybold multiclamp 301 01
1 wooden ruler, L = 1m / 39 inch..... 311 03

1 safety connection lead, 10 cm, yellow/green..... 500 600
1 safety connection lead, 50 cm, red 500 621
1 safety connection lead, 50 cm, blue..... 500 622
1 safety connection lead, 100 cm, red 500 641
1 safety connection lead, 100 cm, blue..... 500 642

1 cartridge..... 666 715
1 valve for gas cartridge..... 666 716
1 PVC tubing, 7 x 1.5 mm, 1 m 667 193

Note:

For carrying out this experiment, as an alternative to the universal measuring instrument P the following can be used:

1 mobile CASSY (524 009)
or
1 Sensor-CASSY (524 010USB) + CASSY Lab (524 200)) / CASSY-Display (524 020)
or
1 Pocket CASSY (524 009) + CASSY Lab (524 200)

Setup

The experimental setup is shown in fig. 1. For the setup the following steps are required:

- Set up the plate capacitor made from the two capacitor plates with the saddle bases on the optical bench S1.
- Set the desired distance between the plates. Distances up to 6 mm can be realised by means of the plastic spacers of defined thickness (1 mm and 3 mm). Ensure that the plates are aligned as parallel as possible.
- Fix electric field meter into one of the saddle bases. Clamp the flame probe with the Leybold multiclamp on top of the stand rod and also fix it in a saddle base.
- **Earth the left-hand negative pole of the 10 kV high voltage power supply and connect it to the earthing socket on the back of the electric field meter.** In addition connect it to one of the capacitor plates.
- Connect the positive pole of the 10 kV high voltage power supply to the free capacitor plate.
- Connect the electric field meter to the universal measuring instrument P and select “Voltage” as the measuring unit.
- Place the voltage measuring plate onto the electric field meter and connect the flame probe to the voltage measuring plate.
- Connect the cartridge to the flame probe, check the firmness of the tube connections.
- Hold a burning lighter or match to the tip of the flame probe and **slowly** open the gas supply until at the tip burns with a small flame, approx. 10 mm high.
- Set the saddle base with the flame probe on the wooden ruler in such a way that the flame probe can be moved in parallel to the capacitor plates. The flame probe should be aligned parallel with the plates in order to disturb the electric field around it as little as possible.
- Carefully move the flame probe and place it into the experimental setup.
- Hold the flame probe during the measurement only by its insulating stand rod, because any contact with metal parts will prevent the potential equalisation.

Note:

- Do not put the flame probe into excessively strong fields; that would cause the flame to become sooty.
- Placing the flame into a setup reduces the dielectric strength of the air and may therefore lead to electric flashovers.

Warning:

It is absolutely necessary to provide correct earthing of the electric field meter S. Because typically the connection is measured using a high voltage, the electric field meter S must never be operated without the 4 mm socket on the back being connected to ground. When it is connected correctly the current flows back to the power supply should the voltage spark across and not to the meter.

Should the earthing not be correct, peripheral equipment (e.g. the meter or Sensor-CASSY) connected to the electric field meter S could become damaged!

Carrying out the experiment

a) Measurement in parallel to the capacitor plates

- With the high voltage supply switched off measure the distance *d* between the flame probe and the plates.
- Increase the high voltage on the capacitor plates to 3.0 kV.
- Move the flame probe on the wooden ruler step by step in parallel to the capacitor plates and note for each step the measured voltage *U* and the position.
- Change the distance between the flame probe and the capacitor plates and repeat the measurement.

b) Measurement perpendicular to the capacitor plates

- Align the wooden ruler perpendicular to the capacitor plates and place the base with the flame probe on it in such a way that the flame probe can be move perpendicular to the capacitor plates.
- Determine the location of the flame probe within the plate capacitor.
- Move the flame probe on the wooden ruler step by step perpendicular to the capacitor plates and note for each step the measured voltage *U* and the position.
- Shift the flame probe in parallel to the capacitor plates and repeat the measurement.

Measuring example and evaluation

a) Measurement in parallel to the capacitor plates

In table 1 the results of an example of a measurement are shown. The distance between the capacitor plates was d = 50 mm, the distance from the flame probe to the earthed capacitor plate was a_1 = 25 mm and a_2 = 40 mm. At the location x = 0 cm the flame probe was located on the line connecting the edges of the capacitor plates.

x / cm	0	4	8	12	16	20	24	28
U_1 / kV	1.42	1.82	1.78	1.78	1.83	1.85	1.71	1.53
U_2 / kV	2.44	2.75	2.73	2.74	2.727	2.72	2.68	2.45

Tab. 1: Measuring results U_1 (a_1 = 25 mm) and U_2 (a_2 = 40 mm)

In figure 3 the measured values are plotted. It is easily seen that the values for the positions between x = 4 cm and x = 24 cm are approximately identical. Only for the positions x = 0 cm and x = 28 cm, where the flame probe reaches the level of the plate edges, does the potential markedly drop. The reason for this is the finite size of the plate.

b) Measurement perpendicular to the capacitor plates

In table 2 the results of an example of a measurement are shown. The distance between the capacitor plates was d = 50 mm, the flame probe was centrally between the capacitor plates. The location x = 0 mm corresponded to the earthed capacitor plate.

x / cm	10	15	20	25	30	35	40
U / kV	0.49	0.82	1.14	1.51	1.77	2.17	2.46

Tab. 2: Measuring results

In figure 4 the measured values are plotted. The values increase with increasing distance from the earthed capacitor plate continuously; the fit of a straight line results in a gradient of B = 66 kV/m. The gradient corresponds to the change in the potential as a function of location, i.e. of the electric field strength E in this position. The measurement therefore indicates clearly that the electric field strength between the capacitor plates is homogeneous. From the equation for the electric field strength $E = \frac{U_C}{d}$ one obtains with U_C = 3.0 kV and d = 5.0 cm: E = 60 kV/m. This corresponds well to the value obtained by fitting the straight line.

Note:

With further measurements of the potential perpendicular and in parallel to the capacitor plates (also at varying heights) the potential and therefore the change in the field between the capacitor plates and also at the edge can be investigated systematically and the influence of the finite size of the capacitor plates on the potential and the field can be made visible.

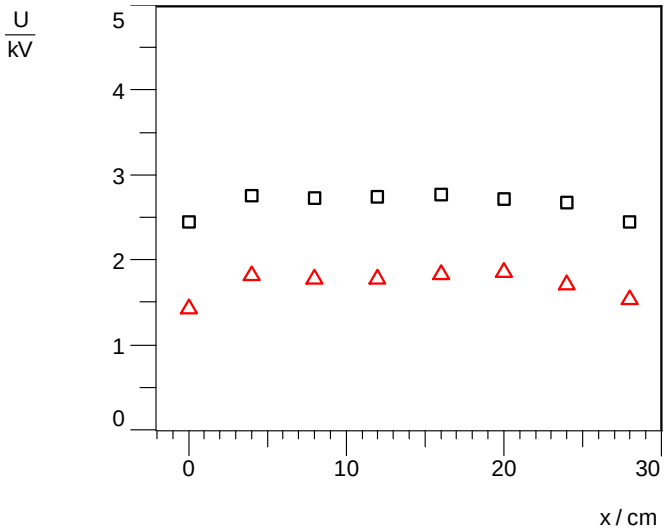

Fig. 3: Voltage U as a function of the location x in parallel to the capacitor plates for the distances a_1 = 25 mm (□) and a_2 = 40 mm (△)

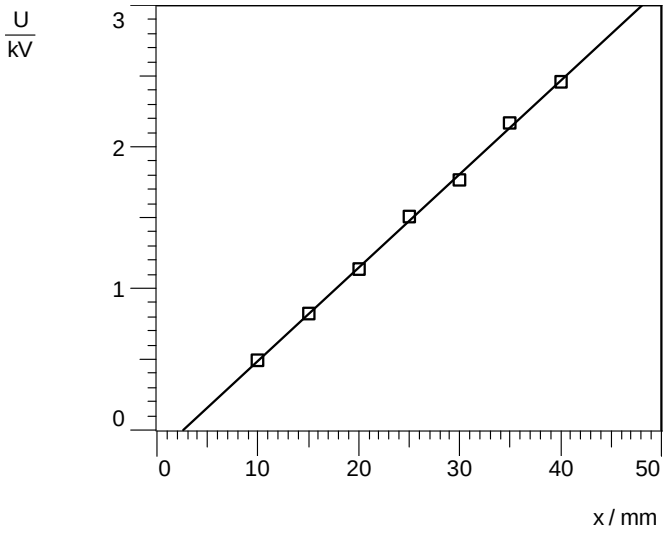

Fig. 4: Voltage U as a function of the location x perpendicular to the capacitor plates

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