Electricity

Electrostatics
Plate capacitor

*LD
Physics
Leaflets*

P3.1.7.4

Measuring the electric field strength inside a plate capacitor

Objects of the experiments

■ To determine the electrical field strength E in a plate capacitor as a function of the applied voltage U

■ To determine the electrical field strength E in a plate capacitor as a function of the distance between the plates d

Principles

The simplest form of a capacitor is the plate capacitor. If the distance between the plates is less than the dimensions of the plates, the electrical field strength between the plates E can be regarded as homogeneous. It is caused by the charges $+Q$ and $-Q$ which are created by applying a voltage U to the plates (see figure 1). The electrical field strength is the higher, the higher the surface charge density Q/A is, i.e. the more charges that are present on the plates or the smaller that the area A of the plates is. In addition, it depends on the dielectric constant ε_r of the material between the plates:

$$E = \frac{Q}{\varepsilon_0 \cdot \varepsilon_r \cdot A} \qquad (I)$$

The dielectric constant ε_r describes the increase of the capacitance $C = Q/U$ of the plate capacitor compared to the vacuum value.

Alternatively, the electrical field strength E can be determined from the applied voltage U and the distance d between the plates:
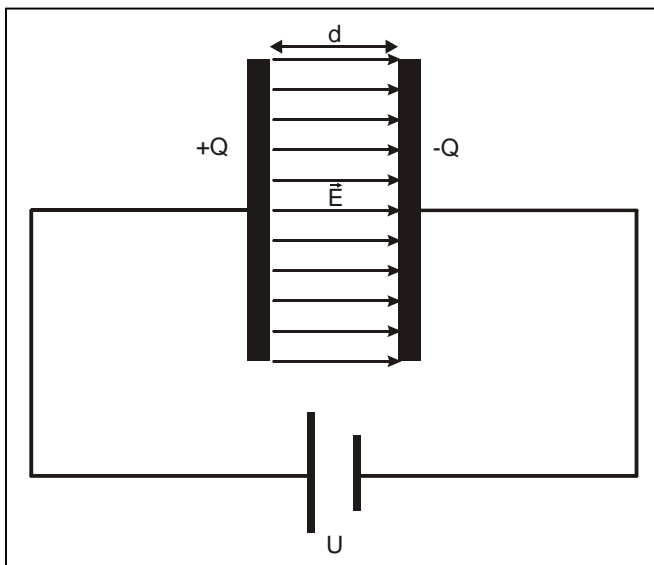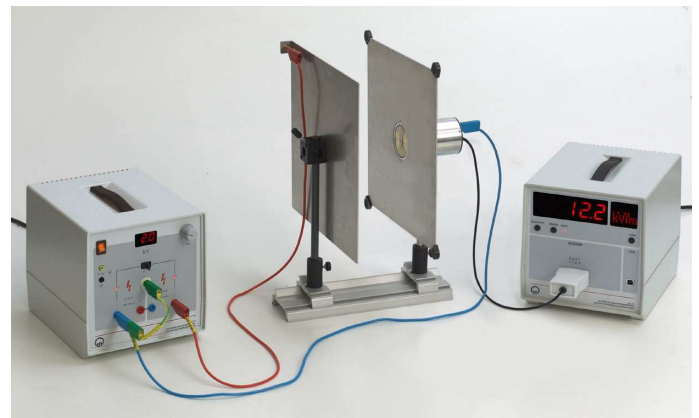
$$E = \frac{U}{d} \qquad (II)$$

Fig. 2: Experimental setup

A comparison of the equations (I) and (II) shows that the capacitance C of the plate capacitor is determined by

$$C = \frac{Q}{U} = \varepsilon_0 \cdot \varepsilon_r \frac{A}{d} \qquad (III)$$

In the experiment, the dependency of the electrical field strength E on the various parameters is investigated. First of all their dependency on the applied voltage U is determined. For this purpose the electrical field strength is measured for a changing applied voltage U at a fixed distance d between the plates. Then the data are plotted and the gradient of the straight line is compared to the value to be expected theoretically, $1/d$.

Then the voltage U is kept at a constant value and the electrical field E strength is measured as a function of the distance d between the plates. The validity of the function $E \sim 1/d$ is checked by means of the measured data.

Fig. 1: Electrical field in the plate capacitor

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

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. 2. For the setup the following steps are required:

- Fix one of the capacitor plates using a stand base onto a plastic stand rod and with a clamp rider with clamp on the optical bench profile S1.

- Push the drilled capacitor plate onto the electric field meter S. In addition attach it with clamp riders with clamp to the optical bench profile S1.

- Connect the electric field meter to the universal measuring instrument P.

- **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.**

- Connect the positive pole of the high voltage 10 kV power supply to the free capacitor plate.

- Adjust the distance between the plates to $d = 6$ mm. Distances up to 6 mm can be realised by means of the plastic defined thicknesses (1 mm and 3 mm). Ensure that the plates are aligned as precisely in parallel as possible in order to keep edge effects a small as possible.

Warning

It is absolutely necessary to provide correct earthing of the electric field meter S. Because typically measurements are made using high voltage, the electric field meter S must never be run without a connection from the 4 mm socket on the back to ground potential. If it is connected correctly, the current flows back to the power supply should voltage flashover across the capacitor 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!

Note:

To obtain the distance between the capacitor plate and the electric field meter S relevant to the size of the electric field, 1 mm must be added. The measuring electrodes in the electric field meter are – on account of the construction of the meter – 1 mm behind the capacitor plate inserted into the electric field meter.

Carrying out the experiment and measuring example

a) Determination of the electrical field strength *E* as a function of the applied voltage *U*

The 10 kV high voltage power supply is switched on, the voltage is increased step by step and the electrical field strength *E* is read on the universal instrument P. In tab. 1 the measured values are shown for an example of a measurement.

$\frac{U}{kV}$	1.0	2.0	3.0	4.0	5.0
$\frac{E}{kV/m}$	142	272	407	552	690

Tab. 1: Example of a measurement of the electrical field strength *E* as a function of the applied voltage *U*

b) Determination of the electrical field strength *E* as a function of the distance *d* between the plates

The high voltage power supply 10 kV is set to $U = 1.0$ kV and the value of the field strength *E* is read on the universal measuring instrument P. Then the voltage is switched off, the plate distance *d* is reduced by means of the spacers step by step to 4, 3, 2 and 1 mm, the plate capacitor is charged with a voltage $U = 1.0$ kV and the electrical field strength *E* is measured. Tab. 2 shows the values in the example of a measurement. The distance d^* corresponds to the actual distance to the electric field meter (see note).

$\frac{d}{mm}$	6.0	4.0	3.0	2.0	1.0
$\frac{d^*}{mm}$	7.0	5.0	4.0	3.0	2.0
$\frac{E}{V/m}$	138	188	242	334	496

Tab. 2: Measuring example showing the dependence of the electrical field strength *E* on the applied voltage *U* (*d*: distance between the capacitor plates, *d**: distance between capacitor plate and electric field meter)

In addition, distances between plates > 6 mm can be set by determining the zero position on the optical bench S1 (the plates sit directly next to each other) and then moving one of the plates by the desired distance.

Evaluation

a) Determination of the electrical field strength *E* as a function of the applied voltage *U*

In figure 3 the values in tab. 1 are plotted. A straight line through the origin was fitted through the points. Its gradient *m* is 137.5 1/m. Equation (II) shows, that the gradient should have precisely the value 1/*d*. With *m* = 137.5 1/m the value *d* = 7.3 mm is obtained which corresponds well to the actual set distance of $d^* = 7.0$ mm between the capacitor plate and the electric field meter S.

b) Determination of the electrical field strength *E* as a function of the distance *d* between the plates

In figure 4 the values in tab. 2 are plotted. For checking if the plot of the values corresponds to the expected function $E \sim 1/d$ a hyperbola with the equation $E = A/d$ was fitted to the values. The trace of the curve closely corresponds to the values. The value for the proportionality constant *A* resulting from the fit is for the measured value *A* = 0.97 kV shown. Comparison with equation (II) shows that *A* should correspond precisely to the applied voltage *U* = 1.0 kV. This has been fulfilled within the measuring precision.

Notes:

For large distances *d* between the plates, the electrical field is no longer homogeneous and is smaller than the value expected according to the theory $E = \dfrac{U}{d}$. The deviation can be systematically investigated experimentally by increasing the distance *d* between the plates step by step to values > 30 cm and measuring the corresponding field strength *E*.

It is also possible to carry out this part of the experiment with a higher voltage. However, it must be observed that the dielectric strength of air is approx. 2 kV/mm. For this reason, flashover cannot be excluded for higher voltages which might damage the connected equipment.
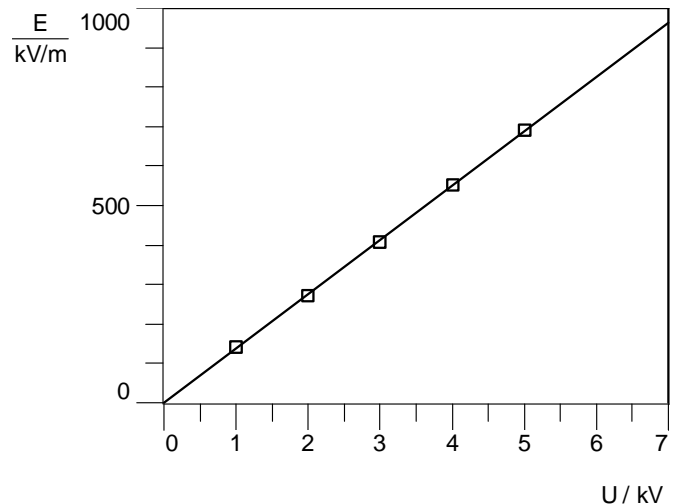

Fig. 3: Electrical field strength *E* as a function of the applied voltage *U*
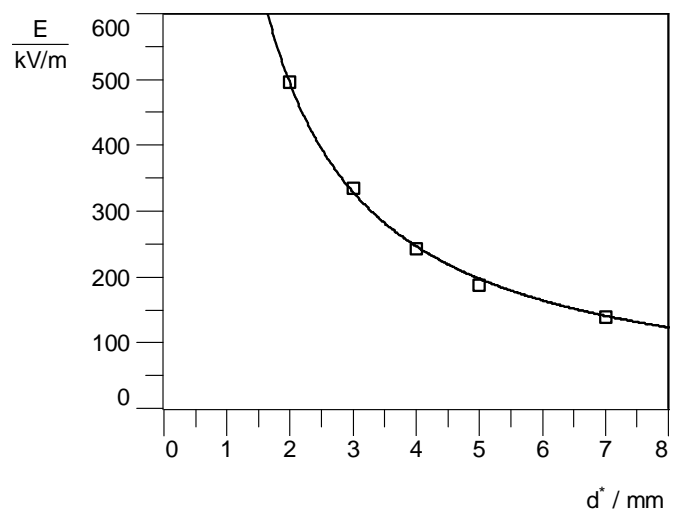

Fig. 4: Electrical field strength *E* as a function of the distance d^* between the capacitor plate and the electric field meter S