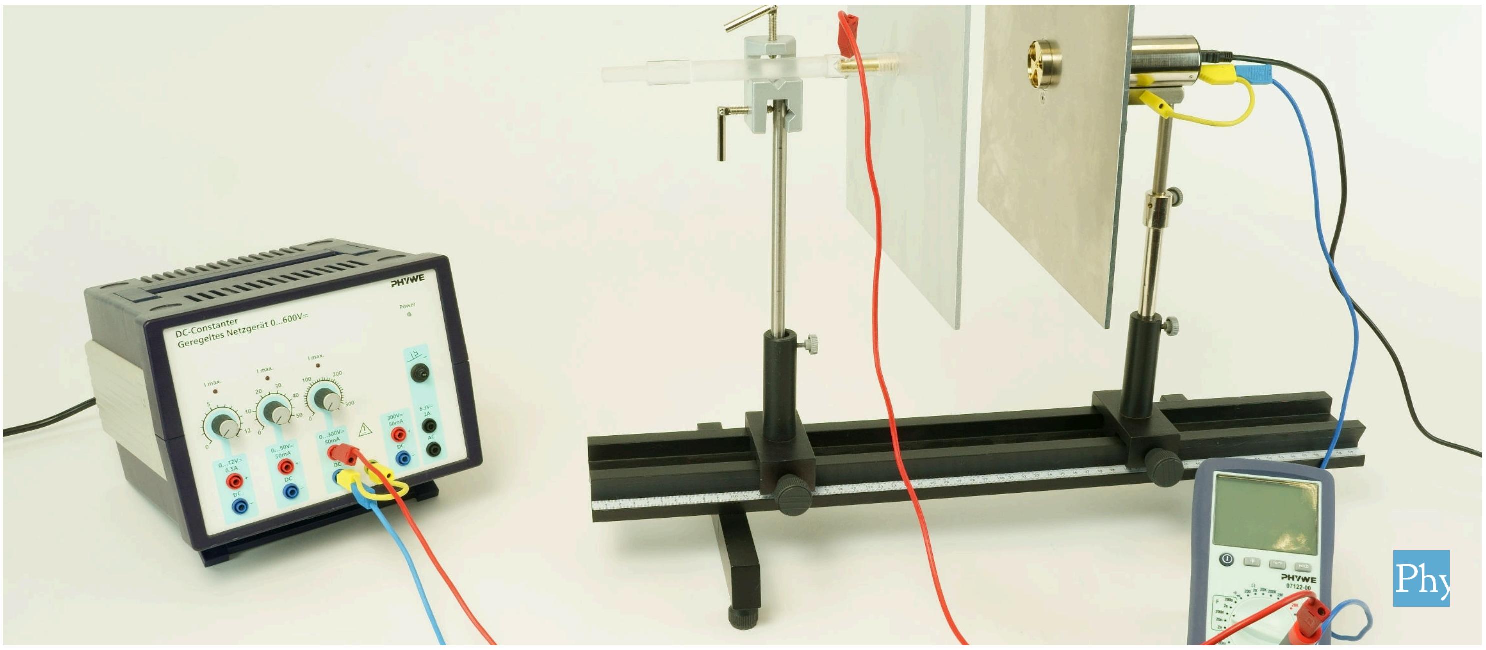
Electric fields and potentials in the plate capacitor



Electrical fields and potentials in the plate capacitor is measured as a function of the plate spacing and the voltage

Physics | Electricity & Magnetism | Electrostatics & electric field

Difficulty level	Group size	Preparation time	Execution time
medium	2	10 minutes	20 minutes

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General information

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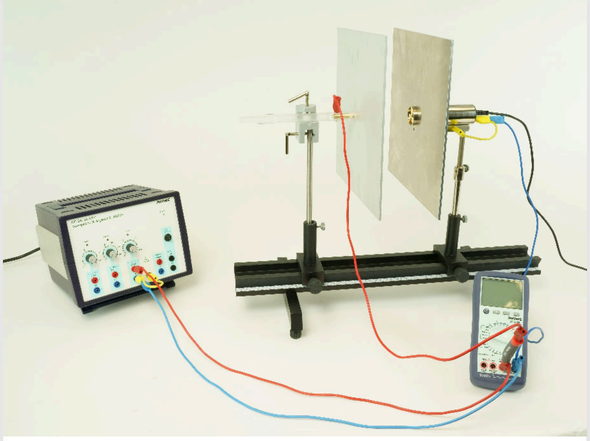
Application



Experimental setup for the measurement of the electric field strength

Electric fields are the cause of many phenomena, especially in particle physics.

The electric field and potential of the plate capacitor are ideal to study the basic principles of homogeneous fields.

In this experiment, the field is investigated as a function of the voltage applied to the capacitor and as a function of the distance between the plates.

The electric potential between the plates is measured with the flame probe. By this principle the air around the tip of the probe is ionized by a flame to avoid electrostatic induction.

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Other information (1/2)

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Prior knowledge

For the theoretical derivation of the fundamentals of this experiment, Maxwell's equations can be used. Basic knowledge about electric fields and the fundamental understanding of a capacitor should be available.

Scientific principle

The plate capacitor is the basic example of a homogeneous electric field. The potential between the plates increases linearly from the grounded plate to the charged plate. The electric field between the plates is uniform and can be varied by the applied voltage and the distance between the plates.

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Other information (2/2)

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Learning objective

In this experiment the students learn that the electric field strength in the plate capacitor depends on the applied voltage and the distance between the plates.

In addition, the linear course of the potential between the capacitor plates is demonstrated experimentally.

Tasks

- The relationship between voltage and electric field strength is investigated, with constant plate spacing.
- The relationship between electric field strength and plate spacing is investigated, with constant voltage.
- In the plate capacitor, the potential is measured with a probe, as a function of position.

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Safety instructions

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The general instructions for safe experimentation in science lessons apply to this experiment.

Working with high voltage is always dangerous and requires increased caution. Make sure that neither you nor others can accidentally touch parts connected to the high voltage source. For your safety and the safety of the equipment, make sure that the grounding is connected.

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Theory (1/3)

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$$\mathrm{rot}\vec{E} = -\frac{\delta}{\delta t}\vec{B}$$

$$\mathrm{div}\vec{D} = \rho$$

follow from Maxwell's equations for the electric field $\vec{E}$ in the plate capacitor.

Taking the steady-state case in the charge-free space into account, the following is given:

$$\mathrm{rot}\vec{E} = 0 \qquad (1)$$

$$\mathrm{div}\vec{D} = 0 \qquad (2)$$

Regarding parallel capacitor plates, eq. (2) implies, that the field is perpendicular to the plates.

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Theory (2/3)

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Since the field is irrotational (cf. eq. (1)) it can be represented as the gradient of a scalar field:

$$\vec{E} = -\mathrm{grad}\varphi = -\frac{\partial \varphi}{\partial x}$$

while $\vec{E}$ because of its uniformity, may also be expressed as the quotient of differences

$$\left|\vec{E}\right| = \frac{\varphi_1 - \varphi_0}{x_0 - x_1} = \frac{U}{d} \qquad (3)$$

where the potential difference is equal to the applied voltage U and d is the distance between the plates.

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Theory (3/3)

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With constant voltage U, the field strength E varies in inverse proportion to the spacing d.

If the measured values are plotted on a double logagaritmic scale, then because

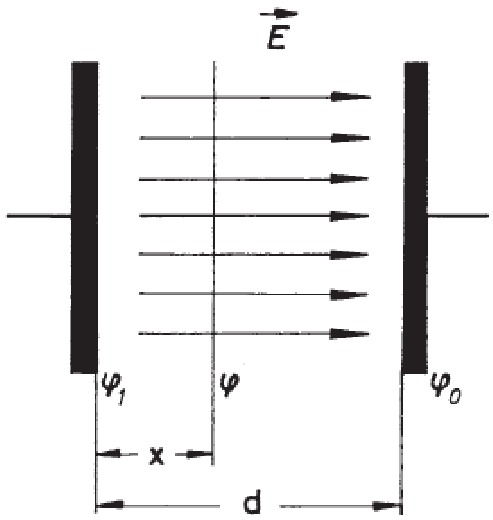
$$\log E = \log \frac{U}{d} = \log U - \log d$$

a straight line is obtained with slope $m = -1$.

With $x_1 = 0$ and $\varphi_1 = U$ follows from (3)

$$\varphi = U - E \cdot x$$

matching the illustration on the right.



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Equipment

Position	Material	Item No.	Quantity
1	PHYWE Power supply, regulated DC: 0...12 V, 0,5 A; 0...650 V, 50 mA / AC: 6,3 V, 2 A	13672-93	1
2	Plate capacitor, 283x283 mm	06233-02	2
3	Capacitor plate w.hole	11500-05	1
4	Potential probe	11501-00	1
5	High-value resistor, 10 MOhm	07160-00	1
6	Blow lamp, butan cartridge,X2000	46930-00	1
7	Butane cartridge C206, without valve, 190 g	47535-01	1
8	Rubber tubing, i.d. 6 mm	39282-00	1
9	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
10	Connecting cord,100 mm, green-yellow	07359-15	1
11	Connecting cord, 32 A, 750 mm, red	07362-01	3
12	Connecting cord, 32 A, 750 mm, blue	07362-04	3
13	Optical bench expert l = 600 mm	08283-00	1
14	Base for optical bench expert, adjustable	08284-00	2
15	Slide mount for optical bench expert, h = 80 mm	08286-02	2
16	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	2
17	Right angle clamp expert	02054-00	2
18	Barrel base expert	02004-00	2
19	Ruler, plastic, 200 mm	09937-01	1
20	Stand tube	02060-00	1
21	Electric Field Meter	11500-30	1

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Setup and procedure

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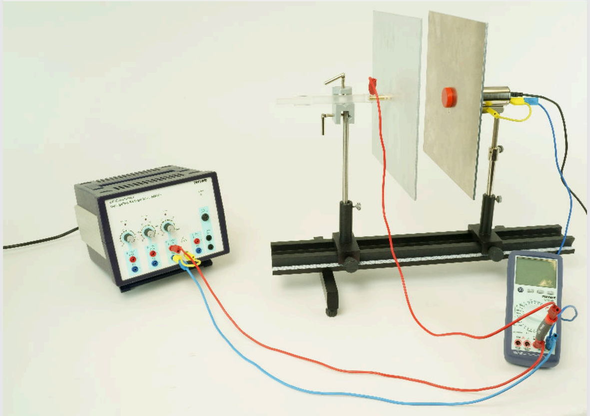
Setup (1/3)



Experimental setup with protection cap for calibration

Setup for **measurements 1** and **2**:

- Attach the electric field meter to the capacitor plate / holder and mount it on the optical bench.
- Mount the second capacitor plate also on the optical bench and connect the power supply and multimeter as shown in the figure.
- Place the protective cap on the electric field meter and connect it via USB to a computer.
- Start the program EFMXX5_ReadOut. Click on "Device info" and "Continue". Start zero adjustment and follow the instructions.

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Setup (2/3)

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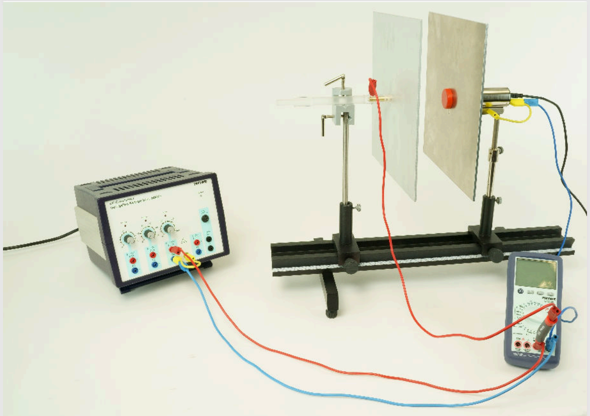

Experimental setup with protection cap for calibration

Setup for **measurements 1** and **2**:

- Remove the cap and "Start measurement display".
- Choose "Measure mode" "E-Fieldmeter".
- Press "Start" for data aquisition.
- Adjust measurement range as needed.

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Setup (3/3)

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setup for the measurement of the electrical potential

Setup for **measurement 3**:

- Mount the voltage measuring attachment to the electric field meter and connect it as shown in the figure on the left.
- With the voltage measuring attachment the electric field meter is capable of measuring voltages in the ranges of $50\,V$, $250\,V$, $500\,V$ and $2500\,V$.
- Choose "Measure mode" "Voltemeter MK 11".
- Press "Start" for data aquisition.
- Adjust measurement range as needed.

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Procedure (1/3)

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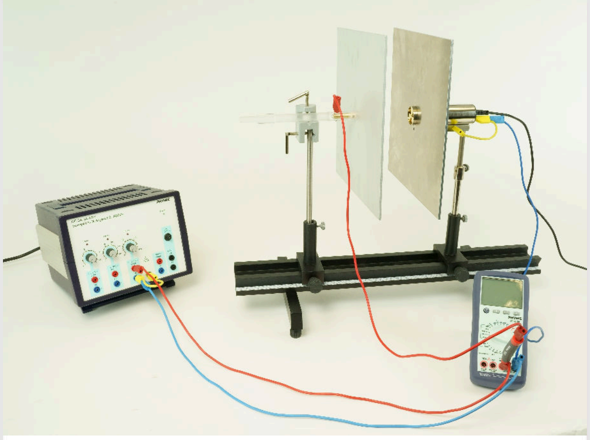

Measurement of the electric field as a function of voltage

Measurement 1: Electric field of the plate capacitor as a function of the distance between the plates

- Place the second capacitor plate $10\,cm$ from the plate at the electric field meter.
- Apply different voltages according to table 1 of the evaluation section.
- Note the resulting values for the measured electric field strength in the table.

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Procedure (2/3)

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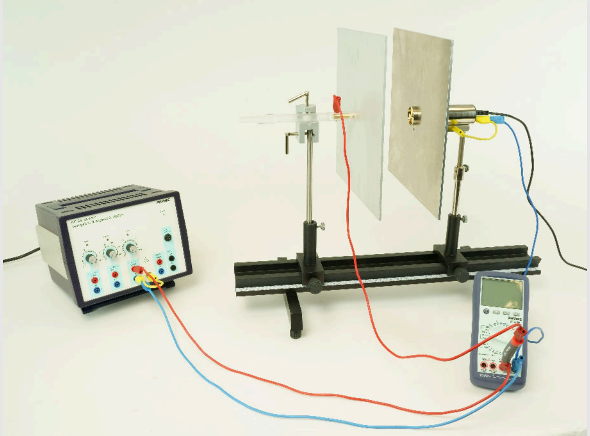

Measurement of the electric field as a function of the distance between the plates

Measurement 2: Electric field strength of the plate capacitor as a function of the distance between the capacitor plates

- Apply a voltage of $200\,V$ to the plate capcitor.
- Take measurements for the distance between the capacitor plates according to table 2 of the evaluation section.
- Note your measurements in the table.

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Procedure (3/3)

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Measurement of the potential as a function of the location between the plates

Measurement 3: Electric potential of the plate capacitor as a function of the location between the plates

- Execute the setup for the measurement of the electric potential and place the capacitor plates at a distance of 10 cm.
- Light an approximately 1 cm large flame at the tip of the glass tube, engulfing the tip of the probe.
- Apply a voltage of $250\,V$ to the capacitor.
- Measure the electric potential in steps of $1\,cm$ between the plates.

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Evaluation (1/3) Table 1

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Note the measured values for the electrical field strength E as a function of the voltage applied to the plate capacitor with fixed distance $d = 10\,cm$ between the plates.

$U\,[V]$	10	25	50	75	100	125	150	200	250
$E\,[kV/m]$									

Create a graph from your measurement series.

Since $E = \frac{1}{d} \cdot U$ the slope m of the linear regression $E = m \cdot U$ should match with the reciprocal distance of the plates $1/d$.

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Evaluation (2/3) Table 2

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Note the measured values for the electrical field strength E as a function of the distance between the capacitor plates at fixed voltage $U = 200\,V$.

$d\,[cm]$	2	3	4	5	6	7	8	10	12
$E\,[kV/m]$									

Create graphs from your measurement series with linear scales and double logaritmic scale. Check the slope of the double logaritmic scale according to the theory.

You can also simply plot the resulting electric field strengths with respect to the reciprocal distance $1/d\,[1/m]$ (note that the distances were measured in cm). Since $E = U \cdot \frac{1}{d}$ the slope m of the linear regression $E = m \cdot \frac{1}{d}$ should then match with the applied voltage U.

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Evaluation (3/3) Table 3

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Note the measured values for the electric potential φ as a function of the location x between the capacitor plates at fixed voltage $U = 250\,V$ and distance $d = 10\,cm$.

$d\,[cm]$	1	2	3	4	5	6	7	8	9
$E\,[kV/m]$									

Create a graph from your measurement series.

According to the theory the resulting graph should match with

$$\varphi = U - E \cdot x$$

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