Electricity

Electrostatics

Plate capacitor

LD Physics Leaflets

P3.1.7.6

Measuring the field strength of a charged sphere in front of a conductive plate (image charge)

Objects of the experiments

- To determine the electric field strength E as a function of the applied voltage U
- To determine the electric field strength E as a function of the distance r between sphere and plate

Principles

If one moves a charged sphere close to a conducting plate, on the surface of the plate an induced charge is generated which screens the external field on the inside of the conducting plate. The field in front of the plate looks exactly the same as if instead of the plate there were another sphere with the opposite charge at double the distance (fig. 1). Charge and field appear as a mirror image on the surface of the conducting plate; for this reason one talks about a mirror or image charge.

In the experiment the electric field strengths in the symmetry axis at the surface of the plate at the distance r from the sphere are determined. The following applies:

$$E = \frac{2Q}{4\pi\varepsilon_0 \cdot r^2} \qquad \text{(I)}$$

The conducting plate or the mirror charge will lead simply to a doubling of the field strength in comparison to a completely isolated sphere.

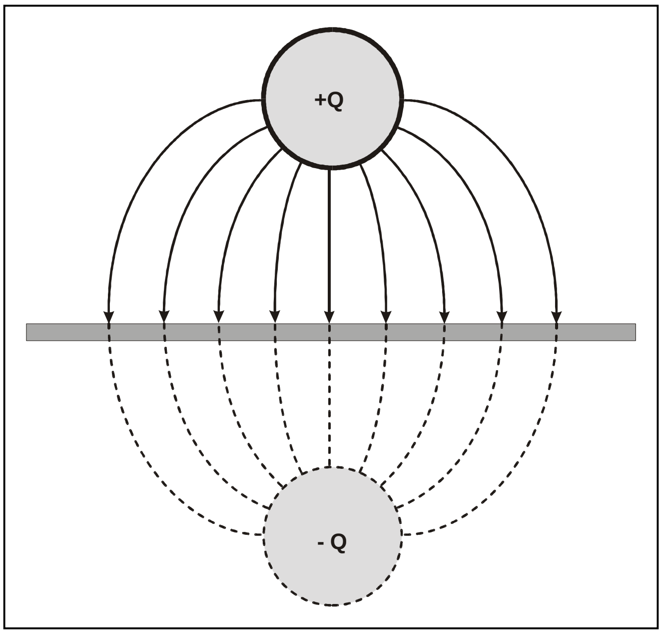

Fig. 1: Field between a charged sphere and a conducting plate with image charge

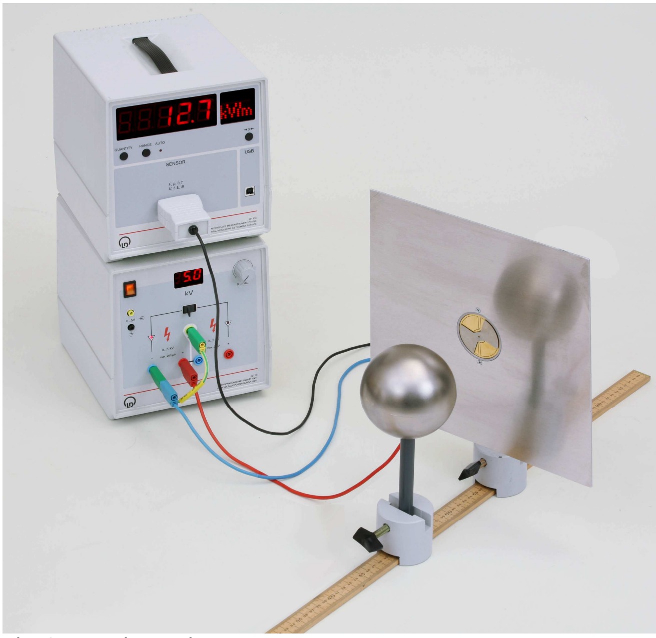

Fig. 2: Experimental setup

The charge Q on the sphere of radius a is, with applied voltage U: $Q = C \cdot U = 4\pi\varepsilon_0 \cdot a \cdot U$. Substituting the values in equation (I) gives the electric field strength as a function of the applied voltage:

$$E = \frac{2a \cdot U}{r^2} \qquad \text{(II)}$$

In the experiment, first of all the dependency of the electric field strength E on the applied voltage U is investigated. To do this for a fixed distance r between the centre of the sphere and the plate surface, the voltage applied to the sphere is increased and then the electric field strength is measured. Then the dependency on the distance is investigated. Here the voltage at the sphere is kept constant, the distance between the sphere and the plate is increased step by step and the electric field strength is measured. The measured results are compared to the values determined by means of equation (II).

CS-0407

Apparatus

1 sphere with connection cable 543 08
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 saddle bases 300 11
1 wooden ruler, L = 1m / 39 inch 311 03
or
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 leads, 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:

- Fit the sphere with the connection cable into a base.
- Push the drilled capacitor plate onto the electric field meter S and also attach the electric field meter to one of the bases.
- Place the sphere and the electric field meter onto the wooden ruler and align the capacitor plate perpendicular to the wooden ruler.
- **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 left-hand positive pole of the 10 kV high voltage meter with the connection cable.
- Connect the electric field meter to the universal measuring instrument P.

Note:

Set up metal objects (e.g. high voltage power supply, universal measuring instrument P) as far away from the sphere as possible in order to disturb the potential and electric field around the charged sphere as little as possible.

Warning:

It is absolutely necessary to provide correct earthing of the electric field meter S. Because typically the measurement is made 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.

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) Measuring as a function of the applied voltage

- Adjust the distance *r* = 20 cm between the centre of the sphere and the electric field meter. Ensure that the centre of the electric field meter is precisely at the same height as the centre of the sphere.
- Increase the voltage on the sphere step by step to 5.0 V and read the value of the electric field strength *E*. Then reduce the voltage to zero.
- Increase the distance to *r* = 40 cm and repeat the experiment.

b) Measurement as a function of the distance *r* between the sphere and the plate

- Adjust the distance *r* = 10 cm and adjust the voltage to *U* = 5.0 kV. Read the value of the electric field strength *E*.
- Increase the distance step by step and read for each step the electric field strength *E*.

Measuring example and evaluation

a) Measuring as a function of the applied voltage

In table 1 the measuring results of an example of a measurement for the electric field strength *E* are shown as a function of the voltage *U* and graphically plotted in figure 3. The E_1 values were measured for the distance r_1 = 20 cm and the E_2 values for the distance r_2 = 40 cm.

U / kV	0.5	1.0	1.5	2.0	2.5
E_1 / kV/m	1.4	2.6	3.9	5.1	6.4
E_2 / kV/m	0.30	0.53	0.80	1.06	1.34
U / kV	3.0	3.5	4.0	4.5	5.0
E_1 / kV/m	7.6	8.9	10.2	11.4	12.7
E_2 / kV/m	1.63	1.94	2.24	2.55	2.90

Tab. 1: Measuring results as a function of the voltage *U*

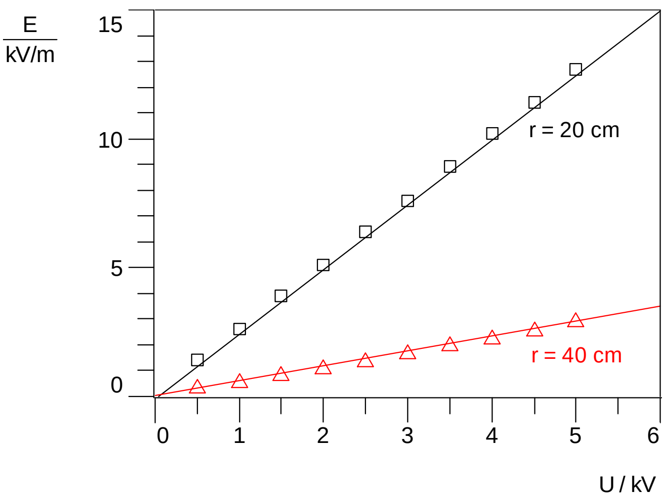

Fig. 3: Electric field strength *E* as a function of the applied voltage *U* for the distances r_1 = 20 cm and r_2 = 40 cm between the sphere and the plate

The linear dependency of the electric field strength *E* on the applied voltage *U* is obvious. The gradient of the fitted straight line is given according to equation (II) by

$$\frac{\Delta E}{\Delta U} = \frac{2a}{r^2}$$

The measurement gives the radius of the sphere as *a* = 5.0 cm:

r = 20 cm: $\frac{\Delta E}{\Delta U}$ = 2.5 m^{-1}; $\frac{2a}{r^2}$ = 2.5 m^{-1}

r = 40 cm: $\frac{\Delta E}{\Delta U}$ = 0.58 m^{-1}; $\frac{2a}{r^2}$ = 0.63 m^{-1}

For both distances the values correspond well to each other.

b) Measurement as a function of the distance *r* between the sphere and the plate

In table 2 the measuring results of an example of a measurement for the electric field strength *E* are shown as a function of the voltage *U* and graphically plotted in figure 4.

r / cm	10	12.5	15	17.5	20	25
E / kV/m	-63.0	-36.3	-24.3	-17.5	-13.1	-8.4
r / cm	30	35	40	45	50	60
E / kV/m	-5.7	-4.2	-3.5	-2.8	-2.3	-1.8

Tab. 2: Measuring results as a function of the distance *r*

The electric field strength rapidly falls as the distance between sphere and plate increases. The function is highly non-linear. To check the dependency $E \sim 1/r^2$ from equation (I) the measured values are in addition plotted on double-logarithmic scales (see figure 5). The function is well represented by a matched straight line with a gradient 1.8; the dependency $E \sim 1/r^2$ is therefore fulfilled in the measurement.

The deviation from the straight line for small distances *r* is caused by the radius of the sphere no longer being small compared to the distance from the plate. This leads to deviations in the electric field strength.

The finite size of the plate influences the values for large values of *r*. However, the deviations are small for the distances used. In addition, at large distances the electric field strength is influenced by further objects or persons close to the measuring setup, which leads to deviations from the expected function.

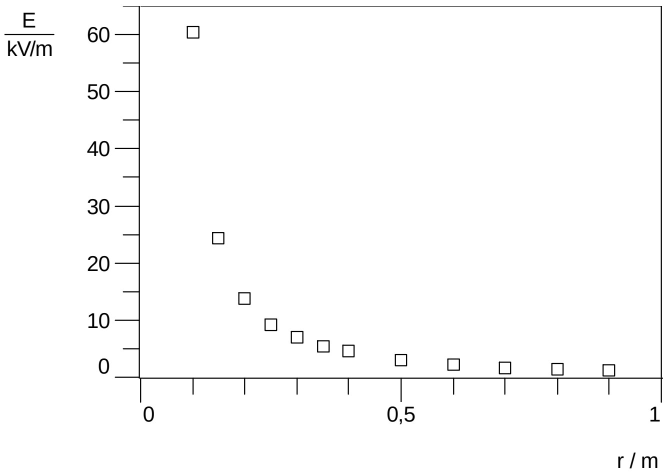

Fig. 4: Electric field strength *E* as a function of the distance *r* between sphere and plate

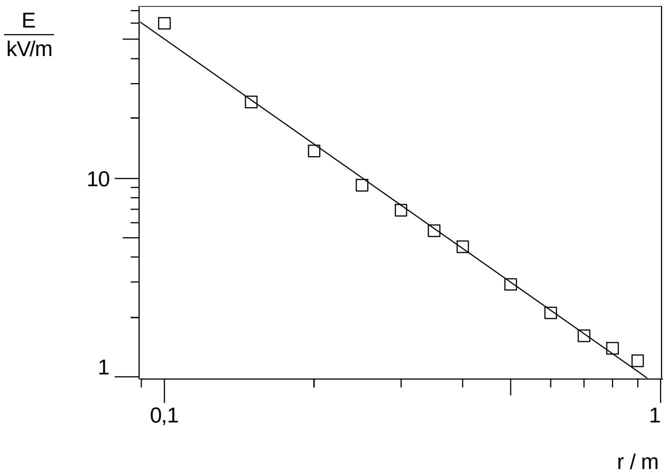

Fig. 5: Electric field strength *E* as a function of the distance *r* in a double-logarithmic plot