Investigating the charge distribution on the surface of electrical conductors

Objects of the experiments

- Investigating the charge distribution on the outside surface of a Faraday's cup and a conical conductor as a function of the curvature of the surface.
- Measuring the charge on the inside surface of a Faraday's cup and a conical conductor.

Principles

In an electrical conductor, excess charges can move freely. In the case of electrostatic equilibrium the charges are, therefore, arranged on the surface of the conductor only; there are no free charges in the interior of the conductor.

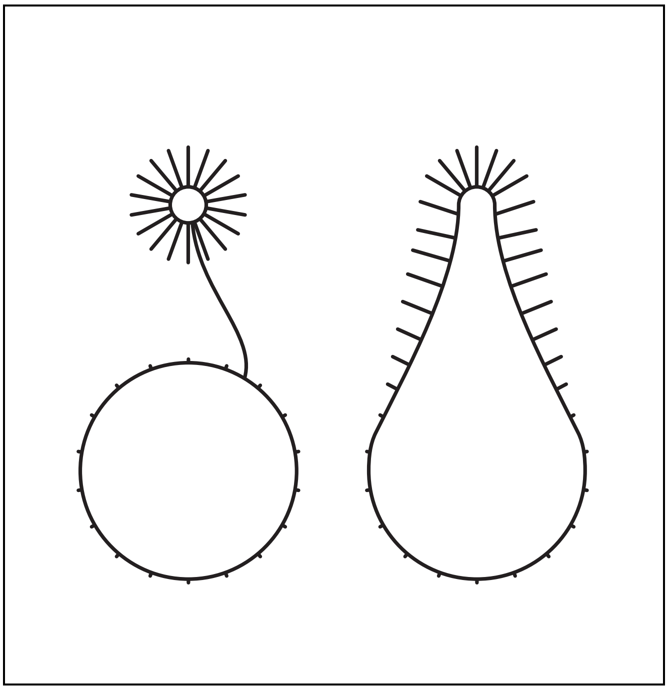
More precisely, the charges are distributed on the surface so that they are not subject to an electric field or a gradient of the potential along the surface. The electric field is perpendicular to the surface at every point of the surface, and the potential is the same everywhere on the surface and in the interior of the conductor. The charge density and the electric field are particularly high at places on the surface with a strong curvature.

Hollow conductors carry electric charges only on their outside surface. There is no electric field in the cavity and the electric potential is constant. If charge is to be completely removed from a conductor, the interior of a metallic hollow body should be touched with the conductor.

In the experiment, electric charge is picked up with an insulated metal plate from charged hollow conductors in order to investigate the charge distribution. The charges picked up are measured with an electrometer amplifier operated as a coulombmeter. The electrometer amplifier itself is equipped with a hollow conductor, namely a Faraday's cup. Any voltmeter may be used to display the output voltage U_A. From the reference capacitance C_A

$$Q = C \cdot U_A \qquad (I)$$

is obtained. For example, at C_A = 10 nF, U_A = 1 V corresponds to the charge Q = 10 nAs. If other capacitances are used, other measuring ranges are accessible.



If two charged metal spheres of different sizes are on the same potential, the electric field strength near the smaller sphere is larger than the field strength near the bigger sphere. Therefore, electric fields at sharp points can be very strong.

1009-Wei

Apparatus

1 conical conductor on insulated rod	543 07
2 Faraday's cup	546 12
1 metal plate on insulating rod	542 52
1 high voltage power supply 10 kV	521 70
1 high voltage cable, 1 m	501 05
1 electrometer amplifier	532 14
1 plug-in unit 230 V/12 V~/20 W	562 791
1 STE capacitor 1 nF, 100 V	578 25
1 STE capacitor 10 nF, 100 V	578 10
1 voltmeter, DC, until $U = \pm 8$ V for example	531 100
1 clamping plug	590 011
1 connection rod	532 16
1 demonstration insulator	540 52
1 saddle base	300 11
1 set of 6 croc-clips, polished	501 861
connection rods	

Safety notes

The high voltage power supply 10 kV fulfils the safety requirements for electrical equipment for measurement, control and laboratory. It supplies a non-hazardous contact voltage. Observe the following safety measures.

- Comply with the instruction sheet of the high voltage power supply.
- Always make sure that the high voltage power supply is switched off before altering the connections in the experimental setup.
- Set up the experiment so that neither non-insulated parts nor cables and plug can be touched inadvertently.
- Always set the output voltage to zero before switching on the high voltage power supply (turn the knob all the way to the left).
- In order to avoid high-voltage arcing, lay the high voltage cable in such a way that there are no conductive objects near the cable.

Preliminary remark

Carrying out this experiment requires particular care because "leakage currents" through the insulators may cause charge losses and thus considerable measuring errors. Moreover, undesirable effects of electrostatic induction may influence the results.

The experiment must be carried out in a closed, dry room so as to prevent charge losses due to high humidity.

Cleaning the insulators with distilled water is recommended because distilled water is the best solvent of conductive salts on insulators. In addition, the insulators should be discharged after every experiment by passing them several times quickly through a non-blackening flame, for example of a butane gas burner.

The experimenter – particularly while measuring charges – must keep the connection rod of the electrometer amplifier in his hand to earth himself.

Setup

The experimental setup has two parts. In Fig. 1, the setup for electrostatic charging of the hollow bodies and picking up a test charge is illustrated. Fig. 2 shows the connection of the electrometer amplifier for the charge measurement.

Electrostatic charging of the hollow bodies:

- Attach the Faraday's cup **(a)** to the demonstration insulator and mount it in the saddle base.
- Connect the high voltage cable to the positive pole of the high voltage power supply and the negative pole to earth.
- Plug the free end of the high voltage cable into the *upper (!)* 4-mm bore of the demonstration insulator.

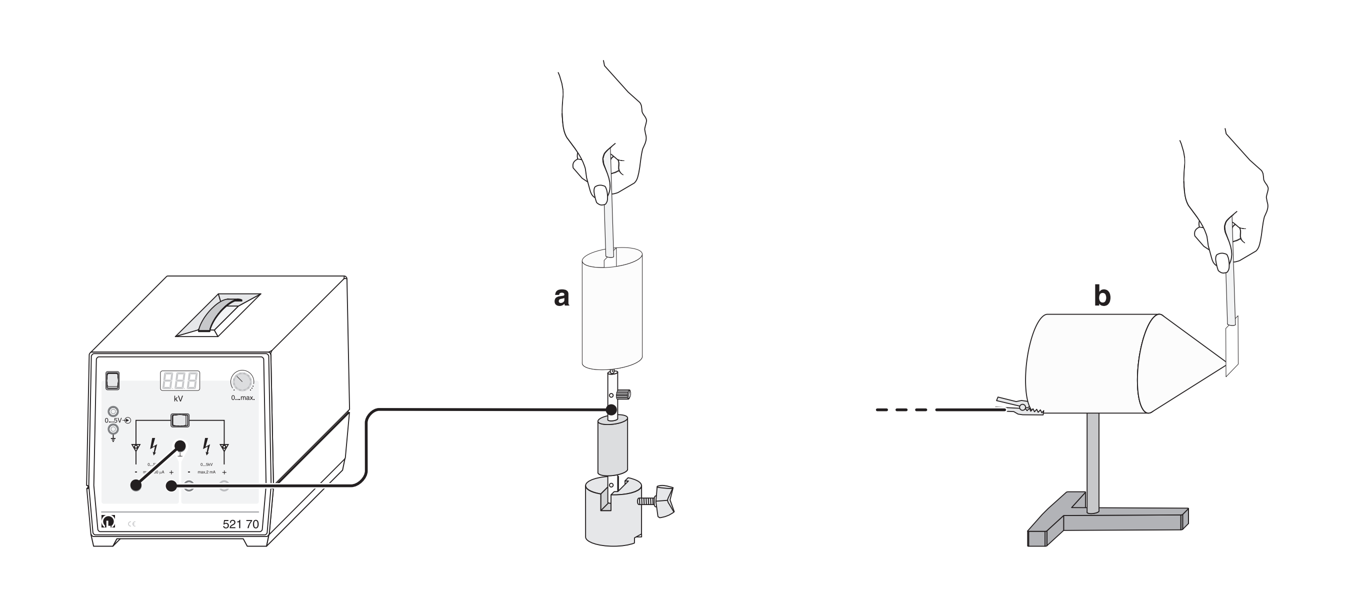
Setup for the measurement of the test charge:

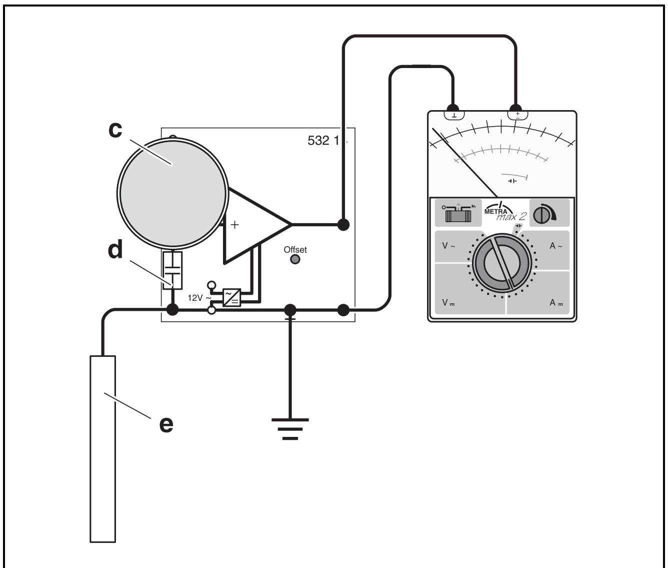
- Supply the electrometer amplifier with voltage from the plug-in unit.
- Attach the other Faraday's cup **(c)** with the clamping plug.
- Attach the STE capacitor 10 nF **(d)**.
- Use a connection lead to connect the connection rod **(e)** to earth and, if possible, a long connection lead to connect the earth to the earth of the high voltage power supply through.
- Connect the voltmeter to the output.

Carrying out the experiment

Note:

The Faraday's cup and the conic conductor remain connected to the high voltage source during the experiment: Do not touch the hollow bodies under investigation even though there is a non-hazardous contact voltage.





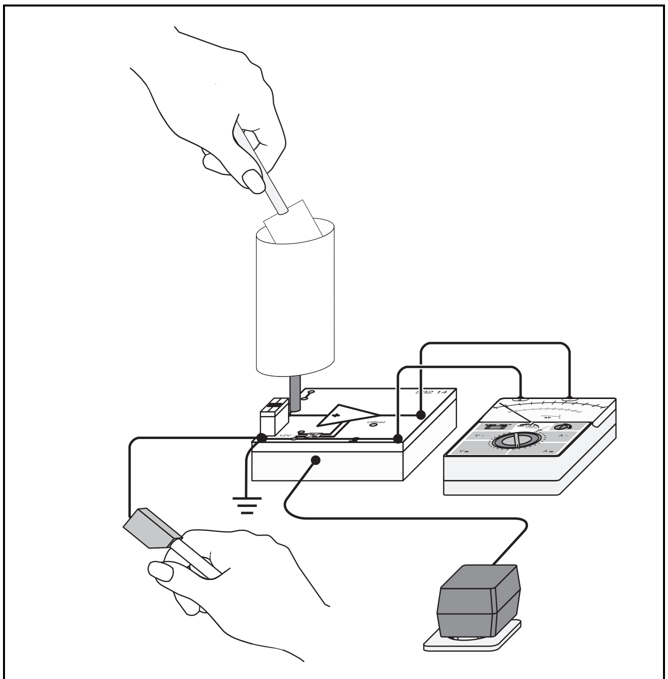


Fig. 1 Experimental setup for the measurement of the charge distribution on a Faraday's cup **(a)** and on a conic conductor **(b)**

Fig. 2 Experimental setup for the measurement of the charge on the insulated metal plate

Fig. 3 Measurement of the charge on the insulated metal plate.

a) Charge distribution on the Faraday's cup:

– Switch the high voltage power supply on, and set the high voltage *U* to 5 kV.
– Discharge the insulated metal plate with the connection rod **(e)**.
– Touch the outer wall of the Faraday's cup **(a)** to pick up charge.
– To measure the charge, discharge the Faraday's cup **(c)** of the electrometer amplifier by touching it with the connection rod **(e)**, then take the connection rod in your hand, and move the insulated metal plate to the inner wall of the Faraday's cup (see Fig. 3).
– Repeat the investigation for several places on the outer and inner wall of the Faraday's cup **(a)**; each time discharge the insulated metal plate with the connection rod **(e)**.

b) Charge distribution on the conic conductor:

– Switch off the high voltage power supply and replace the Faraday's cup with the conic conductor **(b)**; to do so, attach the high voltage cable to the conic conductor with a croc-clip.
– Switch on the high voltage power supply and set the high voltage *U* to 5 kV.
– Move the insulated metal plate towards the apex of the conic conductor from the front and measure the charge on the plate.
– Repeat the investigation for several places on the outer and inner wall of the conic conductor; each time discharge the insulated metal plate with the connection rod **(e)**.

Measuring example

a) Charge distribution on the Faraday's cup:

Place	$\frac{Q}{\text{nAs}}$
Outer wall	6.0
Inner wall	0.1

b) Charge distribution on the conic conductor:

Place	$\frac{Q}{\text{nAs}}$
Outer wall	
apex	8.6
conic part	7.8
cylindrical part	6.2
Inner wall	0.4

Evaluation

Almost no charges can be detected on the inner walls of the Faraday's cup and of the conic conductor. The total charge is on the outer wall.

On the conic conductor, the charge picked up from the outside surface depends on the curvature of the surface. The smaller the radius of curvature, the more charge is found. The radius of curvature of the apex of the conic conductor is particularly small and there is an accumulation of charge.

Since the electric field strength near the surface is proportional to the charge, the field strength near the apex is large as well. This phenomenon is called needle effect or point effect and is of practical significance, for example, in lightning conductors.

Supplementary information

The dependence of the charge density on the radius of curvature can be explained as follows: The potential of a charged metal sphere with radius R and charge Q is

$$U = \frac{1}{4 \cdot \pi \cdot \varepsilon_0} \cdot \frac{Q}{R} \qquad \text{(II).}$$

ε_0: permittivity of free space

As the charge is equally distributed on the surface of the sphere, the charge density is

$$\sigma = \frac{Q}{4\pi \cdot R^2} \qquad \text{(III).}$$

From (II) and (III)

$$U = \frac{\sigma \cdot R}{\varepsilon_0} \qquad \text{(IV)}$$

follows.

Two spheres or, more general, two surfaces with different radii of curvature are on the same potential if their charge densities σ fulfil the proportionality

$$\sigma \propto \frac{1}{R} \qquad \text{(V).}$$