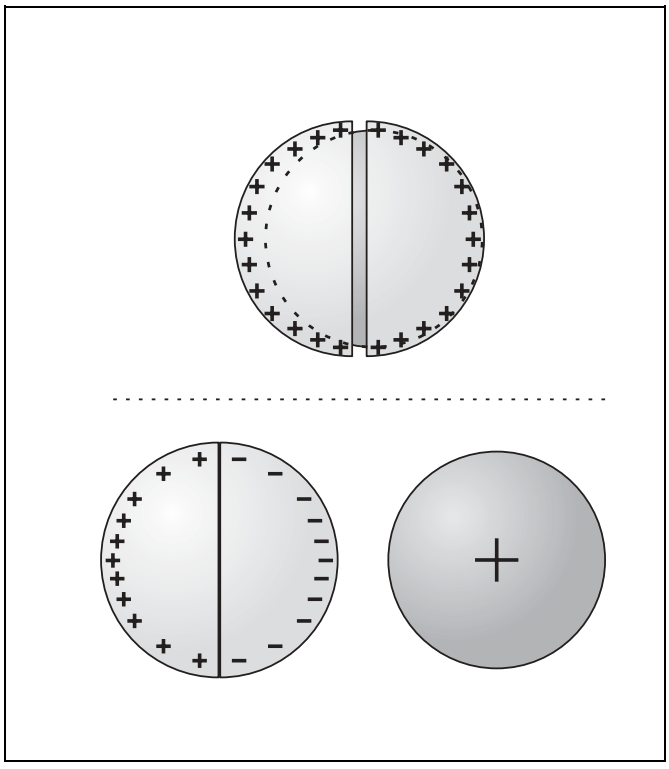
Electrostatic induction with the hemispheres after Cavendish

Objects of the experiments

- Detecting the arrangement of electric charges on the surface of an electrical conductor.
- Detecting the spatial separation of positive and negative charges (electrostatic induction) on an electrical conductor placed near a charged body.

Fig. 1 Arrangement of electric charges on the surface of an electrical conductor (above), and separation of positive and negative charges on an electrical conductor placed near a charged body (below)



Principles

All bodies carry positive and negative electric charges. In a neutral body, the charges cancel each other so that no charge can be measured. A charged body contains an excess of positive or negative charges.

In an electrical conductor, the excess charges can be freely displaced. As charges of equal sign repel each other, charges can be found only on the surface of a conductor in the case of electrostatic equilibrium. The individual charge carriers are then at maximum distance from each other. This is demonstrated in the experiment with two metal hemispheres fitted together to form a sphere that encloses a second sphere. Charges on the outer sphere remain on its surface and are not displaced onto the inner sphere, even if the latter touches the outer sphere (see Fig. 1). However, if the inner sphere is charged first, then the charges move onto the outer sphere as soon as the latter encloses the inner sphere and touches it.

When an electrical conductor is placed near a charged body, the positive and negative charges of this conductor are spatially separated as a result of the fact that charges of different signs attract each other and charges of equal sign repel each other. This separation of charges is called electrostatic induction and the charges appearing on the conductor are called induced charges. In the experiment, electrostatic induction is detected by placing two metal hemispheres – fitted together to form a sphere – near a charged body so that, as far as possible, positive charges appear only on one hemisphere and negative charges on the other (see Fig. 1). Next, the hemispheres are separated near the charged body so that they keep their charges.

The charges on the entire sphere and the hemispheres are measured almost without current with an electrometer amplifier operated as a coulombmeter. Any voltmeter may be used to display the output voltage U_A. From the reference capacitance C

$$Q = C \cdot U_A \qquad \text{(I)}$$

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

Apparatus

1 sphere on insulated rod	543 02
1 pair of hemispheres	543 05
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 voltmeter, until $U = \pm 10$ V for example	531 100
1 STE capacitor 1 nF	578 25
1 STE capacitor 10 nF	578 10
1 coupling plug	340 89
1 connection rod	532 16
2 stand rods, 25 cm	300 41
2 Leybold multiclamps	301 01
1 insulated stand rod, 25 cm	590 13
3 saddle bases	300 11
connection leads	

Safety notes

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

- Observe the instruction sheet of the high voltage power supply.
- Always make certain 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 insulator rods which hold the spheres with distilled water is recommended because distilled water is the best solvent of conductive salts on the insulators. In addition, the insulator rods should be discharged after every experiment by passing them quickly through a non-blackening flame several times — for example of a butane gas burner.

The high voltage power supply and the point of the high voltage cable must be at a sufficient distance from the rest of the experimental setup so as to avoid interference by electrostatic induction.

For the same reason 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. 2, the arrangement of the spheres and the high voltage power supply is illustrated. Fig. 3 shows the connection of the electrometer amplifier for the charge measurement.

Arrangement of the entire sphere and the hemispheres:

– Attach the hemispheres to the stand material with the notches **(c)** pointing downward.
– Align the hemispheres so that they are opposite each other at the same height and enclose the entire sphere without touching it.

High voltage supply:

– Connect the high voltage cable to the positive pole **(a)** of the high voltage power supply and the negative pole **(a)** to earth.
– Put the free point of the high voltage cable **(b)** through the uppermost hole of the insulated stand rod.

Setup for the charge measurement:

– Supply the electrometer amplifier with voltage from the plug-in unit.
– Plug the coupling plug **(d)** in.
– Attach the capacitor 10 nF **(e)**.
– Use a connection lead to connect the connection rod **(f)** to earth and, if possible, the earth to the earth of the high voltage power supply through a long connection lead.
– Connect the voltmeter to the output.

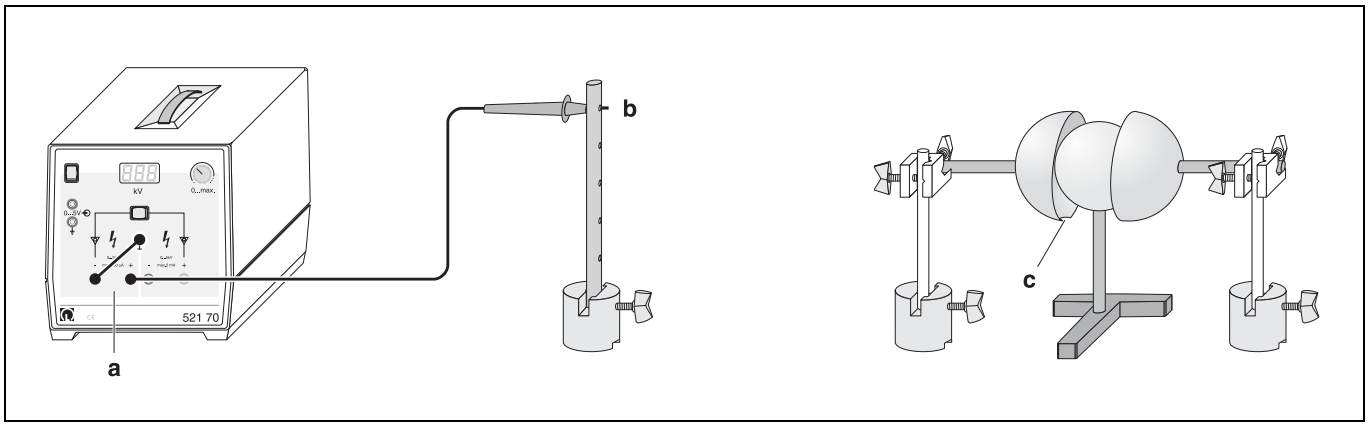


Fig. 2 Experimental setup with the hemispheres after Cavendish.

Carrying out the experiment

Notes:

Touch the hemispheres and the entire sphere only at the saddle base.

Keep the connection rod in your hand during charge measurements.

*Discharge the capacitor before each charge measurement by touching the coupling plug **(d**) of the electrometer amplifier with the connection rod.*

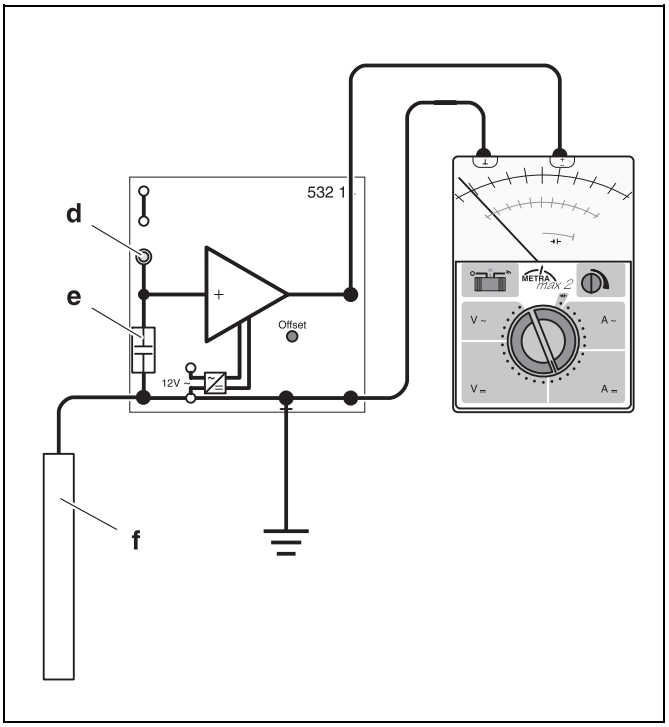


Fig. 3 Connection of the electrometer amplifier for the measurement of the charges

a) Charge distribution on electrical conductors

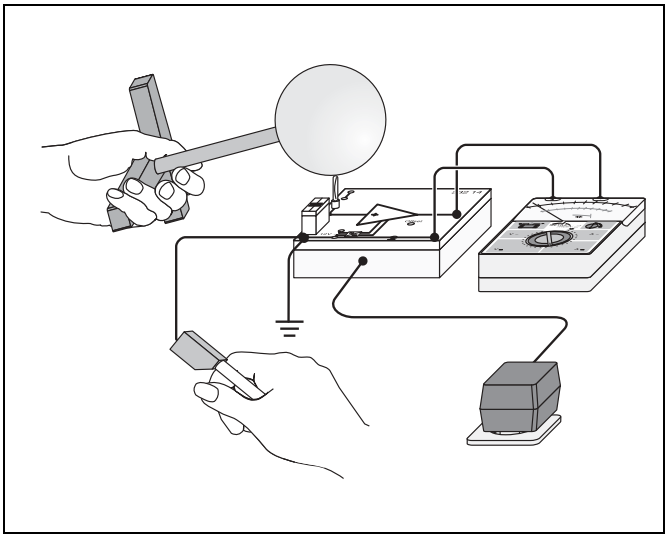
a1) Charging the outer sphere

- Separate the two hemispheres and the entire sphere, and discharge them by contact with the connection rod **(f)** (earthing in field-free space).
- Enclose the entire sphere with the hemispheres so that both spheres have contact.
- Set the high voltage to 5 kV.
- Charge one hemisphere by touching it with the point of the high voltage cable.
- Set the high voltage to zero.
- Separate the hemispheres.
- To measure the charges, keep the connection rod **(f)** in your hand, and touch the coupling plug **(d)** with the hemispheres and the sphere one after another (see Fig. 4).

a2) Charging the inner sphere

- Separate the two hemispheres and the entire sphere, and discharge them by contact with the connection rod.
- Set the high voltage to 5 kV.
- Charge the entire sphere by touching it with the point of the high voltage cable.
- Set the high voltage to zero.
- Enclose the entire sphere with the hemispheres so that both spheres have contact.
- Separate the hemispheres.
- Measure the charges of the hemispheres and the entire sphere with the electrometer amplifier (keep the connection rod in your hand).

Fig. 4 Measurement of the charge



b) Electrostatic induction

- Separate the two hemispheres and the entire sphere, and discharge them by contact with the connection rod.
- Set the high voltage to 5 kV.
- Charge the entire sphere by touching it with the point of the high voltage cable.

– Set the high voltage to zero.
– Fit the hemispheres together so that they form an entire sphere, and place them near the charged entire sphere. The separating plane must not be directed towards the centre of the entire sphere.
– Separate the hemispheres.
– Measure the charges on the hemispheres paying attention to their signs (voltmeter with zero in the middle of the display; keep the connection rod in your hand).

Measuring example

High voltage: U = 5 kV

a) Charge distribution on electrical conductors

a1) Charging the outer sphere

Table 1: Distribution of the charges after the outer sphere has been charged

body	$\frac{Q}{\text{nAs}}$
hemisphere 1	18
hemisphere 2	18
entire sphere	2

a2) Charging the inner sphere

Table 2: Distribution of the charges after the inner sphere has been charged

body	$\frac{Q}{\text{nAs}}$
hemisphere 1	12
hemisphere 2	12
entire sphere	1

b) Electrostatic induction

Table 3: Distribution of the charges

body	$\frac{Q}{\text{nAs}}$
entire sphere	28
hemisphere 1	9
hemisphere 2	–8

Evaluation

a) Charge distribution on electrical conductors

a1) Charging the outer sphere

The two hemispheres are equally charged since they form an entire sphere, on the surface of which the charges are distributed evenly.

The inner sphere is not charged although it touches the hemispheres. No charges move inside (*Faraday* cage).

Only when the hemispheres are separated, some charge may pass over.

a2) Charging the inner sphere

The charge moves from the inner sphere onto the outer hemispheres and is evenly distributed there.

b) Electrostatic induction

On both hemispheres charges are displaced by the electric field of the charged sphere so that the hemispheres are equally charged with opposite signs.

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