IIE1

Modul Electricity II

Cavendish Experiment

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1.1 Preliminary Questions

- What is induction? Describe in your own words.
- What is a Faraday cage and how does it work?
- In this experiment, you will charge a ball with a positive voltage. What is the charge-carrier that is transferred in this interaction (if any)?

1.2 Theory

A conductor, by definition, contains free charge carriers. In a metal, these are electrons, but we can find different carriers in other materials, e.g. ions in a solution. These charge carriers are free to move about the conducting material. In accordance with Coulomb's law, charges of the same type will repel one another. In a metal, this means that the free charges will all migrate to the surface, where they can maximise the distance between themselves.
An uncharged object contains the same number of positive and negative charges, with a charge density, D, of zero. A charged object, on the other hand, has an excess of one charge type, with $D \neq 0$. These excess charges create an electrostatic field, which acts to resist the addition of further charges to the object. We can charge a conductor by applying a voltage to it. The amount of charge that can be transferred to a conductor depends on its capacity and can be described from Gauss's law:

$$Q = U \cdot C, \tag{1.1}$$

where Q is the charge in Coulombs [C], U is the voltage (or potential difference) in volts [V] and C is the capacitance in Farads [F]. For a spherical conductor, the capacitance is proportional to the radius:

$$C = 4\pi\epsilon_0 \cdot R \tag{1.2}$$

With the electric field constant $\epsilon_0 = 8.8541 \cdot 10^{-12} \frac{F}{m}$.

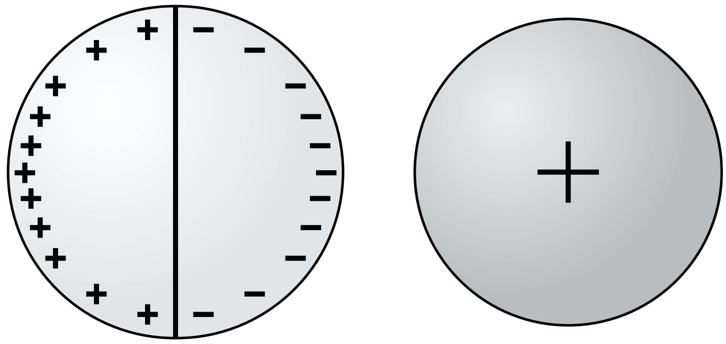

Figure 1.1: Induction of a positively charged sphere on two uncharged spherical shells

In the absence of external fields, the free charge carriers in a conductor are evenly distributed on the surface (at least for a perfectly spherical conductor). As one might expect, this changes when we apply an external electric field, which creates an additional force to the free charge carriers. In combination with the internal electric field (generated by the Coulomb repulsion between like charge carriers), the external field generates a new, nonuniform charge distribution in the conductor. We find areas with an excess of positive charge and a charge density of

$D > 0$, and areas with an excess of negative charge and a charge density of $D < 0$. Repulsion between charge carriers still means that the free charge carriers remain on the surface of the conductor only, and not in the bulk. The influence of external electrostatic fields on the distribution of charges is called induction or electrostatic induction.

1.3 Experiment

1.3.1 Equipment

Component	Number
Sphere on a stand	1
Hollow Hemispheres on a stand	2
High voltage power supply	1
High voltage cable on a stand	1
Preamplifier for a charge measurement	1
Aluminium rod for grounding	1
Capacitor 1 nF	1
Capacitor 10 nF	1
Multimeter	1
Experiment leads	5

1.3.2 Experimental Setup and Adjustment

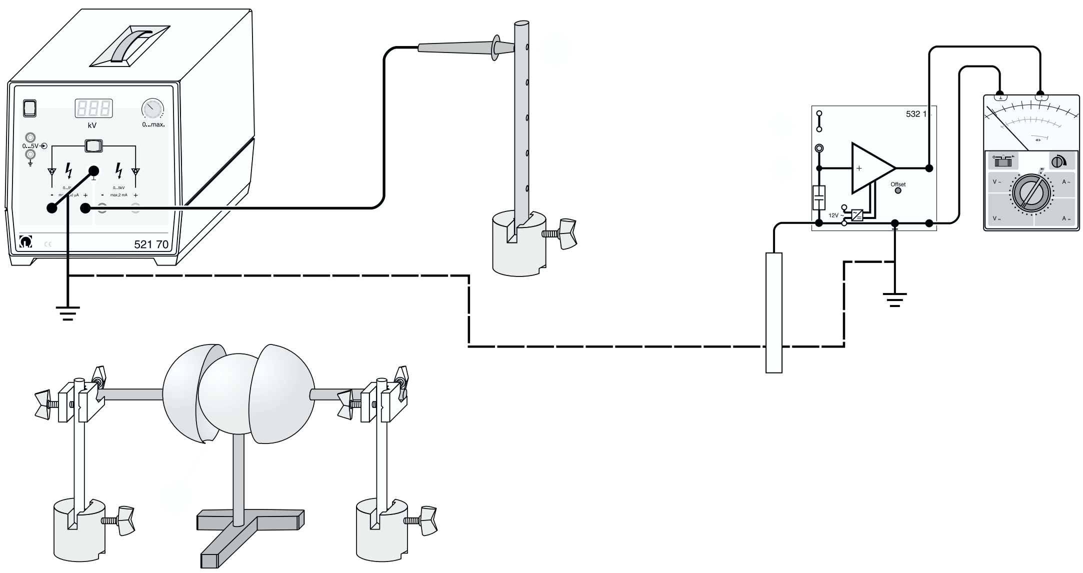

Figure 1.2: Scheme of the experimental setup

1. Mount both of the hemispheres on tripods. Adjust their heights so that you are able to bring them together to make a single ball, or use them to enclose the solid metal sphere (see bottom of Figure 1.2)

2. Switch the multimeter to the dc voltage setting, and connect the positive probe to the output of the preamplifier. Plug the minus probe into the preamplifier’s ground plug

3. Use one of the provided cables to also connect the aluminium tab to the preamplifier ground plug
4. Connect the ground plugs of the high-voltage supply and the preamplifier together
5. On the high-voltage supply, use a cable to connect the negative output with the ground plug
6. Plug the high-voltage probe (the one with the pointy needle attached) into the positive output of the high-voltage supply
7. Plug the capacitor into the preamplifier

1.3.3 Implementation

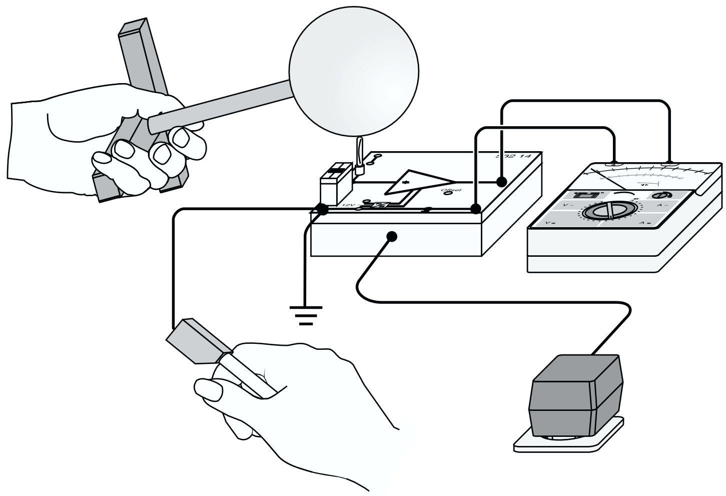

Figure 1.3: Implementation of the charge measurement

The goal now is to work out the charge on the balls and hemispheres for various experiment configurations. To make a measurement of the charge:

1. The grounding rod should be plugged into the same plug on the preamplifier as the measurement tip (see Figure 1.3). The preamplifier is very sensitive, and this will prevent the build-up of charge on the measurement capacitor (due to free charges in the air and stray currents) that would otherwise adversely influence the measurements.
2. The multimeter should be set to Min/Max mode, and then zeroed
3. You'll want to have the grounding rod in one hand (bottom of Figure 1.3), and the use your other hand to hold the ball/hemisphere on the measurement tip on the preamplifier (top of Figure 1.3). Remember to only hold the base of the ball/hemisphere - don't touch the metal itself

The charge Q flows from the ball/hemisphere through the measurement tip to charge the capacitor. As per equation 1.1, this creates a potential across the capacitor. The internal resistance of the multimeter gives a big error if you try to measure this potential directly. For this reason, we will use a preamplifier, with an amplification factor of 1. The preamplifier includes an impedance converter. At the input, it has a very high resistance, and at the output, a very

low resistance. The result is that the effective internal resistance in the multimeter is raised to around 10 G-Ohm.
The two provided capacitors can be used to measure different ranges of charge. You should start with the 10 nF capacitor. If the voltage read at the multimeter is too small, then switch to the 1 nF capacitor.

Measurement of the Capacitance

- Discharge the ball with the grounded aluminium rod
- Set the voltage on the power supply to 1kV
- Charge the ball, by touching it gently with the tip of the high-voltage probe. Then immediately turn the power supply voltage back to zero.
- Measure the voltage on the ball
- Repeat this with 2, 3, 4, and 5 kV
- Repeat this with the ball replaced by the two hemispheres, pressed together so that they form a single ball

Charged Ball

- Discharge the ball and hemispheres with the grounded aluminium rod
- Set the voltage on the power supply to 3kV
- Charge the ball, then immediately turn the power supply voltage back to zero.
- Bring the two hemispheres slowly towards either side of the charged ball, so that they are both touching the ball.
- Separate the hemispheres from the ball, and measure the charge on each of the three objects
- Repeat with voltages of 4kV and 5kV

Charged Hemispheres / Hollow Ball

- Discharge the ball and hemispheres with the grounded aluminium tab
- Set the voltage on the power supply to 3kV
- Bring the two hemispheres together (making a hollow ball) and charge them up
- Turn the voltage supply back to zero
- Separate the two hemispheres, and bring them to touch either side of the ball (the same position as above)
- Separate the hemispheres, and measure the charge on each of the hemispheres and the ball
- Repeat with voltages of 4kV and 5kV

Charge Separation due to Induction

- Discharge the ball and hemispheres with the grounded aluminium rod
- Charge the ball with 3kV, as described above
- Bring the two hemispheres together (making a hollow ball). Don't charge them though
- Charge the ball, and bring it towards the two hemispheres. You should bring the ball in as close as possible along a line perpendicular to the 'equatorial plane' of the hollow ball (i.e. the plane in which both hemispheres touch âĂŞ see fig. 1.1)). Do not actually touch the hemispheres with the ball
- Take the ball away. Then separate the hemispheres, and measure the charge on the hemispheres and the ball
- Repeat with voltages of 4kV and 5kV

1.3.4 Tasks for Evaluation

Determination of Capacitance

Calculate the charge on the surface of the solid sphere, using equation 1.1. Plot this as a function of the voltage used to charge the sphere. Perform a linear fit, and deduce the capacitance of the solid sphere. Compare this with the theoretical capacitance of the sphere given by equation 1.2, and discuss any differences. In the same way, determine (both experimentally and theoretically) the capacitance of the hollow sphere. What do you notice? What is the influence of the air inside the hollow sphere? Calculate the surface charge density of the hollow and solid spheres.

Charged ball

Calculate the charge on the ball and shell the three different charging voltages. Present the results in a table. How are the charges in the ball and shell distributed? Explain the distribution. Is the total charge the same as in the first exercise?

Charged hemispheres

Again, calculate the charge on the ball and shells for the three different charging voltages, and present the results in a table. How are the charges in the ball and shell distributed? Explain the distribution. Compare the total charge with the values from the first and second exercises.

Charge separation through induction

Once more, calculate the charge on the ball and shells for the three different charging voltages, and present the results in a table. Explain the measured distribution of positive and negative charge. Did the charge on the solid ball change due to inductance? Explain, and compare with the first exercise.

1.4 Literature

- Paul A. Tipler, *Physik für Naturwissenschaftler und Ingenieure*, Spektrum
- Horst Stöcker, *Taschenbuch der Physik*, Verlag Harri Deutsch