Investigating the deflection of electrons in electrical and magnetic fields

Objects of the experiments

- Investigation of the deflection of electrons in the electrical field of a plate capacitor
- Investigation of the deflection of electrons in the magnetic field of a Helmholtz pair of coils

Principles

In the Thomson tube (electron deflection tube) the deflection of electrons in electric and magnetic fields can be quantitatively investigated. The existence of cathode rays, the straight-line movement in field-free space and the deflection in electric and magnetic fields was qualitatively investigated in experiments with the vacuum tube diode (555 610), the vacuum tube triode (555 612) and the Maltese cross tube (555 620).

In the Thomson tube all the electrons pass a slit aperture behind the anode and tangentially hit a luminous screen with a cm grid which is set up at an angle to the path of the light., Here the electron beam becomes visible and allows quantitative analysis. At the outlet of the slit aperture a plate capacitor is mounted where the electron beam can be vertically deflected by an electrostatic field. In addition the electron beam can be deflected in the magnetic field of a Helmholtz pair of coils.

In the electric field an electron moves on a parabola-shaped curve. If the electron is accelerated by a given anode voltage U_A and then passes through the electric field of a plate capacitor with the voltage U_P and the distance between the plates is d, the following applies for the path

$$y = \frac{E}{4 \cdot U_A} \cdot x^2 . \qquad (1)$$

On account of the construction of the tube, the electric field is smaller then the value expected according to theory. This can be taken into account in the experiment by a correction factor:

$$E_{exp} = 0{,}75 \cdot E_{theo} = 0{,}75 \cdot \frac{U}{d} . \qquad (2)$$

In the magnetic field of a Helmholtz pair of coils, at right angles to the axis of the beam an electron will move on a circular track. For the curve along a circular track the following applies

$$y = r - \sqrt{r^2 - x^2} \quad \text{with} \quad r = \sqrt{\frac{2 \cdot m \cdot U_A}{e \cdot B}} . \qquad (3)$$

The radius r depends on the anode voltage U_A and the magnetic field of the pair of coils.

$$B = \mu_0 \cdot \left(\frac{4}{5}\right)^{\frac{3}{2}} \cdot \frac{N \cdot I}{R} \qquad (4)$$

with current I, number of windings N and coil radius R.

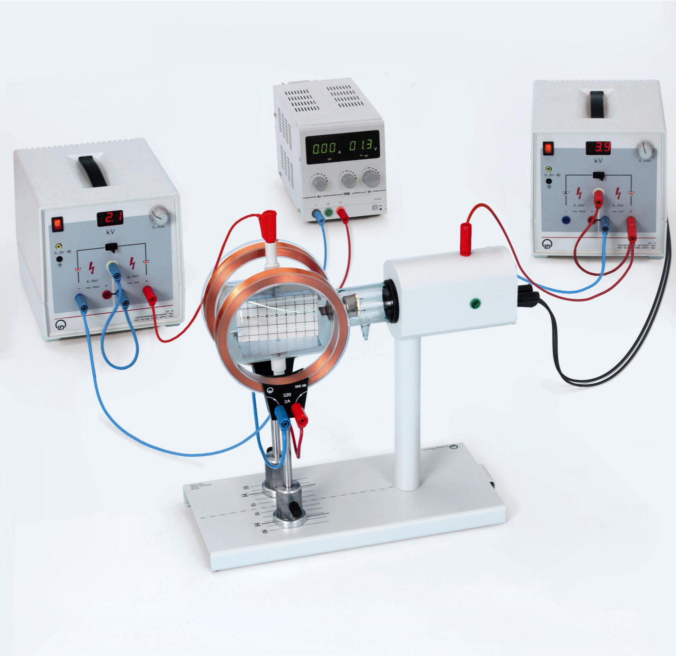

Fig. 1: Deflection in the electric field or in the magnetic field

If the values for x and y are read off, in addition the specific charge can be estimated

$$\frac{e}{m} = \frac{2 U_A}{(B \cdot r)^2} . \qquad (5)$$

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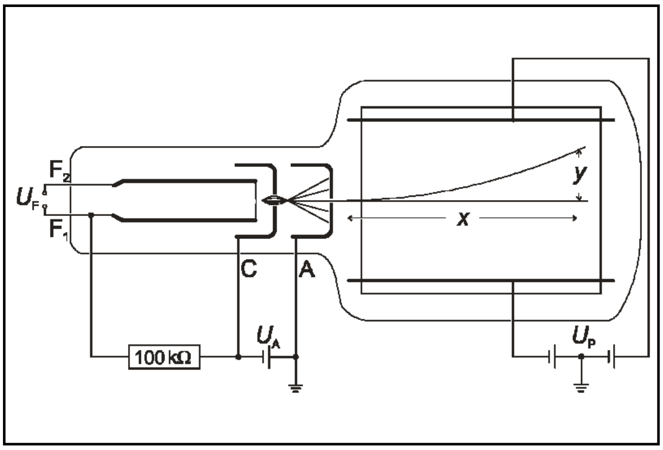

Fig. 2: Deflection in an electric field

Safety note:

The Thomson tube is a thin-walled evacuated glass cylinder. Danger of implosion!

- Do not expose the tube to any mechanical loads.
- Only connect the Thomson tube by means of safety connection leads.
- Observe the operating instructions for the Thomson tube (555 624) and the tube stand (555 600).

Setup

The experimental setup is shown in fig. 1. The connections are also shown in fig. 2 for the deflection in the electric field and in fig. 3 for the deflection in the magnetic field. The 100kΩ resistance is integrated in the tube stand (555 600). For setting up, the steps described below are required:

- Carefully insert the Thomson tube into the tube stand.
- Connect sockets F_1 and F_2 on the tube stand for the cathode heater to the 10 kV output at the rear of the high voltage power supply.
- Connect socket C on the tube stand (cathode cap of the Thomson tube) to the negative pole and socket A (anode) to the positive pole of the 10 kV high voltage power supply and in addition earth the positive pole.
- Place the Helmholtz pair of coils in the positions marked with H (Helmholtz geometry) on the tube stand. A deviation from the Helmholtz geometry will lead to systematic errors in the calculation of the magnetic field. For this reason such a deviation should be kept as small as possible. Adjust the height of the coils in such a way that the centres of the coils are aligned to the level of the beam axis.
- Connect the coils in series to the direct current power supply so that the current indicated at the power supply corresponds to that flowing through the coils. Ensure that the current flows in the same direction through the coils.
- Connect one capacitor plate to the positive pole at the right-hand output, the other to the negative pole of the left-hand output of the second 10 kV high voltage power supply and earth the middle socket of the high voltage power supply.

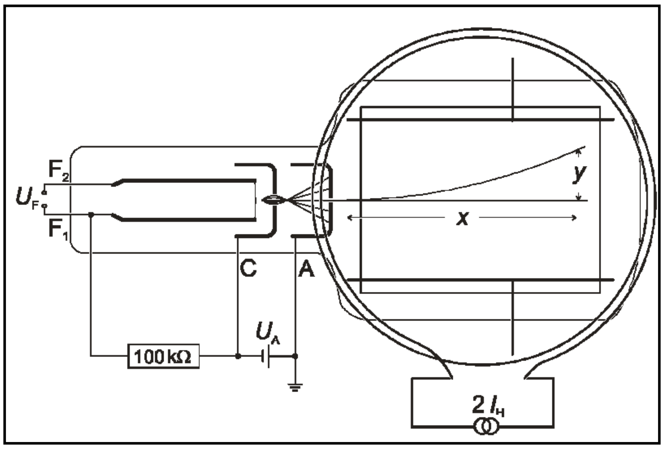

Fig. 3: Deflection in the magnetic field

Carrying out the experiment

- Measure the distance *d* between the capacitor plates.
- Switch on the high voltage power supply. Now the cathode is being heated.
- Slowly increase the anode voltage U_A and observe the beam slowly increasing in brightness at the centre of the luminous screen.

Deflection in an electric field

- While U_A < 5 kV is kept at a fixed value slowly increase the voltage at the capacitor plates U_P and observe the change to the beam.
- For different values of U_A and U_P read the value pairs (x; y) for the track from the luminous screen. Then return the voltage U_P to zero.

Deflection in the magnetic field

- While U_A < 5 kV is kept at a fixed value slowly increase the current *I* through the Helmholtz pair of coils and observe the change to the beam.
- For different values of U_A and *I* read the value pairs (x; y) from the luminous screen.

Measuring example and evaluation

The distance between the capacitor plates was d = 5.5 cm.

Deflection in the electric field

If the voltage at the capacitor plates is increased, the electrons are deflected on a parabola-shaped track. The direction of the deflection depends on the polarity of the applied voltage, the degree of the deflection on the applied voltage.

For U_A = 4.0 kV and various values of U_P value pairs (x; y) were read off. The results are shown in the table below and in fig. T4.

Curves of the shape $y = A \cdot x^2$ were matched to the measured values (by means of CASSY Lab) and in addition entered in fig. 4. The curves correspond well to the measured values.

x / cm	y / cm		
	U_P = 2.0 kV	U_P = 3.0 kV	U_P = 5.0 kV
1.0	0.0	0.0	0.0
2.0	0.0	0.1	0.1
3.0	0.2	0.2	0.3
4.0	0.3	0.4	0.6
5.0	0.5	0.6	0.9
6.0	0.6	0.9	1.3
7.0	0.8	1.2	1.8
8.0	1.1	1.6	2.3
9.0	1.4	2.0	

From the formula for the track (equation 1 and equation 2)

$$y = \frac{E}{4 \cdot U_A} \cdot x^2 = 0{,}75 \cdot \frac{U_P}{4 \cdot U_A \cdot d} \cdot x^2$$

the value of y_{theo} was also calculated for a number of examples for a given *x*.

U_A /kV	U_P/kV	x/cm	y/cm	y_{theo}/cm
4.0	2.0	9.0	1.4	1.4
4.0	3.0	9.0	2.0	2.1
4.0	5.0	8.0	2.3	2.7

Deflection in the magnetic field

If the current through the Helmholtz pair of coils is increased, the electrons are deflected onto a circular track. The direction of the deflection is determined by the polarity of the applied voltage, e.g. by the direction of the current flow. The size of the deflection depends on the current, i.e. on the strength of the magnetic field.

For various values of U_A and *I* value pairs (*x; y*) were read off. The results are shown in the table below and in fig. 5.

x / cm	y / cm		
	I = 100 mA	I = 150 mA	I = 260 mA
1.0	0.0	0.0	0.1
2.0	0.1	0.1	0.2
3.0	0.15	0.2	0.3
4.0	0.2	0.4	0.5
5.0	0.3	0.5	0.8
6.0	0.5	0.6	1.2
7.0	0.6	0.9	1.5
8.0	0.8	1.1	1.9
9.0	0.9	1.4	2.4

Curves of the shape $y = R \cdot \sqrt{R^2 - (x - A)^2}$ were matched to the measured values (by means of CASSY Lab) and in addition entered in fig. 5. The parameter corresponds to a shift along the axis.

The curves correspond well to the measured values. The parameter *A* is approx. 0.8 cm. The magnetic field of the pair of coils extends beyond the area of the plate capacitor; for this reason the electron beam is deflected before it reaches the mica plate.

If one uses the value pairs with equation 3 to calculate the radius of the curve and with equation 4 to calculate the applied magnetic field, equation 5 can be used to estimate from this the specific charge. The number of windings of the coils is *N* = 320, the average coil radius is *R* = 6.7 cm. The results for three value pairs are summarised in the table below.

U_A/kV	I/A	x/cm	y/cm	r/cm	B/mT	$\frac{e}{m}/10^{11}\frac{C}{kg}$
4.0	0.10	9.0	0.9	45.5	0.429	2.1
4.0	0.15	9.0	1.4	18.1	0.644	2.2
4.0	0.26	9.0	2.4	9.62	1.12	1.9

This results in an average value for the specific charge of $\frac{e}{m} = 2.1\ 10^{11}\ \frac{C}{kg}$.

Literature value $\frac{e_0}{m_0} = 1.7588\,10^{11}\ \frac{C}{kg}$

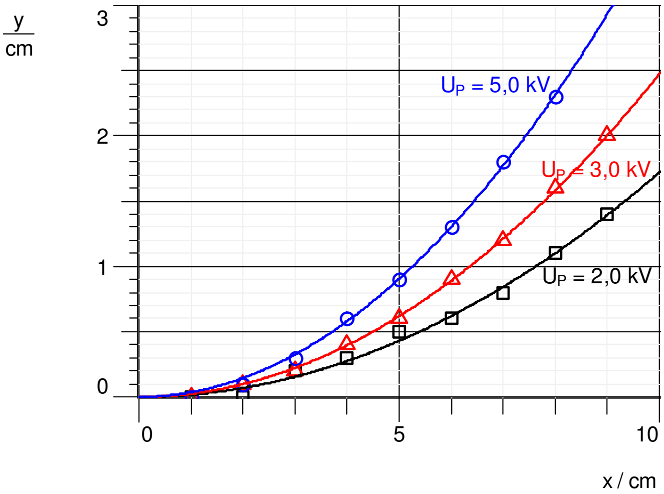

Fig. 4: Deflection in the electric field

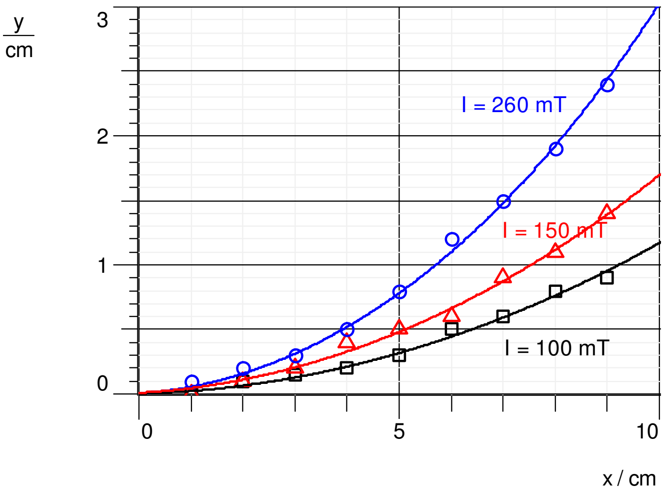

Figure 5: Deflection in the magnetic field

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Notes

In the experiment the electrons are accelerated between a negatively charged cathode and an earthed anode (see circuit diagrams in figures 2 and 3). The capacitor plates are connected in such a way that the centre of the mica plate is at zero potential (see circuit diagram in figures 2 and 3). This means that between the anode and the mica plate no field is active and therefore there are no accelerating/braking forces on the electrons. The speed of the electrons when entering the capacitor plates can then be calculated from the acceleration voltage U_A. The deflection of the electrons in the electric field of the capacitor is given in equation 1.

If the anode and the centre of the mica plate are at a different potential, the potential difference must also be taken into account when calculating the electron speed. Equation 1 cannot be used for calculating the deflection in the electric field of the capacitor.