OBJECTIVES

- 1. Get familiar with the related physics theory.
- 2. Investigate the influence of a uniform magnetic field magnitude on the trajectory of electron in motion by using the experimental setup.
- 3. Determine the specific charge of electron from the obtained data.
- 4. Estimate error and uncertainty of the measurement.
- 5. Discuss the observation and results.

THEORY

J.J. Thomson was the first who determine the specific charge of electron in 1897. One way how to determine the specific charge of electron is based on the influence of magnetic field on a charged particle in motion. In the experimental set-up (Figure 1) the electron gun with h – distance between parallel-plate electrodes and U – potential between them is used to produce beam of electrons. The electrons are emitted from the heated cathode and, due to negative charge and homogeneous electric field with intensity $E = \frac{U}{h}$ existing between electrodes, are uniformly accelerated towards the anode (i.e. against the direction of electric field intensity). When the initial velocity of electron is low its motion in the electric field is expected to be linear. Thus, the electron of charge e and mass m_e is accelerated between electrodes to the maximal velocity v, whilst the energy of the electron that reach the anode fulfills the conservation energy law:



Figure 1: Electron motion in electric \vec{E} and magnetic \vec{B} fields.

After passing a narrow hole in the anode the electron moves by inertia straightforwardly (no electric filed out of the electrodes). However, if the electron in its motion flies into the uniform magnetic field with induction B it become subjected to the Lorentz force:

$$\vec{F} = e(\vec{v} \times \vec{B}) \tag{2}$$

(1)

In case when the directions of electron motion (velocity vector) and magnetic induction are perpendicular to each other, the Lorentz force is perpendicular to both of them (its direction can be found by the so-called right-hand rule) and electron trajectory becomes curved. When the uniform magnetic field can be taken as infinite (i.e. exists on the large enough area) and no other forces are present, the electron trajectory will be a circle with radius \mathbf{R}_c lying in plain perpendicular to the magnetic induction. In this case, the Lorentz force can be equated to the centripetal force with magnitude:

$$F = \frac{m_e v^2}{R_c} \tag{3}$$

After defining of electron velocity from Eq. (1) and its substitution in Eq. (2) and (3) the specific charge of electron $\frac{e}{m_e}$ can be derived as:

$$\frac{e}{m_e} = \frac{2U}{B^2 R_c^2} \tag{4}$$

EXPERIMENTAL ARRANGEMENT

The experimental set-up for the investigation of electron motion in magnetic field is shown in Figure 2. The electron beam is emitted by an electron gun in a flask 6 filled with argon (pressure about 0.1 Pa). Due to collisions of emitted electrons with argon atoms the atoms become ionized. Recombination of ions back to neutral state leads to light emission. Therefore, the electron trajectory becomes visible.



Figure 2: Experimental set-up consists of: 1 - power supply for Helmholtz coils, 2 - voltage controller, 3 - current limiter, 4 - ammeter for Helmholtz coils current measurement, 5 - Helmholtz coils, 6 - argon-filled flask with electron gun, 7 - low voltage source for electron gun power supply, 8 - potentiometer for grid voltage setting (0–50 V), 9 - potentiometer for anode voltage setting (0–300 V), 10 - output (6.3 V~) for cathode heating, 11 - voltmeter for measurement of accelerating voltage.



The electron velocity can be adjusted by means of the accelerating voltage U, which is the sum of the grid voltage (to be set in range 0–50 V by potentiometer 8) and the anode voltage (to be set in range 0–250 V by potentiometer 9). Here, the electron gun's cathode is heated by alternating voltage 6.3 V (Figures 2 and 3).



Figure 3: Electron gun circuit scheme

The magnetic field, in which the electron beam is curved, is generated along the axis of the coaxial Helmholtz coils (Figure 2). In the actual experiment the magnetic field is generated by the identical Helmholtz coils of radius a = 200 mm placed at the same distance from each other. In such arrangement, in case if equal magnetizing current of magnitude I flows through the both coils in the same direction the magnetic induction between coils can be assumed as constant and equal to:

$$B \approx B_0 = \frac{8}{5\sqrt{5}} \frac{\mu_0 nI}{a} \tag{5}$$

Where, $\mu_0 = 4\pi \cdot 10^{-7} \text{ N} \cdot \text{A}^{-2}$ is the magnetic permeability constant and *n* is the number of wire turns in each coils (in this case *n* = 154). Current through the Helmholtz coils is adjusted by means of a current limiter **3** on the low voltage source **1**, thus avoiding its decrease when the coils heat up. The output voltage in this case should be set to maximum value using the potentiometer **2**.

In agreement with theory, if the emitted electrons enter the magnetic field perpendicularly, they move along the circular trajectories that can be observed in the flask. If the trajectory is helical, the flask must be rotated along its axis so that the trajectories are circular (**don't do it by yourselves, ask the instructor**). The radius of the electron trajectory in the actual case is not measured but adjusted. In the flask there is a scale with crossbars coated by luminophore on which the electron beam must point on. The distance from the electron gun to the crossbar is equal to $L = 2R_c = 4$, 6, 8 and 10 cm.



PROCEDURE:

Safety warning: The acceleration voltage at the electron gun may be as high as 300 volts. For this reason, do not manipulate with power circuit connections. Ask the instructor to turn the equipment on.

- 1. Before switching on the power supply for the electron gun 7, set the grid voltage (potentiometer 8), anode voltage (potentiometer 9) and magnetizing current (current limiter 3) to zero value.
- 2. Ask the instructor to switch on the power supplies. Wait at least 2 min (cathode heating) before starting to increase the acceleration voltage.
- 3. Set the voltage controller (potentiometer 2) and grid voltage (potentiometer 8) at maximum value.
- 4. Increase the total acceleration voltage *U* that is measured by voltmeter **11** by means of the anode voltage increasing (potentiometer **9**). Do not exceed 300 V of the total acceleration voltage.
- Increase the magnetizing current of coils *I* that is measured by ammeter 4 by means of current limiter
 Do not exceed the current of 5 A.
- 6. Observe the influence of the magnetic field on the electron beam. The beam path (electron's trajectory) should be circular. If the observed trajectory is helical ask the instructor to adjust the flask along its axis. Performed once at the medium settings.
- 7. For total acceleration voltages in the range 130–300 V find such magnetizing currents when the electron beam hits on one of the crossbars with luminophore, i.e. when the radius of the electron's trajectory can be determined. Perform around 16 measurements.
- To finish the experiment, set the magnetizing current (current limiter 3), anode voltage (potentiometer 9) and grid voltage (potentiometer 8) to zero value. Set the voltage controller (potentiometer 2) to zero value and tell instructor to switch off the power supplies.
- 9. Use the equation (5) to find the magnetic induction. Calculate for each combination of measured and calculated values the specific charge of electron (equation 4).
- 10. Find the average calculated value $\left(\frac{e}{m_e}\right)_{calc}$ and compare it with the accepted one that is

$$\left(\frac{e}{m_e}\right)_{acc} = 1.76\times 10^{11}\,C/kg$$

11. Find the measurement uncertainty and calculate relative error:

$$\frac{\delta\left(\frac{e}{m_e}\right)}{\frac{e}{m_e}} = \frac{\left(\frac{e}{m_e}\right)_{calc} - \left(\frac{e}{m_e}\right)_{acc}}{\left(\frac{e}{m_e}\right)_{acc}} \times 100\%$$

12. Discuss the observation and results.

