Specific charge of the electron - e/m (Item No.: P2510200)

Curricular Relevance

Area of Expertise: Physics → **Education Level:** University → **Topic:** Modern Physics → **Subtopic:** Quantum Physics → **Experiment:** Specific charge of the electron - e/m

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	1 Hour	2 Hours	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Cathode rays, Lorentz force, electron in crossed fields, electron mass, electron charge

Overview

Short introduction

Principle

Electrons are accelerated in an electric field and enter a magnetic field at right angles to the direction of motion. The specific charge of the electron is determined from the accelerating voltage, the magnetic field strength and the radius of the electron orbit.

Fig.1: Experimental set-up for determining the specific charge of the electron.

Equipment

Position No.	Material	Order No.	Quantity
1	PHYWE Narrow beam tube	06959-00	1
2	Helmholtz coils, one pair	06960-00	1
3	e/m - Observation chamber	06959-01	1
4	PHYWE Power supply, regulated DC: 0...12 V, 0,5 A; 0...650 V, 50 mA / AC: 6,3 V, 2 A	13672-93	1
5	PHYWE power supply, universal DC: 0...18 V, 0...5 A / AC: 2/4/6/8/10/12/15 V, 5 A	13500-93	1
6	Digital multimeter 2005	07129-00	2
7	Conn.cord,safety,32A, 25cm, red	07335-01	1
8	Conn.cord,safety,32A, 25cm, blue	07335-04	1
9	Conn.cord,safety,32A,100cm, red	07337-01	2
10	Conn.cord,safety,32A,100cm, blue	07337-04	2
11	Conn.cord,safety,32A,100cm,yellow	07337-02	3
12	Connecting cord, 32 A, 1000 mm, red	07363-01	3
13	Connecting cord, 32 A, 1000 mm, blue	07363-04	1

Tasks

Determination of the specific charge of the electron (e/m_0) from the path of an electron beam in crossed electric and magnetic fields of variable strength.

Set-up and procedure

The experimental set up is as shown in Fig. 1. The electrical connection is shown in the wiring diagram in Fig. 2 and Fig. 3. The two coils are turned towards each other in the Helmholtz arrangement. Since the current must be the same in both coils, connection in series is preferable to connection in parallel. The maximum permissible continuous current of 5 A should not be exceeded.

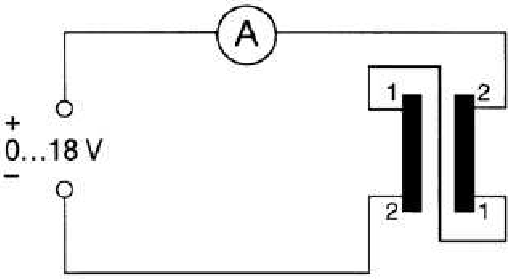

Fig. 2: Wiring diagram for Helmholtz coils.

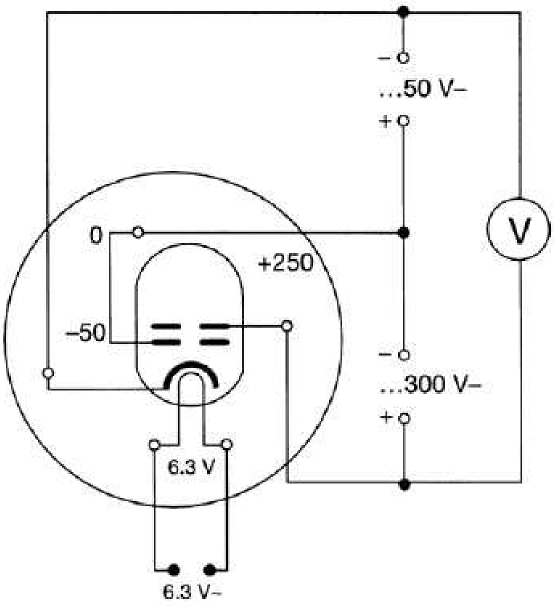

Fig. 3: Wiring diagram for Narrow beam tube.

If the polarity of the magnetic field is correct, a curved luminous trajectory is visible in the darkened room. By varying the magnetic field (current) and the velocity of the electrons (acceleration and focussing voltage) the radius of the orbit can be adjusted, such that it coincides with the radius defined by the luminous traces. When the electron beam coincides with the luminous traces, only half of the circle is observable. The radius of the circle is then 2, 3, 4 or 5 cm.

For detailed description of the narrow beam tube, please refer to the operating instructions.

If the trace has the form of a helix this must be eliminated by rotating the narrow beam tube around its longitudinal axis.

Theory and evaluation

If an electron of mass m_0 and charge e is accelerated by a potential difference U, it attains the kinetic energy:

$$e \cdot U = \frac{1}{2} \cdot m_0 \cdot v^2 \qquad (1)$$

where v is the velocity of the electron.

In a magnetic field of strength $\vec{B}$ the Lorentz force acting on an electron with velocity $\vec{v}$ is:

$$\vec{F} = e \cdot \vec{v} \times \vec{B}.$$

If the magnetic field is uniform, as it is in the Helmholtz arrangement the electron therefore follows a spiral path along the magnetic lines of force, which becomes a circle of radius r if $\vec{v}$ is perpendicular to $\vec{B}$.

Since the centrigugal force $m_0 \cdot v^2/r$ thus produced is equal to the Lorentz force, we obtain

$$v = \frac{e}{m_0} \cdot B \cdot r,$$

where B is the absolute magnitude of $\vec{B}$. From equation (1), it follows that

$$\frac{e}{m_0} = \frac{2U}{(B \cdot r)^2}. \qquad (2)$$

To calculate the magnetic field B, the first and fourth Maxwell equations are used in the case where no time dependent electric fields exist.
We obtain the magnetic field strength B_z on the z-axis of a circular current I for a symmetrical arrangements of two coils at a distance a from each other:

$$B_z = \mu_0 \cdot I \cdot R^2 + \left\{ \left(R^2 + \left(z - \frac{a}{2}\right)^2\right)^{3/2} + \left(R^2 + \left(z + \frac{a}{2}\right)^2\right)^{3/2} \right\}$$

with $\mu_0 = 1.257 \cdot 10^{-6} \frac{\mathrm{Vs}}{\mathrm{Am}}$

and R = radius of the coil.

For the Helmholtz arrangement of two coils ($a = R$) with number of turns n in the centre between the coils one obtains

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

For the coils used, $R = 0.2\,\mathrm{m}$ and $n = 154$. The mean,

$$e/m_0 = (1.84 \pm 0.02) \cdot 10^{11}\ \mathrm{As/kg}$$

was obtained from the values given in Table 1.

Literature value: $e/m = 1.759 \cdot 10^{-11}\ \mathrm{As/kg}$.

Table 1: Current I and specific charge of the electron, in accordance with eq. (2) and eq. (3) for various voltages U and various radii r of the electron trajectories.

	r =0.02 m		r =0.03 m		r =0.04 m		r =0.05 m	
$\frac{U}{V}$	I	$\frac{e/m_0}{10^{11}\,\frac{\mathrm{As}}{\mathrm{kg}}}$	I	$\frac{e/m_0}{10^{11}\,\frac{\mathrm{As}}{\mathrm{kg}}}$	I	$\frac{e/m_0}{10^{11}\,\frac{\mathrm{As}}{\mathrm{kg}}}$	I	$\frac{e/m_0}{10^{11}\,\frac{\mathrm{As}}{\mathrm{kg}}}$
100	2.5	1.7	1.6	1.8	1.1	2.2	0.91	2.0
120	2.6	1.9	1.7	1.9	1.3	1.9	1.0	2.0
140	2.8	1.9	1.9	1.8	1.4	1.9	1.1	1.9
160	–	–	2.0	1.9	1.5	1.9	1.2	1.9
180	–	–	2.2	1.7	1.6	1.8	1.3	1.8
200	–	–	2.3	1.8	1.7	1.8	1.4	1.7
220	–	–	2.4	1.8	1.8	1.8	1.4	1.9
240	–	–	2.5	1.8	1.9	1.7	1.5	1.8
260	–	–	2.6	1.8	1.9	1.9	1.6	1.7
280	–	–	2.7	1.8	2.0	1.8	1.6	1.8
300	–	–	2.8	1.8	2.1	1.8	1.7	1.7