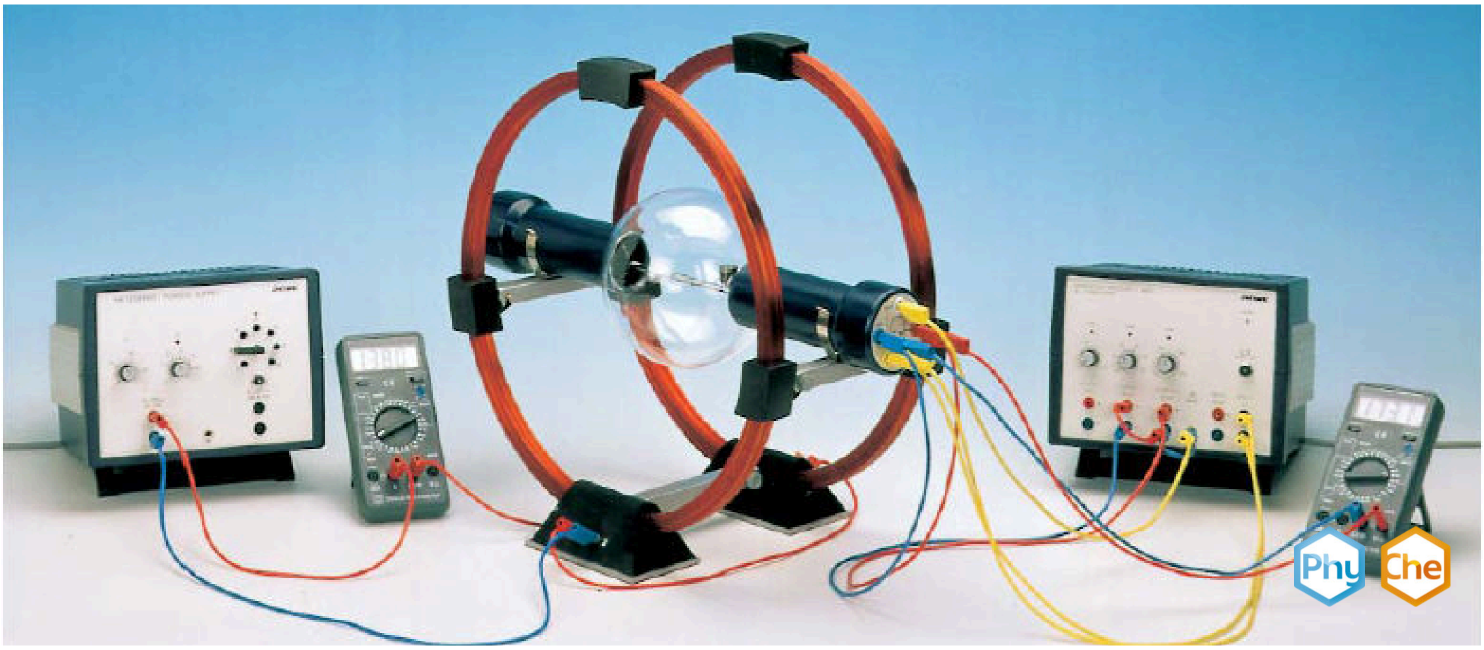
Specific charge of the electron - e/m



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.

Physics	Modern Physics	Quantum physics
Chemistry	Physical chemistry	Atomic structures & properties

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

https://www.curriculab.de/c/5f0ec9bab6127b00030447f6

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General information

Application

A mass spectrometer

Mass spectrometry is an analytical technique, which accurately measures the mass of different molecules within a sample. It is normally used to identify samples and determine the purity of samples.

A mass spectrometer generates multiple ions from the sample under investigation, it then separates them according to their **specific mass-to-charge ratio**, and then records the relative abundance of each ion type. Results are displayed as spectra of the signal intensity of detected ions as a function of the mass-to-charge ratio.

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Other information (1/2)

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Prior knowledge

When electrons enter a gas sample, the gas breaks down into charged molecules (ions). If they are exposed to an electric and a magnetic field, ions with the same mass-to-charge ratio are deflected to the same extent.

Scientific 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.

Other information (2/2)

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Learning objective

- Specific charge of the electron
- Lorentz force
- Electron ionization

Tasks

Determine 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.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

At this experiment dangerous voltages are used. Under no circumstances wires and the plugs must be touched. Only the given at workstation high voltages shall be used. The heater voltages of the tubes to produce the electron beam shall not exceed the given voltages.

Be very careful when handling the setup.

Theory (1/3)

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

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

where v is the velocity of the electron.

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

$$\overrightarrow{F} = e \cdot \overrightarrow{v} \times \overrightarrow{B}$$

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Theory (2/3)

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

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

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

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

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

Theory (3/3)

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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:

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

with $\mu_0 = 1.257 \cdot 10^{-6} \frac{Vs}{Am}$ and *R* is radius of coil.

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

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

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Equipment

Position	Material	Item No.	Quantity
1	Helmholtz coils, one pair	06960-06	1
2	PHYWE Narrow beam tube	06959-00	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	13504-93	1
6	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C...760°C	07122-00	2
7	Safety connecting cable, 32A, l = 25cm, red	07335-01	1
8	Safety connecting cable ,32A, l = 25cm, blue	07335-04	1
9	Safety connecting cable, 32A, l = 100cm, red	07337-01	2
10	Safety connecting cable, 32A, l = 100cm, blue	07337-04	2
11	Safety connecting cable, 32A, l = 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
14	holder for fine beam tube	06962-01	2

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Setup and procedure

Setup (1/2)

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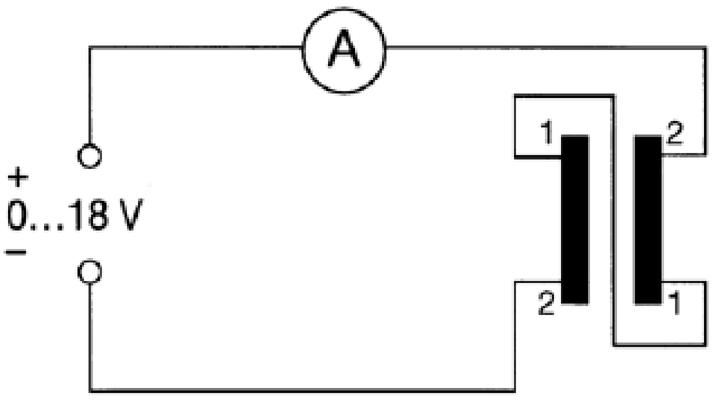

Wiring diagram for Helmholtz coils

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 5A should not be exceeded.

If the polarity of the magnetic field is correct, a curved luminous trajectory is visible in the darkened room.

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Setup (2/2)

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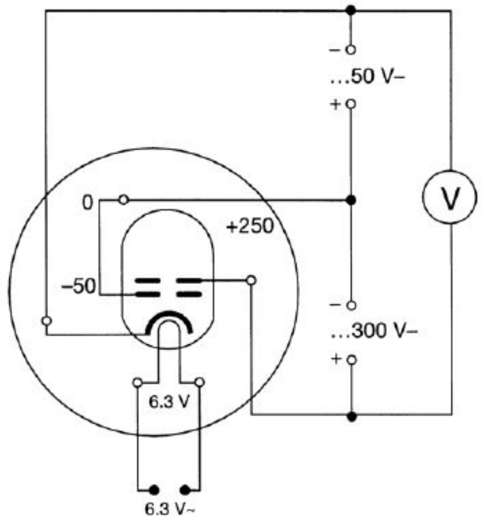
If the trace has the form of a helix this must be eliminated by rotating the narrow beam tube around its longitudinal axis.

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



Wiring diagram for Narrow beam tube

Procedure

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Experimental setup

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.

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Evaluation

Evaluation (1/2)

For the coils

$R = 0.2\,m$ and $n = 154$,

current I and specific charge of the electron e/m_0 are determined for various voltages U and various radii r of the electron trajectories.

Compare the mean value of the measured specific charge of the electron and the literature value:

$e/m = 1.759 \cdot 10^{11}\,As/kg$.

	$r = 0.02m$		$r = 0.03m$		$r = 0.04m$		$r = 0.05m$	
$\frac{U}{V}$	I	$\frac{e/m_0}{10^{11}\,\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\,\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\,\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\,\frac{As}{kg}}$
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

$\overline{e/m_0}$ = $(1.84 \pm 0.02).\,10^{-11}\,As/kg$

Current I and specific charge of the electron e/m_0

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Evaluation (2/2)

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How does Lorentz force acts on the electron?

- It causes the electron to move in a circular motion
- It influences the speed of the electron

Check

What might be the most remarkable error in the measurements?

- Radius of the coils
- Electric current
- Radius of the circle

Check

Slide	Score / Total
Slide 16: Multiple tasks	**0/2**

Total Score 0 / 2

Show solutions Retry

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