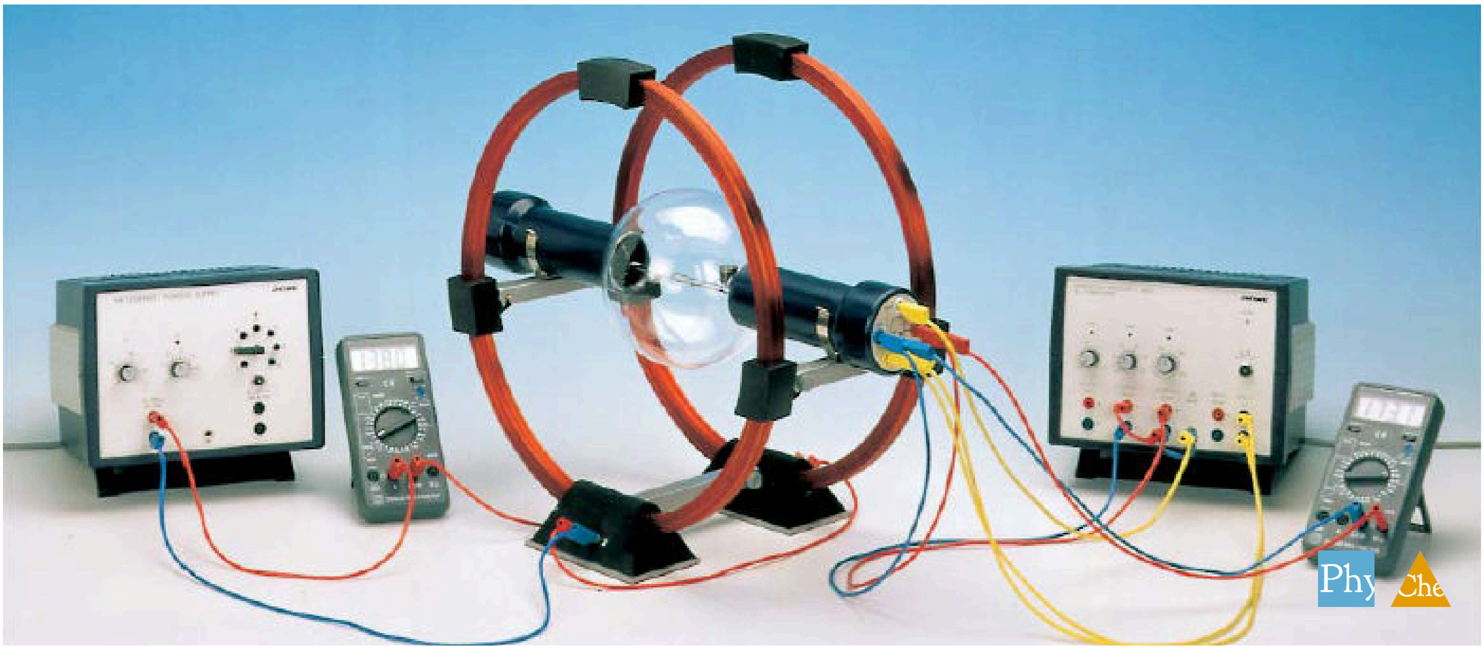
# Specific charge of the electron- e/m



| | | |
|---|---|---|
| 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 |

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# General information

## Application

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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)

### Prior knowledge

When electrons are bombarding into a gas sample, the gas break into charged molecules, or ionized. By subjecting them to an electric field and magnetic field, ions of the same mass-to-charge ratio will undergo the same amount of deflection.

### 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)

### Learning objective

To learn about the specific charge of the electron, Lorentz force and electron ionization.

### 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.



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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 structure.

## 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:

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

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:

$$\overrightarrow{F} = e.\overrightarrow{v} \text{ x } \overrightarrow{B}$$



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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 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 $m_0 . v^2/r$ thus produced is equal to the Lorentz force, we obtain

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

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

$$\frac{e}{m_0} = \frac{2U}{(Br)^2}.$$

## 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:

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

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

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



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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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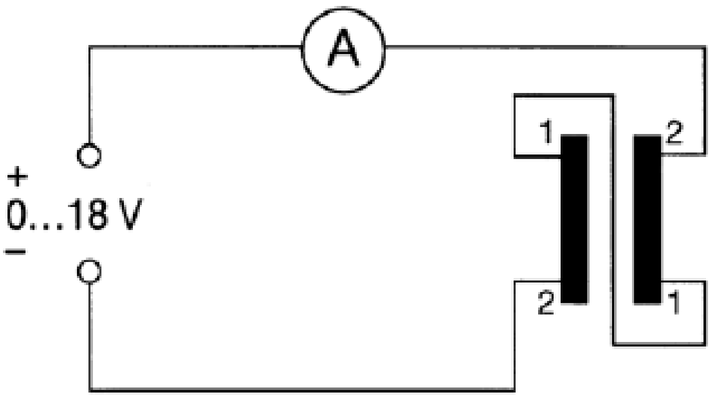
# Setup and procedure

## Setup (1/2)




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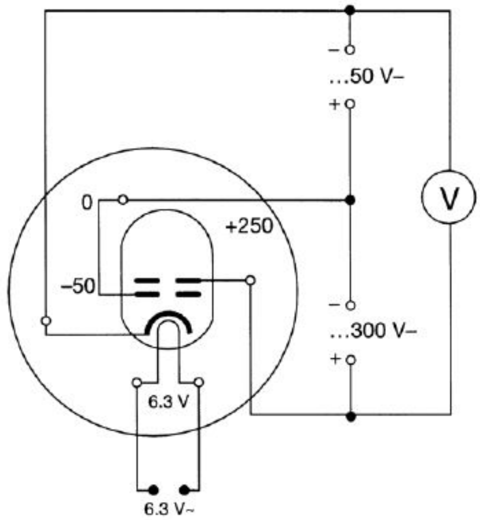
If the trace has the form of a helix this must be eliminated by rotating the narrow beam tube around its longitudinal axis.

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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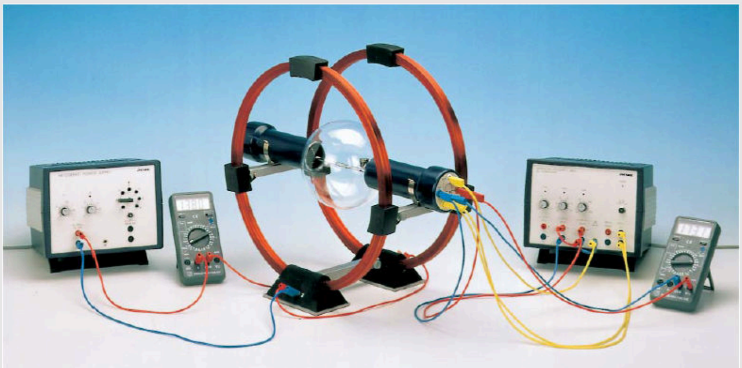

Experimental setup

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 (1/2)

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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:

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

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

# Evaluation (2/2)

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How does Lorentz force acts on the electron?

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

Check

What might be the most remarkable error in the measurements?

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

Check



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| Slide | Score / Total |
|---|---|
| Slide 15: Multiple tasks | **0/2** |

**Total Score** 0 / 2

Show solutions

Retry



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