Related topics

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

Principle and task

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.

Equipment

Narrow beam tube	06959.00	1
Pair of Helmholtz coils	06960.00	1
Power supply, 0...600 VDC	13672.93	1
Power supply, universal	13500.93	1
Digital multimeter	07134.00	2
Connecting cord, 100 mm, red	07359.01	1
Connecting cord, 100 mm, blue	07359.04	1
Connecting cord, 750 mm, red	07362.01	5
Connecting cord, 750 mm, blue	07362.04	3
Connecting cord, 750 mm, yellow	07362.02	3

Problems

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, 2. 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.

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, that it coincides with the radius defined by the luninous traces. When the electron beam ciinudes with the luminous traces, only half of the circle is observable. The radius of the circle is then 2, 3, 4 or 5 cm.

Further explanation of the narrow beam tube, please prefer 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:

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

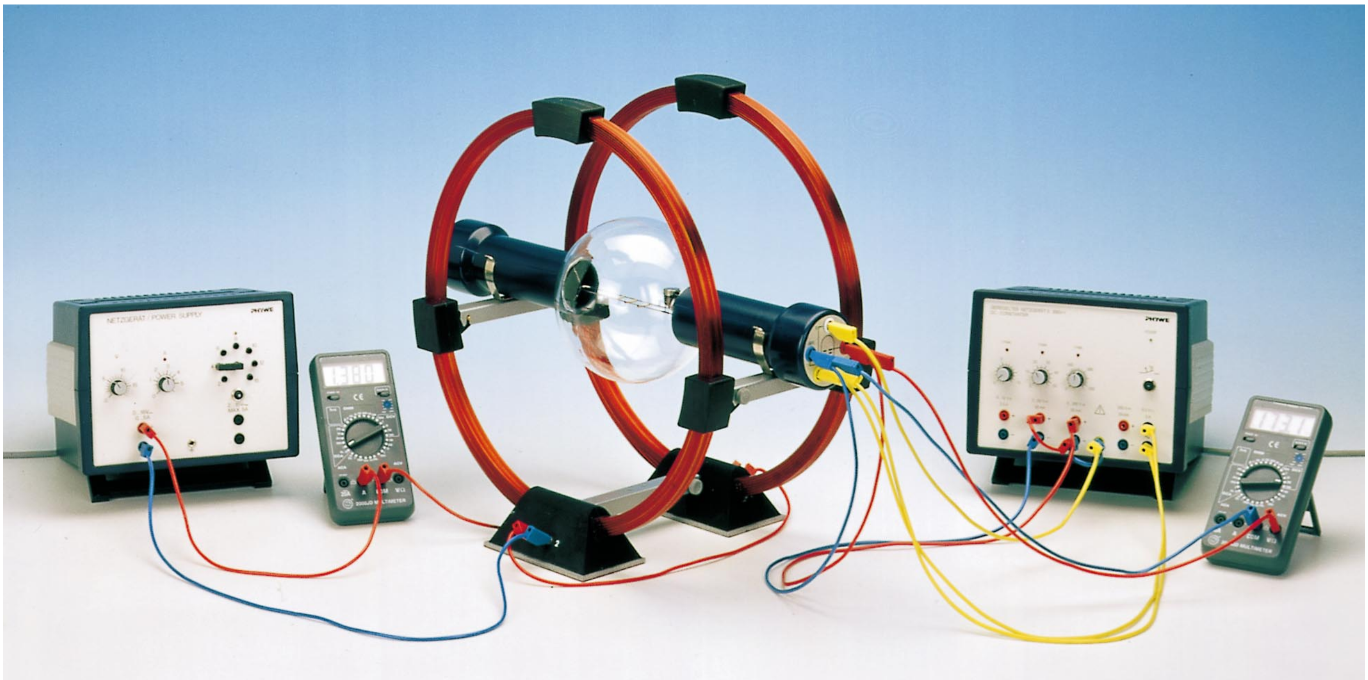
where v is the velocity of the electron.

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 arangement the eletron therefore follows a spiral path along the magnetic lines of force, which becomes a circle of radius r if $\vec{v}$ is perpendicular to $\vec{B}$.

Fig.1: Experimental set-up for determining the half-life of Ba-137 m.



Tabele 1: Current streth I and specific charge of the electron, in accordance with equations (2) and (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	$\frac{e/m_0}{10^{11}\,\frac{AS}{kg}}$	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
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

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

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

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

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

To colculate the magnetic field B, the first and fourth Maxwell equartions 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 2 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 $\mu_0 = 1.257 \cdot 10^{-6} \frac{Vs}{Am}$

and R = radius of the coil

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

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

See also experiment 4.2.09:
“Magnetic field of paried coils in Helmholtz arrangement”.

For the coils used, R = 0.2 m and n = 154.
The mean,

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

was obtained from the values given in Tabe 1.

Literature value:

$$e/m = 1.759 \cdot 10^{11} \text{ As/k}$$

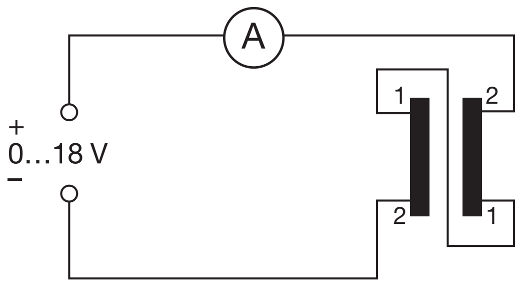


Fig. 2: Wiring diagram for Helmholtz coils.

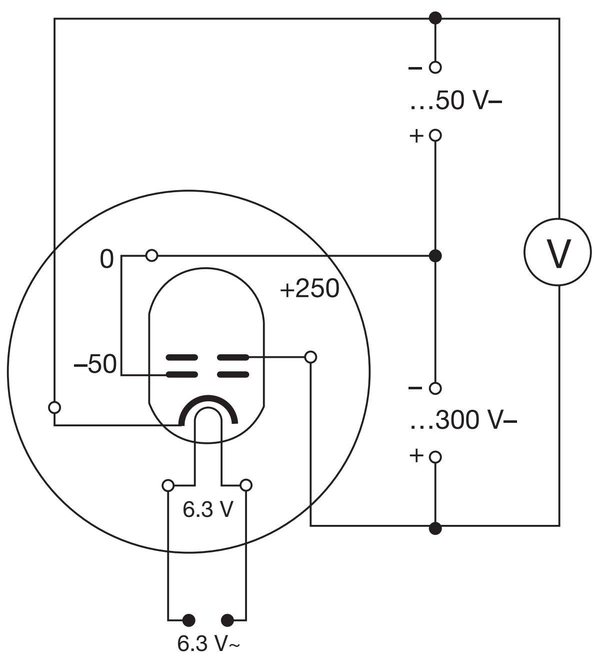


Fig. 3: Wiring diagram for Narrow beam tube.