ELWE

Operating Manual

Helmholtz coil

84 81 500

Gb

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84 81 500.12
06/03

Printed in Germany by ELWE **Didactic** GmbH

2	Helmholtz coil

1. Description

A magnetic field which is essentially homogeneous over a large region can be produced with the Helmholtz coils assembly. It consists of two flat coils which are arranged parallel to each other with a mean separation of 15 cm. Each coil has 124 turns of enamelled copper wire (1.5 mm diameter) and a DC resistance of 1.2 Ohms. The external coil diameter is D = 30.7 cm and the internal coil diameter is d = 28.3 cm. Thus the mean coil radius is R = 14.75 cm. The two coils can be connected in series or opposition. The maximum permissible current through each coil is 5 A. This current can be provided, for example, by the stabilized power supply unit (85 21 149).

2. Operation

To determine e/m for the electron, the narrow beam tube (84 81 420) must be placed in the space between the coils. There is no electrical connection between the narrow beam tube and the coils. Thus it is possible at any time to lift the tube out of the coils assembly, e.g. to measure the magnetic field strength with a Hall probe. A spring clamp on the top crossbar of the coils serves to hold the probe.

Together with the rotating frame (84 81 510), the Helmholtz coil can also be used for induction and oscillatory circuit beats experiments.

The magnitude of the magnetic field B depends on the geometric dimensions of the coils assembly, on the number of turns and on the field current I.

When the coils are connected in series cooperation, the magnetic field B produced in the central region between the two flat coils by a current I, can be calculated according to the formula

$$B = \mu_0 \cdot N \cdot I \cdot \frac{R^2}{\sqrt{R^2 + a^2}^3}$$ where

N	=	124	Number of turns of <u>one</u> coil
I			Current flowing in the coils, in Ampere
R	=	14.75 cm	Mean coil radius
2a	=	15 cm	Mean separation of coils
μ_0	=	$1.2566 \cdot 10^{-6}$ mkg/C^2	Vacuum permeability

Substituting these values in the formula given above, we obtain $\frac{B}{I} = 7{,}48 \cdot 10^{-4} \frac{T}{A}$ $(\pm 2\%)$

When the two coils are connected in opposition, the magnetic field produced in the region between them has a constant gradient dB/dx over a large part of this region. The gradient is given by the expression:

$$\frac{dB}{dx} = \mu_0 \cdot N \cdot I \frac{3 \cdot a \cdot R^2}{\sqrt{R^2 + a^2}^5} = 6{,}05 \cdot 10^{-3} \frac{I}{A} \cdot \frac{T}{m}$$

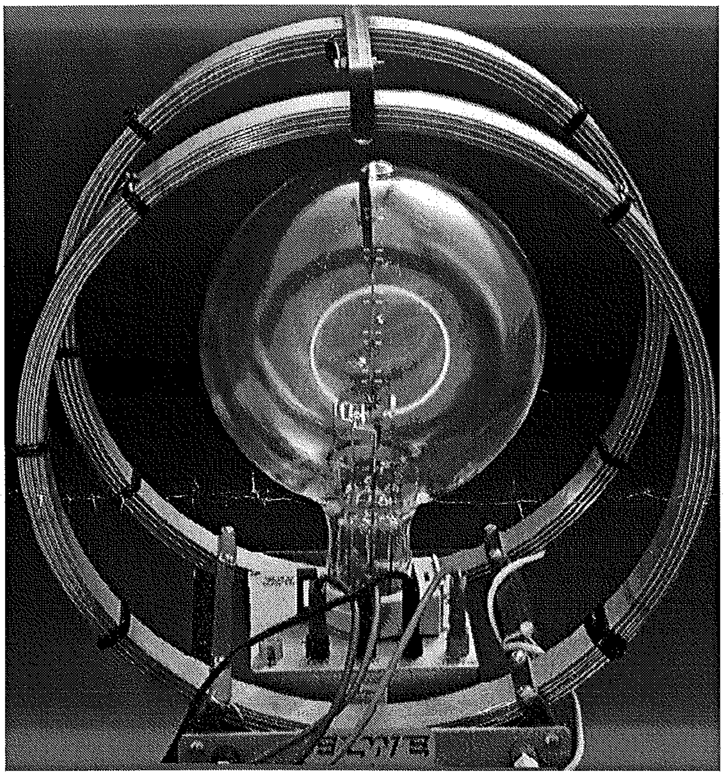

Fig. 1: Filament beam tube with Helmholtz tube 6734

A quantitative determination of the charge to mass ratio for the electron can be made with the filament beam tube.

A spherical glass bulb contains an electron gun consisting of an indirectly heated oxide-coated cathode, an anode with a hole through it and a Wehnelt cylinder. The bulb is filled with a rare gas (neon) at a residual pressure of about 1.3 Pa. Reference marks inside the tube permit exact adjustment of the circle diameter, free from parallax. The tube is mounted on a baseplate.

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Printet by ELWE Didactic GmbH
84 81 420.12
02/02

Technical data of the filament beam tube::

Bulb diamter	165 mm
Total height including baseplate	260 mm
Anode voltage	+200 to +400 V
Filament heater voltage	6 to 8 V
Wehnelt cylinder voltage	0 to -30 V
Anode current	< 0.3 mA
Filament heater current	150 to 200 mA
Filament beam circle diameter	20 to 120 mm
Separation of reference marks	20 mm

How is a filament beam produced ?

When the cathode is heated to a temperature of 850°C, the barium oxide spot emits a copious stream of electrons. These electrons are accelerated by a positive anode voltage, chiefly in the immediate vicinity of the cathode. The reason for the potential gradient concentration close to the cathode is the space charge produced by the gas contained in the tube at low pressure. After passing through this space charge zone, the electrons retain their original velocity and direction of motion nearly unchanged and pass through the hole in the anode to the space beyond.
Collisions between these primary electrons and neutral gas atoms produce positive ions along the trajectory of the electrons. Due to their low mobility, these positive ions remain nearly stationary and form a channel with low space charge. This channel is the preferrred propagation path for the electrons. This effect is called "gas constriction". On their way, the electrons collide with gas atoms agein and again, exciting them to emission of visible light. Thus a sharply focussed visible "filament beam" appears in the ion channel. This beam is propagated in a straight line in a fieldfree space.

Together with the hole aperture anode, the Wehnelt cylinder forms an electrostatic lens which focusses the electron emission from the cathode. The negative voltage applied to the Wehnelt cylinder is adjusted for optimum focus of the filament beam. At the same time, the Wehnelt cylinder functions as ion trap.

The electron beam can be deflected magnetically. When the tube is placed in a magnetic field such that the beam is at right angles to the field, the filament beam is deflected to a circle. The diameter 2r of this circle depends on the charge to mass ratio e/m of the electron, on the magnetic induction B and on the velocity of the electrons v. The diameter of the circle can be read against the reference marks. The magnetic induction can be calculated or measured with a Hall probe.

The energy conversion relationship

$$1/2\ m\ v^2 = e\ U \qquad (1)$$

permits calculation of the electron velocity, so that the charge to mass ratio e/m can be determined by experiment.

The following apparatus is required to carry out the experiment:

1	Filament beam tube No. 6733
1	Helmholtz coil No. 6734
1	Power supply unit for the tube, No. 5211
1	Power supply unit for the coil (0 to 12 V DC, well-smoothed, output current rating 4 A) e.g. Mains power unit No. 5207 or a nickel/cadmium steel accumulator battery No. 5281 or 5282 with 2.4 Ohms rheostat No. 5611
1	Voltmeter 300 V DC
1	Current meter 3 A DC
8	Connecting leads
1	Rod magnet
(1)	Magnetic field measuring unit NO. 7310

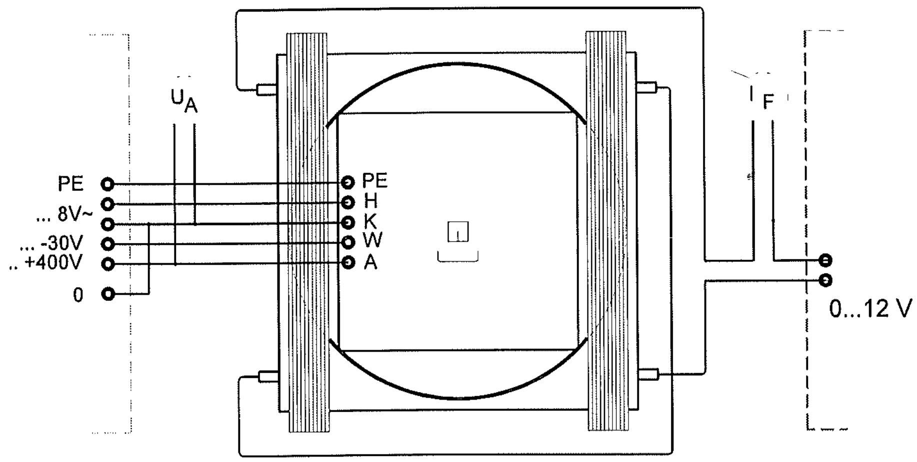

Fig. 2

Set-up of the experiment

Connect-up the tube to the power supply as shown in Fig. 2. An additional voltage source may be required for the heater (6 to 8 V).

Set the anode voltage to about 300 V and the Wehnelt cylinder voltage to zero. The filament beam appears after a heat-up time of about 2 minutes. No adjust the negative Wehnelt cylinder voltage such that the beam is focussed as sharply as possible.

The experiment should be carried out in a darkened room.

Preliminary experiment

Approach a rod magnet to the tube.
Result: The filament beam is deflected.

Explanation: Electrons moving in a magnetic field experience a deflecting force F, called the Lorentz force and obeying the relationship

$$F = e * v * B \sin(\vec{v},\vec{B}) \qquad (2)$$

$\sin(\vec{v},\vec{B})$ is the sine of the angle between the velocity vector $\vec{v}$ and the magnetic flux density vector B.

Determination af the charge to mass ratio e/m for the electron

Position the filament beam tube in the Helmholtz coil such that the filament beam is at right angles to the magnetic field direction.

The filament beam is deflected to a circle. Each electron experiences the Lorentz force

$$F_L = B * e v \qquad (3)$$

mutually at right angles to $\vec{v}$ and $\vec{B}$. The force acting on the elctron is always at right angles to the direction of motion, so that no acceleration is produced in the direction of motion. Thus the acceleration is entirely a radial one, accounting for the resulting circular path of motion. The motion is circular because the magnitude of the radial acceleration remains constant in a homogeneous magnetic field.

The Lorentz force F_L acts as constant centripetal force

$$F_C = mv^2/r \qquad (4)$$

and forces the electrons to move on a circular path with radius r obeying the relationship

$$e v B = mv^2/r. \qquad (5)$$

Combining this with relationship (1), we obtain the following expression for the charge to mass ratio of the electron

$$e/m = 2 U / B^2 r^2. \qquad (6)$$

The voltage U, the radius r of the circular path of motion and the magnetic field B must be determined in the experiment.

It is convenient to use a digital voltmeter for measuring the electron acceleration voltage U.

The diameter 2r of the path of motion is easily determined by reference to the ladder steps provided at intervals of 20 mm.

The magnitude of the magnetic field B can be determined with the magnetic field measuring unit (No. 7310), or it can be calculated using the equation given in the description for the Helmholtz coil 6734.

$$B = I_{Field} * 7{,}48 * 10^{-4} \text{ T} \qquad (7)$$

Example of a set of measurements

2r (mm)	I (A)	B(mT)	U (V)	e/m (10^{11}As/kg)
60	2.0	1.50	191	1.90
	2.25	1.68	235	1.84
	2.5	1.87	292	1.86
80	1.6	1.20	211	1.84
	2.0	1.50	325	1.82
100	1.5	1.12	273	1.74
	1.75	1.31	375	1.75

Published value: e/m = 1,7588047 * 10^{11} C/kg

Note that the accelerating voltage must be greater than about 200 V, otherwise no filament beam will be formed.

Thus for the smallest possible radius (2r = 40 mm), a filament beam is formed only with the larger magnetic field producing currents (I = 3 A), and even then it may be rather weak.

*) In order to ensure that the filament beam lies in the homogeneous region of the magnetic field when the circle diameter is 100 mm, the coils set must be raised by about 2 cm (place small wooden blocks under the coils set).