Deflection of electrons in an axial magnetic field

Objects of the experiments

- Demonstration of the deflection of a divergent electron beam in an axial magnetic field
- Focussing of a divergent electron beam by an axial magnetic field

Principles

The Maltese cross tube is used for demonstrating the straight-line movement of electrons in field-free space. The existence of cathode rays was qualitatively investigated in experiments using the vacuum tube diode and the vacuum tube triode.

In the Maltese cross tube electrons are accelerated by the anode in the direction of a fluorescent screen and there they can be observed in the form of a luminous image. The electron gun creates a divergent electron beam imaging the body placed between the fluorescent screen and the electron gun on the fluorescent screen. A Maltese cross is placed between the anode and the fluorescent screen, the shadow of which is visible on the fluorescent screen. The Maltese cross can be connected to any potential via a separate connection.

In the experiment the deflection of electrons is demonstrated in an axial magnetic field created by a pair of Helmholtz coils. The electron gun emits a divergent beam; the electron paths are therefore at an angle to the field lines of the magnetic field. The velocity component vertical to the magnetic field lines lead, on account of the Lorentz force, to a deflection at right-angles to the magnetic field lines. The velocity component in parallel to the field, however, remains unchanged. Therefore the electrons move in a screw-shaped path. The radius of the path and the angular velocity of the electrons on the path depend on the size of the magnetic field, the velocity of the electrons and the angle between electron beam and magnetic field. The time an electron requires to go once around the circular path does not, however, depend on the velocity but only on the size of the magnetic field. If in the experiment the current through the Helmholtz pair of coils is increased and in that way the magnetic field increased, the shadow will therefore rotate as a unit on the fluorescent screen.

On the screw-shaped path the direction of movement will at certain points in time be again in the direction of the beam axis. Because the time for one completion of the circular path is the same for all electrons, all electrons arrive at this point at the same time. If the electrons leave the magnetic field at this point in time, their paths cross the beam axis at a single point. By making an appropriate choice of magnetic field and therefore coil current, the divergent electron beam can, in this way, be focussed. The experimental setup can therefore also be used for demonstrating magnetic electron lenses.

Fig. 1: Experimental setup

Apparatus

1 Maltese cross tube 555 620
1 tube stand 555 600
1 Helmholtz pair of coils 555 604
1 High voltage power supply 521 70
1 DC power supply 0 – 16 V / 0 – 5 A 521 545
1 safety connection lead, 25 cm, red 500 611
2 safety connection leads, 50 cm, red 500 621
1 safety connection lead, 50 cm, blue 500 622
2 safety connection leads, 100 cm, red 500 641
2 safety connection leads, 100 cm, blue 500 642
2 safety connection leads, 100 cm, black 500 644

CS-1006

LD Didactic GmbH · Leyboldstraße 1 · D-50354 Hürth · Telephone: (02233) 604-0 · Fax: (02233) 604-222 · e-mail: info@ld-didactic.de

Safety notes

The Maltese cross tube is a thin-walled evacuated glass cylinder. Danger of implosion!

- Do not expose the tube to any mechanical loads.
- Only connect the Maltese cross tube by means of safety connection leads.
- Observe the operating instructions for the Maltese cross tube (555 620) and the tube stand (555 600).

Setup

The experimental setup is shown in fig. 1. For setting up, the steps described below are required:

- Place one coil from the pair of Helmholtz coils directly in front of the tube holder.
- Carefully insert the Maltese cross tube (through the first coil) into the tube stand.
- Connect sockets F_1 and F_2 on the tube stand for the cathode heater to the 10 kV output at the rear of the high voltage power supply.
- Connect socket C on the tube stand (cathode cap of the Maltese cross tube) to the negative pole and socket A (anode) to the positive pole of the 10 kV high voltage power supply and in addition earth the positive pole.
- Set up the second coil. Align the pair of Helmholtz coils around the tube in such a way that the coils are arranged in the Helmholtz geometry (distance between the coils 6.7 cm) and the beam axis of the tube coincides with the line connecting the two centres of the coils (see fig. 2). Connect the coil in series to the direct current power supply so that the current flows through the coils in the same direction.
- Connect the Maltese cross to socket A.

Carrying out the experiment

- Switch on the high voltage power supply. Now the cathode is being heated.
- Select an anode voltage between 2.5 and 5 kV and observe the shadow of the Maltese cross on the fluorescent screen
- Slowly increase the magnetic field by increasing the current flowing in the coils and observe the rotation and focussing of the shadow.
- Reverse the polarity of the current through the coils and again increase the current.

Observation and evaluation

After the cathode heater is switched on the light shadow of the cross becomes visible on the fluorescent screen of the tube. When the voltage at the anode is increased a second shadow appears on the fluorescence screen which has exactly the same shape, size and location as the light shadow (compare with experiment 3.8.3.1).

If the current through the pair of Helmholtz coils is increased the electron shadow will shrink. On account of the divergent electron beam in the Maltese cross tube the electron paths run at an angle to the magnetic field lines. The electrons are therefore deflected onto screw-shaped paths which results in a rotation of the shadow. The speed of rotation is the same for all electrons, so that the entire cross rotates as a whole. The rotational direction depends on the direction of the magnetic field and therefore on the direction of the coil current. When they leave the magnetic field, the electrons continue moving in a straight line in the direction they have just reached on their screw-shaped path in the magnetic field. On the screen the shadow will therefore also appear enlarged or reduced in size.

For appropriate settings of the anode voltage and coil current, focussing of the electron beam to a single point is possible; if a yet larger current is chosen the image will again appear larger. This means that this setup is suitable for realising a magnetic electron lens and it can also be viewed as a model for electron optics using static magnetic fields.