Electricity

Free charge carriers in a vacuum
Maltese cross tube

Physics Leaflets

P3.8.3.1

Demonstrating the linear propagation of electrons in a field-free space

Objects of the experiments

- Demonstrating the linear propagation of electrons in a field-free space

Principles

The Maltese cross tube is used for demonstrating the linear propagation of electrons in a 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 linear propagation of electrons in a field-free space is demonstrated. To do this the Maltese cross is connected to the anode potential and the shadow of the Maltese cross in the electron beam is compared to the shadow cast by the light. From the observed identical size of the two shadows one can conclude that the electrons move in a straight line. A magnet can be used to deflect the electrons on account of the Lorentz force; then the shadow appears to be shifted and slightly distorted.

Then the Maltese cross is left potential-free and is negatively charged by the electrons that hit it. In this case the charges created in the space around the Maltese cross create a repulsive potential so that the image on the screen appears to be enlarged and distorted.

Fig. 1: Experimental setup

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).

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Setup

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

- Carefully insert the Maltese cross tube 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.
- Connect the Maltese cross to socket A.

Carrying out the experiment

- Switch on the high voltage power supply. Now the cathode is being heated.
- Observe on the fluorescent screen how the voltage at the anode slowly increases to 4.5 kV.
- Move the magnet from the side towards the fluorescent screen and observe how the image changes.
- Remove the cable between socket A and the Maltese cross. Again, observe the changes to the image.

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. Light spreads out in straight lines. For this reason a light shadow of the cross appears on the fluorescent screen when the cathode heater is switched on.

When the voltage at the anode is increased a second shadow appears on the fluorescent screen which has exactly the same shape and size as the light shadow. The anode voltage accelerates the electrons in the direction of the fluorescent screen. Some electrons do not hit the screen but the cross itself. For this reason a second shadow becomes visible on the fluorescent screen. This is nearly identical in shape, size and location to the light shadow and therefore evidence that electron rays spread along straight lines just like light.

When the magnet is moved close to the fluorescent screen the shadow is shifted and slightly distorted. The direction of the shift depends on where the magnet is placed. In the magnetic field the electrons are deflected on account of the Lorentz force. This leads to the observed shift in the shadow. The inhomogeneity of the magnetic field will in addition lead to a slight distortion because not all of the electrons are deflected to an equal degree.

If the cable connecting the Maltese cross to the anode is removed, the shadow will become larger and noticeably distorted. Now the potential of the cross is no longer fixed. Because some electrons hit the cross it becomes charged with a negative charge. The charging of the space around the Maltese cross will lead to other electrons being repelled and finally to the observed enlargement and distortion of the shadow.

Note:

The light shadow and the electron shadow are usually not completely identical even if no external fields are applied. On account of the construction of the electron gun the optical path of the light and the electron can be slightly different.