

# Electricity

Electrical conduction in gases  
*Cathode rays and canal rays*

**LD**  
**Physics**  
**Leaflets**

P3.9.3.1

Magnetic deflection of cathode and canal rays

## Experiment objectives

- Qualitative observation of cathode rays and canal rays under the influence of magnetic fields.

## Principles

In a gas discharge tube it is possible to observe both cathode rays and canal rays (commonly called anode rays). This requires the tube to be evacuated to a very low pressure while a high voltage is applied across the electrodes.

Positive ions from the residual gas are accelerated towards the cathode where their collisions release electrons. These, in turn, are accelerated, largely unimpeded, towards the anode.

Some electrons pass through an opening in the anode into the space beyond it. This electron beam can be viewed in the residual gas. Such a beam is called a cathode ray (Goldstein 1876), since the electrons are emitted by the cathode. On the screen in the glass tube it is possible to see a highly focussed fluorescence.

The positive ions are similarly accelerated towards the cathode and some of them also pass beyond through an opening in the electrode. Goldstein called these positive rays of ions canal rays, though they are also commonly called anode rays. They can be seen as a diffuse light in the space between the cathode and the screen on the glass. Ions striking the screen cause a slight fluorescence upon it.

Both cathode rays and anode rays can be affected by magnets (Hittorf 1869).

In this experiment, it will be observed that the cathode ray can be deflected quite easily, unlike the anode ray. It can be deduced from this that the ions have a much smaller specific charge than the electrons.



Fig. 1. Experiment set-up

## Equipment

1	Discharge tube, canal rays .....	554 161
1	Rotary-vane vacuum pump D 2.5 E.....	378 752
1	Pirani vacuum gauge with display .....	378 5131
1	Male ground joint, ST 19/26, DN 16 KF.....	378 023
1	Cross piece, DN 16 KF.....	378 015
1	Fine vacuum ball valve, DN 16 KF .....	378 777
1	Variable leak valve, DN 16 KF.....	378 776
5	Clamping rings, DN 10/16 KF .....	378 050
3	Sets of 2 centring rings, DN 16 KF, ....from	378 045ET2
1	Leybold high-vacuum grease.....	378 701
1	High-voltage power supply, 10 kV .....	521 70
2	Cables for high voltages, 1.5 m .....	501 051
1	Pair of magnets, 35 mm diam.....	510 48
<i>Additionally recommended:</i>		
1	Exhaust filter, AF 8 .....	378 764

## Safety instructions

When the discharge tube is operated with high voltages in excess of 5 kV X-rays will be generated\*:

- Always keep the operating voltage for the discharge below 5 kV.

Evacuating a damaged discharge tube leads to a risk of implosion:

- Handle the discharge tube carefully and avoid any mechanical stresses.
- Check the discharge for damage, e.g. cracks, before attempting to evacuate it.

\*The discharge tube does not emit impermissibly high X-ray radiation when operated using the 10 kV high voltage power supply (521 70). Even at low pressure, the dosage 0.1 m from the touchable surface while cathode rays are being produced is less than 1 µSv/h.

## Experiment set-up

Set up the experiment as shown in Fig. 1.

- Firmly attach the fine vacuum ball valve to the suction nozzles of the rotary vane pump and attach the cross piece to the set-up.
- Attach the variable leak (dosing) valve and the vacuum gauge tube to the sides of the cross piece. Attach the male ground joint to the cross piece in such a way that it is pointing upward.
- Coat both male and female joints for the discharge tube with a similarly thin layer of vacuum grease.
- Vary carefully press the discharge tube over the male joint, making sure you don't tilt it.
- Check that the vacuum components are connected properly and carefully close the clamping rings.
- Connect the vacuum gauge tube to the vacuum display instrument.
- Wire up the electrodes of the discharge tube to the right-hand 5-kV output ( $I < 2\text{mA}$ ) of the high-voltage power supply using high-voltage cables.
- Recommended: operate the rotary vane pump with an exhaust filter.

## Experiment procedure

Note: in order to get the best observations of the light phenomena, carry out the experiment in complete darkness.

- Turn on the high voltage power supply and set the output voltage to  $U = 5 \text{kV}$ .
- Turn on the vacuum gauge display instrument.
- Open the dosing valve and the fine vacuum ball valve all the way and turn on the rotary valve pump.
- Close the dosing valve so that the pressure in the discharge tube drops to between  $4 \cdot 10^{-2}$  and  $6 \cdot 10^{-2} \text{ mbar}$ .
- Now the light phenomena beyond the electrodes can be affected with the help of the magnets. The magnets between the electrodes and the end caps should be moved towards the tube on both sides, such that the canal (anode) ray or the cathode ray passes between the north pole of one magnet and the south pole of the other. The magnetic field is then perpendicular to the direction in which the ions or electrons are moving.

## Observations

The cathode ray and therefore the dot of light on the screen behind the anode can be affected by means of magnets, i.e. a magnetic field. For example, if the north pole of a magnet is moved to below the cathode ray behind the anode, the dot moves to the left, as seen looking along the direction of motion. The cathode ray consists of carriers of negative charge (cf. the left-hand rule)

The faint, blueish, diverging beam behind the cathode (canal or anode ray) is not visibly affected by the magnets used in this experiment. The fact that the effect is not seen implies that the mass of the particles involved is very much greater in comparison to their charge than that of electrons.

Note: in order to estimate the radius of deflection, it is possible to use the speed of the electrons or ions, assuming that they are accelerated from one electrode to the other without colliding on the way:

$$\frac{1}{2} \cdot m \cdot v^2 = q \cdot U \Rightarrow v = \sqrt{\frac{2 \cdot U \cdot q}{m}}$$

The radius  $r$  of the circle around which the particles are deflected by the magnetic field is found by equating the Lorentz force with the centrifugal force:

$$F_L = q \cdot v \cdot B = F_Z = \frac{m \cdot v^2}{r} \Rightarrow r = \sqrt{\frac{2 \cdot U \cdot m}{B^2 \cdot q}}$$

If the accelerating voltage for both types of particle is equal to  $U$  and the magnetic flux is equal to  $B$  (i.e.  $\frac{2 \cdot U}{B^2} = \text{const.}$ ) the radius will be smaller for a large specific charge  $\frac{q}{m}$  and the deflection will be correspondingly greater. The specific charge for electrons can be determined quantitatively with the help of experiments P3.8.4.1 (Perrin tube) or P3.8.5.1 (Thomson tube).