Investigating spontaneous gas discharge in air as a function of pressure

Objects of the experiments

- Observing spontaneous gas discharge in air as a function of pressure.
- Measuring the high voltage from the current-limited high-voltage power supply as a function of pressure.

Principles

Glow discharge is a special form of gas discharge. It takes place spontaneously at low pressures and with a relatively small current density and is accompanied by conspicuous luminous effects. Investigating these effects has yielded basic knowledge on the structure of atoms.

In the experiment, a cylindrical glass tube is connected to a vacuum pump and slowly evacuated. A high voltage is applied to the electrodes at the front. At standard pressure no discharge occurs. Only at a certain reduced pressure a current begin to flow accompanied by glow light. If the pressure is further reduced, several phases can be observed: first a streamer extends from the anode to the cathode. Then almost the entire space is filled with a luminous column. A surface glow covers the cathode. The column becomes shorter and shorter and disintegrates into several layers whereas the surface glow grows. The layering of the luminous zone comes about because the electrons which excite atoms by collision have to cover an accelerating gap after each collisional excitation in order to acquire the energy needed for another excitation. The distance between the layers thus is a visible measure of the free path.

Fig. 1 Luminous effects of spontaneous gas discharge at reduced pressure

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Apparatus

1 discharge tube, open	554 16
1 rotary-vane vacuum pump, D 2.5 E . . .	378 752
1 small flange DN 10 KF with male ground joint NS 19/39	378 023
1 cross	378 015
4 centring rings DN 16 KF	378 045
4 clamping rings	378 050
1 variable leak valve	378 776
1 ball valve with two flanges DN 16 KF . .	378 777
1 vacuum meter THERMOVAC TM 21 . . .	378 500
1 gauge tube TR 211	378 501
1 gauge head cable, 3 m	378 502
1 high-vacuum grease P, 50 g	378 701
1 high-voltage power supply, 10 kV	521 70
2 high-voltage cables	501 05
additionally recommended:	
1 exhaust filter AF 1.8	378 764

Setup

The experimental setup is illustrated in Fig. 2.

– If possible, operate the rotary-vane vacuum pump with an exhaust filter.
– Attach the ball valve with two flanges **(a)** to the inlet manifold of the rotary-vane vacuum pump and connect the cross over that.
– Mount the variable leak valve **(b)** and the gauge tube **(c)** on the sides of the cross.
– Evenly lubricate the ground socket of the discharge tube with a thin layer of high-vacuum grease. Press the discharge tube on the male ground joint **(d)** without wedging or using force, and connect the male ground joint to the cross.
– Check the setup of the vacuum components, and close the clamping rings carefully.
– Connect the gauge tube to the vacuum meter THERMOVAC.
– Connect the electrodes of the discharge tube with high-voltage cables to the right 5-kV output (I < 2 mA) of the high-voltage power supply.

Carrying out the experiment

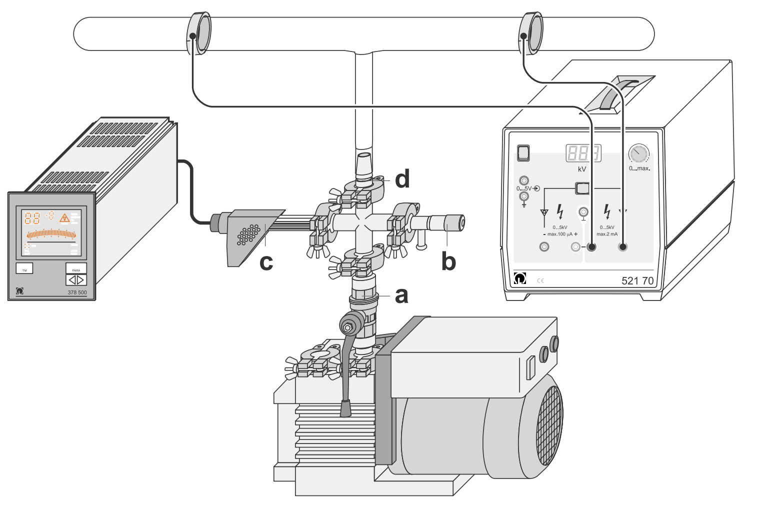
Remark: for best possible observation of the luminous effects, the experiment should be carried out in a completely darkened room.

– Switch the high-voltage power supply on, and set the output voltage to U = 5 kV.
– Switch the vacuum meter THERMOVAC on.
– Open the variable leak valve completely, the ball valve partly, and switch the rotary-vane vacuum pump on.
– Close the variable leak valve gradually and cautiously so that that pressure in the discharge tube is reduced more and more.
– Observe the discharge process while the pressure decreases. Describe the luminous effects, and write your observations down together with the pressure p and the high voltage U in each case. For this purpose it is advisable to keep the pressure constant by cautiously controlling the variable leak valve for a sufficient time period of observation when a luminous effect characteristic of gas discharge is visible.
– To achieve the ultimate vacuum, open the ball valve completely, and close the variable leak valve.

Measuring example

Diagrams of the processes in the discharge tube and of the voltage in dependence on the pressure (see Figs. 3a-i).

Fig. 2 Experimental setup for investigating spontaneous gas discharge in air as a function of pressure



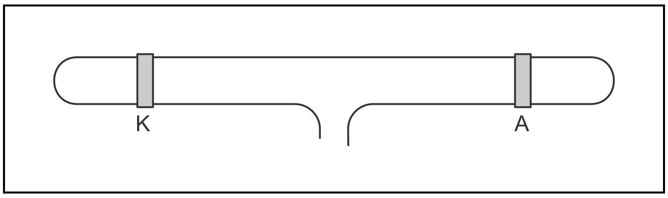


Fig. 3a *p* = 1013 mbar: no discharge occurs (*U* = 5.0 kV)

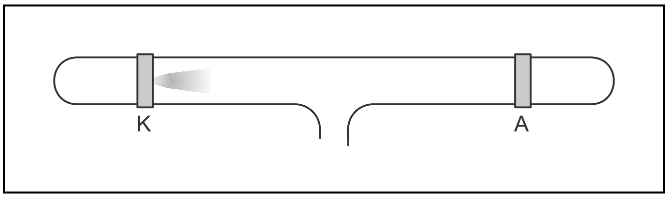


Fig. 3b *p* = 40 mbar: small luminous cone in front of the cathode (blue-red streamer from the cathode to the anode, *U* = 2.6 kV)

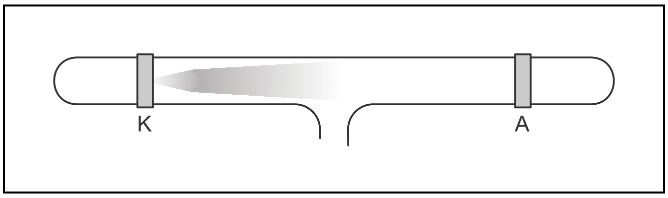


Fig. 3c *p* = 7 mbar: the streamer becomes thicker (positive column), small luminous spot at the cathode, small dark space in front of the cathode (*U* = 1.1 kV)

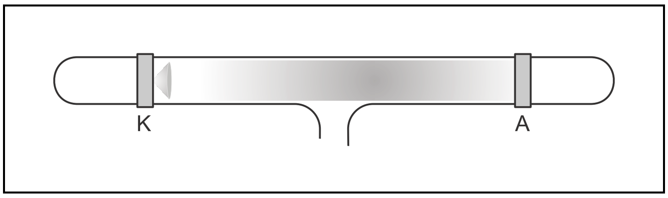


Fig. 3d *p* = 0.8 mbar: the whole cathode is covered with a luminous layer; dark space between cathode and the positive column widens (*U* = 0.8 kV)

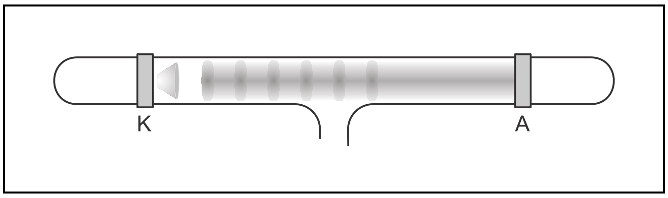


Fig. 3e *p* = 0.35 mbar: positive column loses colour, and bright and dark zones emerge (*U* = 0.6 kV)

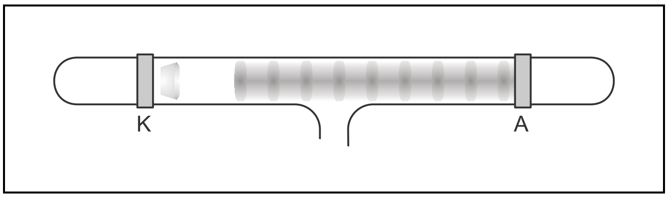


Fig. 3f *p* = *0.2* mbar: diffuse light at the cathode, large dark space, positive column: distance between layers increases (*U* = 0.7 kV)

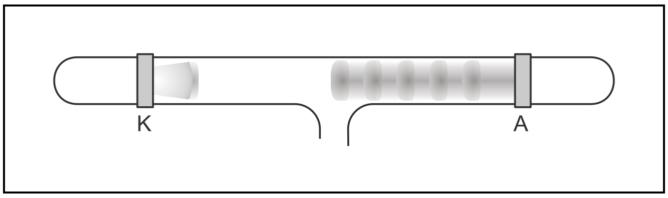


Fig. 3g *p* = 0.1 mbar: dark space widens; layers in the positive column become mushroom shaped (*U* = 0.8 kV)

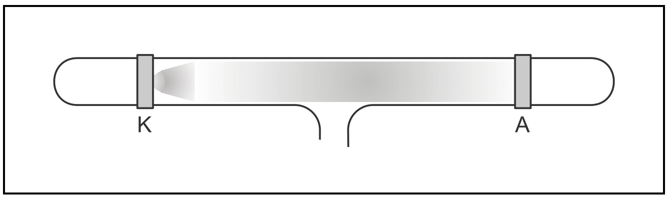


Fig. 3h *p* = 0.06 mbar: glow light in front of the cathode expands, and the positive column disappears (*U* = 1.8 kV)

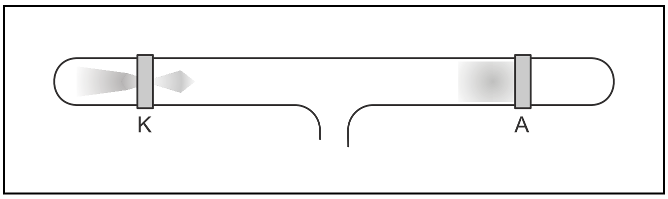


Fig. 3i *p* = 0.035 mbar: glow light in front of the cathode disappears; in front of the anode fluorescence arises, and behind the cathode there is a luminous effect (*U* = 5.0 kV)

Evaluation and results

At standard pressure, there are, apart from uncharged molecules, some negative and positive ions in the discharge tube – produced, e. g., by cosmic radiation – which, according to their charge, migrate to the anode or the cathode if an electric field is applied. However, no discharge occurs. As practically no current flows through the discharge tube, the high voltage reaches the set value.

By reducing the gas pressure, the free path of the ions is increased. If the field is sufficiently strong, the velocities acquired by the ions are so high that positive ions knock out electrons from the cathode. These electrons migrate to the anode and, on their way, ionize neutral molecules (impact ionization).

If the pressure in the discharge tube decreases, a blue-red luminescent “current thread” appears for some time and passes into a luminescent effect filling the whole space if the tube is further evacuated (positive column). The voltage breaks down since the current exceeds the power of the high-voltage power supply.

If the pressure continues decreasing, the luminescent effect disintegrates into layers with the shape of discs or mushrooms respectively. The distance between these layers increases. The luminescent effect itself becomes weaker.

In front of the cathode, a dark space appears. On the cathode a blue light spot arises.

Eventually this luminescent effect disappears. The glass surface begins to fluoresce. Behind the anode a green fluorescent spot is seen which is caused by the cathode rays. At the other end of the tube, behind the cathode, canal rays are observed (positive gas ions).

While the luminescent effect in the tube disappears, the voltage gradually assumes its initial value since the current through the discharge tube decreases.

The electrons acquire the kinetic energy necessary for impact ionization by passing a certain path length (up to the dark space) in the electric field.

Impact ionization causes the molecules to light up.

The surface glow directly on the cathode is caused by positive ions impinging on the surface.

In the positive column, positive as well as negative ions move at high velocities into different directions. This gives rise to new excitations, but hardly to recombination.

If the positive column is made up of layers, the energy of the electrons in such a layer is sufficient for impact ionization. The energy loss has to be compensated by another acceleration before the next luminescent layer can be formed.

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