Electricity

Free charge carriers in a vacuum
Tube diode

Recording the characteristic of a tube diode

Objects of the experiments

- Recording the characteristics of a tube diode at three different cathode heating voltages.
- Identifying the space-charge limited region and the saturation region.
- Verifying the Child-Langmuir equation.

Principles

A tube diode consists of a hermetically sealed, evacuated glass bulb containing two electrodes: a thermionic cathode that emits electrons and an anode (see Fig. 1). If a suitable voltage is applied between the cathode and the anode, then there will be an electric current between the two poles.

The cathode is a filament which is made to glow by an electric voltage. The hot filament emits electrons (thermionic emission). If the anode potential is positive with respect to the anode potential, then the electrons are accelerated towards the anode, where they are absorbed („anode current"). The magnitude of the anode current depends, among other things, on the voltage between the anode and the cathode („anode voltage"). If the polarity of the anode voltage is reversed, then there can be no current because the electrons escaping from the cathode cannot run against the field directed in the opposite direction. A tube diode, therefore, can be used as a block filter or as a rectifier for alternating currents (cf. experiment P3.8.1.2).

So, in principle, a tube diode has the same properties as a semiconductor diode. With the increasing development of semiconductor diodes, tube diodes lost more and more of their importance. Today, in integrated circuits mainly semiconductor devices are used because they require less space.

In this experiment, the characteristic of a tube diode is to be recorded. The characteristic describes the dependence of the anode current I_A on the anode voltage U_A. In Fig. 2, the typical shape of a diode characteristic is shown.

Fig. 1 Diagram of the diode P
1 pin socket
2 cathode plate
3 cathode filament
4 anode
5 anode connecting lead

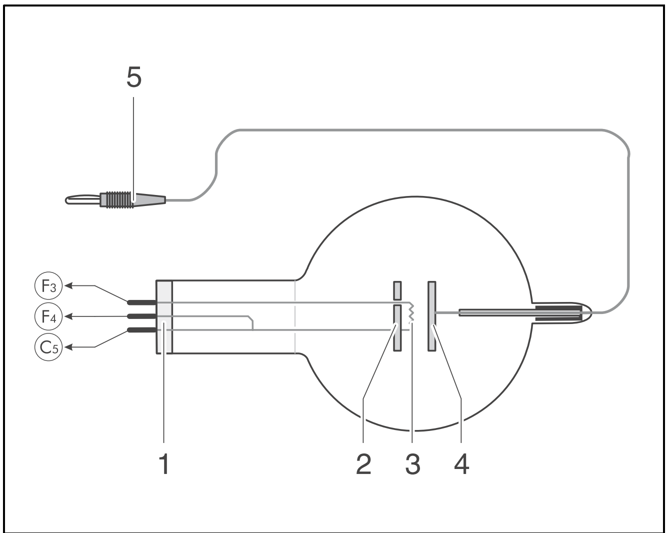
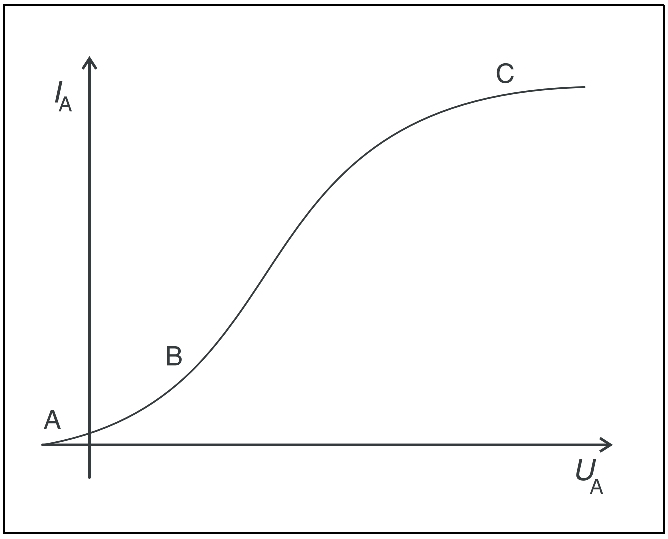


Fig. 2 Typical shape of a diode characteristic with the reverse-bias region (A), the space-charge restricted region (B), and the saturation region (C)



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Apparatus

1 planar diode P		555 210
1 universal stand P		555 200
1 DC power supply 0 … 500 V		521 65
1 amperemeter, AC, $I \leq 10$ mA	for example	531 100
1 voltmeter, DC, U $\leq$ 500 V	for example	531 711
1distribution box		502 04
3 safety connection leads, 100 cm, red		500 641
2 safety connection leads, 100 cm, blue		500 642
1 safety connection lead, 50 cm, blue		500 622
1 connecting lead, yellow/green, 200 cm		501 43

Three regions are distinguished:

Reverse-bias region (A):

The anode potential is negative with respect to the cathode potential. The electrons cannot run against the electric field.

Since the electrons escape from the cathode with a kinetic energy $E_{kin} > 0$, there is nevertheless an anode current until the anode voltage is high enough to stop even the fastest electrons.

Space-charge restricted region (B):

At small field strengths, not all electrons that have escaped from the cathode can be carried away. They gather around the cathode like a cloud to form a negative space charge. Therefore, at low voltages, the field lines starting at the anode do not end at the cathode but at the electrons of the space charge. The electric field stemming from the anode is thus shielded. Only when the voltage increases do the field lines reach deeper and deeper into the sphere around the cathode, and the anode current rises. The dependence of the anode current on the cathode voltage is described by the Child-Langmuir equation stating that:

$I_A \propto U_A{}^{3/2}$

or

$I_A{}^{2/3} \propto U_A(I)$.

Safety notes

The tube of the diode P is a thin-walled, evacuated glass bulb. There is danger of implosion! When the tube is in operation, contact-hazardous voltages can be present at the connection field of the universal stand P!

- Do not subject the tube to mechanical stresses.
- Use only safety connection leads at the connection field of the universal stand P.
- Observe the notes contained in the instruction sheet of the diode P (555 210) and of the universal stand P (555 200).

The current increases until the space charge around the cathode is dissipated. Then the anode current has reached its saturation value. A further rise in the anode voltage has no longer any influence on the anode current.

Saturation region (C):

In the saturation region, the emission current is independent of the anode voltage. However, it can be increased by enlarging the number of electrons escaping from the cathode. This can be achieved by an enhancement of the heating voltage. The magnitude of the saturation current thus depends on the temperature of the cathode, and a characteristic of its own corresponds to every heating voltage.

Setup

The experimental setup is illustrated in Fig. 3. The setup is accomplished by the following steps:

– To insert the diode P into the universal stand P, properly position the glass pins and then gently press the tube until all pin contacts are securely seated in their sockets.
– Connect the power supply to the mains via the distribution box.
– Connect the negative poles of the heating voltage output **(a)** and the 500-V output **(b)** at the power supply with a safety connection lead and, in addition, connect them to the ground socket of the distribution box.
– Use safety connection leads to connect the negative pole of the heating voltage output to the socket F4 of the universal stand P and the positive pole to the socket F3.
– In order to measure the anode current I_A, plug the anode connecting lead into the minus socket of the amperemeter, and connect the plus socket of the amperemeter to the positive pole of the 500-V output.
– In order to measure the anode voltage U_A, connect the voltmeter to the 500-V output.
– Choose appropriate measuring ranges (for example, mA at the amperemeter and 500 V at the voltmeter).
– Switch on the power supply and the amperemeter.

The filament of the diode P should immediately be red-hot.

– If necessary, exercise caution and turn the tube to check whether the contact between the universal stand P and the diode P is all right.

Carrying out the experiment

Note:

After the heating voltage has been adjusted or changed, the filament reaches its new temperature within a few seconds. So you can start the measurement immediately after adjusting the heating voltage.

– Set the heating voltage to 5.0 V with the rotary potentiometer **(a)**.
– Starting from 0 V, increase the anode voltage U_A successively with the rotary potentiometer **(b)**, and read the anode current I_A at several voltages (cf. Measuring example).
– Repeat the measurements at the heating voltages 5.5 V and 6.0 V.

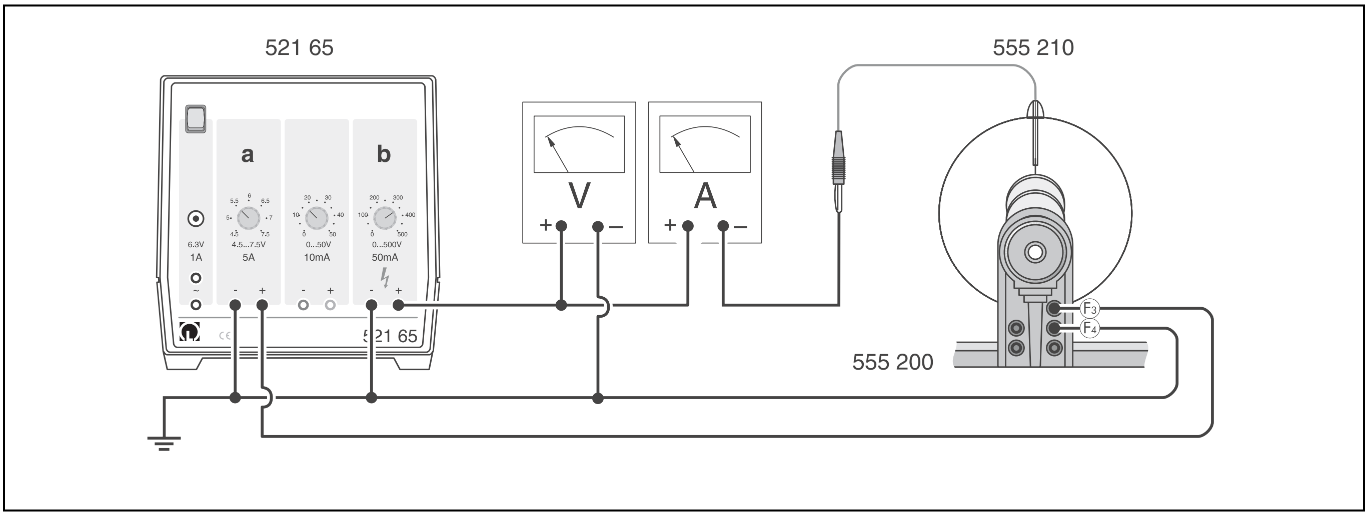

Fig. 3 Experimental setup for recording a diode characteristic

Measuring example

Table 1: The anode current I_A as a function of the anode voltage U_A at three different heating voltages U_1, U_2, U_3

$\frac{U_A}{V}$	$U_1 = 5.0$ V $\frac{I_A}{\text{mA}}$	$U_2 = 5.5$ V $\frac{I_A}{\text{mA}}$	$U_3 = 6.0$ V $\frac{I_A}{\text{A}}$
6	0.03	0.06	0.06
10	0.045	0.115	0.15
16	0.0515	0.21	0.29
20	0.052	0.22	0.40
26	0.053	0.28	0.555
30	0.053	0.28	0.65
36	0.054	0.28	0.76
40	0.055	0.29	0.83
46	0.055	0.29	0.94
50	0.0555	0.29	0.97
56	0.056	0.29	1.12
60	0.056	0.29	1.15
70	0.056	0.29	1.15
80	0.057	0.29	1.15
90	0.058	0.29	1.15
100	0.058	0.29	1.15
110	0.058	0.29	1.2

Evaluation and results

In Fig. 4, the anode current I_A is plotted against the anode voltage U_A at three different heating voltages. The space-charge restricted region B and the saturation region C are clearly discernible. A higher heating voltage leads to a higher saturation current. This demonstrates the fact that the saturation current depends on the number of electrons escaping from the cathode.

In order to verify the Child-Langmuir equation, $I_A^{2/3}$ is plotted against the anode voltage U_A in Fig. 5. The linear relation which is to be expected according to Eq. (I) is clearly seen and the validity of the law is confirmed.

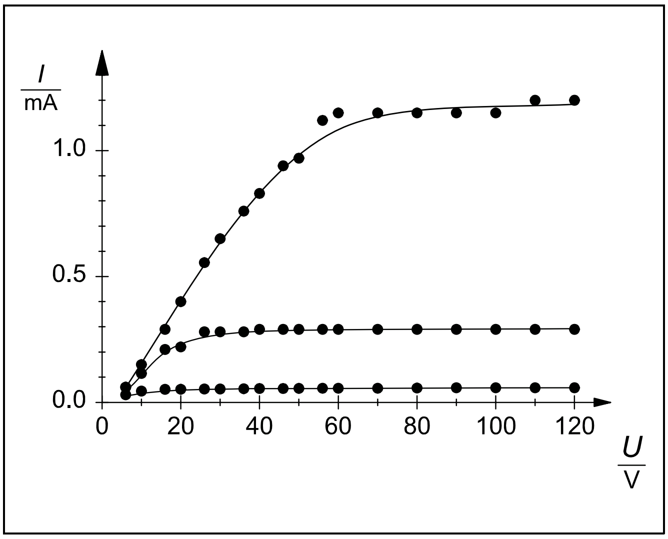

Fig. 4 Diode characteristic at different heating voltages U_1, U_2, U_3. The anode current I_A is plotted against the anode voltage U_A.

Fig. 5 Space-charge restricted region: $I_A^{2/3}$ as a function of U_A. According to the Child-Langmuir equation a straight line is the result.