PHYSICS EXPERIMENT

Thermionic diode

RECORD THE CHARACTERISTIC FOR A THERMIONIC DIODE

- Record the characteristic of a thermionic diode at three different cathode heater voltages
- Identify the space charge and saturation regions
- Confirm the *Child-Langmuir* law

UE3070100

02/17 UK

BASIC PRINCIPLES

A thermionic diode is an evacuated glass bulb that contains two electrodes, a heated cathode that emits electrons due to the thermoelectric effect, and an anode (see Fig. 1). A positive voltage between cathode and anode causes a current flow due to electrons emitted from the cathode being drawn towards the anode. If the voltage is low, the anode current is prevented from flowing, since the charge of the emitted electrons around the cathode, the space charge, shields the cathode from the electric field around it. As the anode voltage rises, the field lines penetrate more deeply into the space around the cathode and the anode current increases. It continues to rise until the space around the cathode is fully discharged. As a result, the anode current reaches saturation level. If the voltage on the anode is sufficiently negative, however, electrons cannot get to the anode at all. The anode current is zero in this case.

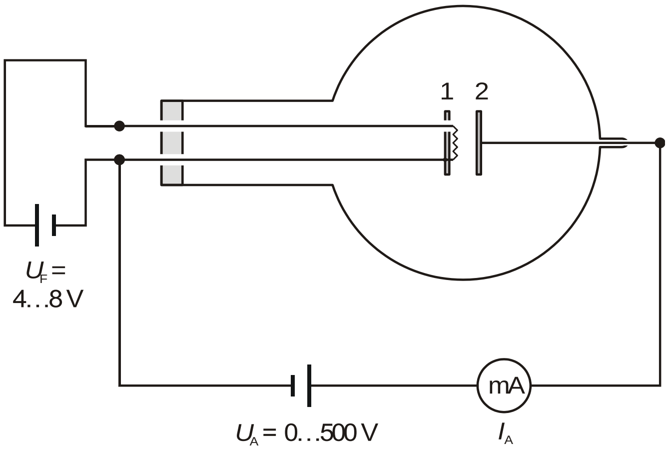

Fig. 1: Circuit (above) and experiment set-up (below) for recording the characteristic of a thermionic diode for different cathode heater voltages (1) Cathode, (2) Anode

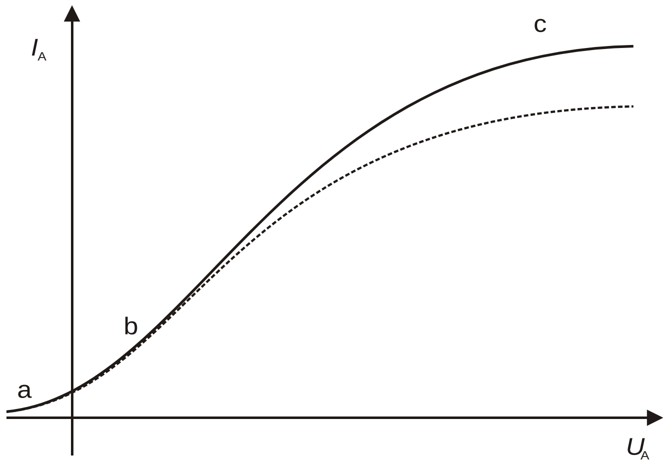

Fig. 2: Characteristic of a thermionic diode
(a) Reverse bias region, (b) Space charge region, (c) Saturation region

The relationship between the anode current I_A and the anode voltage U_A is called the characteristic of the diode (see Fig. 2). A distinction is made between the reverse-bias region, the region where current begins to flow, the space charge region, and the saturation region.

In the reverse-bias region, the anode is at a negative voltage with respect to the cathode. Therefore anode current cannot flow, as the electrons are unable to move against the electric field.

If the anode current is negative but its magnitude is less than 1 V, some of the fast moving electrons can reach the anode in spite of the reverse voltage. The relationship between the anode current I_A and the anode voltage U_A can be represented by an exponential curve.

In the space charge region, the anode voltage is positive and is distinctly below 100 V. The relationship between the anode current I_A and the anode voltage U_A is described by the *Child-Langmuir* law.

$$I_A \sim U_A^{\frac{3}{2}} \text{ or } I_A^{\frac{2}{3}} \sim U_A \qquad (1)$$

In the saturation region, the anode current depends on the temperature of the cathode. By increasing the heater voltage U_F, the anode current can be made to increase.

LIST OF APPARATUS

1 Diode S	1000613 (U185501)
1 Tube holder S	1014525 (U185001)
1 DC power supply 0–500 V @230 V	1003308 (U33000-230)
or	
1 DC power supply 0–500 V @115 V	1003308 (U33000-115)
1 Analogue Multimeter Escola 100	1013527 (U8557380)
1 Set of 15 safety leads	1002843 (U138021)

SAFETY INSTRUCTIONS

Thermionic diodes are thin-walled, glass bulbs. Handle with care: danger of implosion!

- Do not expose the diode to any mechanical strains.
- Do not expose the connecting lead of the anode to any tension.

Extreme care must be observed when operating the diode with the 500-V DC power supply unit, as voltages that are dangerous for the body to come into contact with can be present in the region of the connections.

- For all connections, only use safety leads provided for the experiment.
- When making connections, make sure that the power supply unit is switched off at all times.
- When inserting and removing the diode, make sure that the power supply unit is switched off at all times.

The neck of the bulb gets hot during operation. Therefore:

- Allow the diode to cool before removing it.

SET-UP

Note: Switch off the 500-V DC power supply unit (make sure the toggle switch is at the “0” position), turn all adjustment buttons completely to the left and connect the apparatus to the power supply unit only after all connections have been made!

Introducing the diode:

- Insert the diode into the diode holder. While doing so, make sure that the contact pins of the diode fit perfectly into the contact openings of the holder which are provided for this purpose. Note that the middle guide pin of the diode should jut out of the holder slightly.

Connecting the heater voltage:

- Using the safety connecting leads, connect the sockets F3 and F4 of the diode holder to the heater voltage output (4-8 V) of the 500-V DC power supply unit.

Accelerating voltage/anode current:

- Using the safety connecting leads, connect the socket C5 of the diode holder to the negative terminal (black socket) of the 0-500V output of the 500-V DC power supply unit. (The connections C5 and F4 are connected to one another within the diode.)
- Using the safety connecting leads, connect the positive terminal (red socket) wit the positive input of the DC ammeter.
- Connect the anode lead (red lead on the glass bulb of the diode) with the negative output of the DC ammeter.

EXPERIMENT PROCEDURE

- Connect the 500-V DC power supply unit to the mains supply and switch it on (set the toggle switch to the “1” position).
- Set the heater voltage to U_F = 6 V and wait for approximately 1 minute till the final temperature has been attained.
- Starting with 0 V, increase the anode voltage U_A in steps of 20 V till it has reached 100 V. Subsequently increase U_A in steps of 50V till it has reached 450 V. In each case, measure the anode current I_A.
- Take further sets of readings for U_F = 6.3 V and 6.6 V.
- Plot the measurement points of all three sets of measurements onto a common I_A-U_A graph.

SAMPLE MEASUREMENTS

Table 1: Anode current I_A as a function of the anode voltage U_A for three different heater voltages U_F

	U_F = 6.0 V	U_F = 6.3 V	U_F = 6.6 V
U_A / V	I_A / mA	I_A / mA	I_A / mA
0	0.04	0.06	0.08
20	0.55	0.59	0.71
40	1.28	1.42	1.59
60	1.62	2.18	2.54
80	1.79	2.50	3.41
100	1.80	2.61	3.95
150	1.85	2.75	4.58
200	1.90	2.79	4.70
250	1.90	2.82	4.78
300	1.94	2.88	4.82
350	1.97	2.90	4.86
400	1.98	2.95	4.90
450	1.98	2.97	4.98

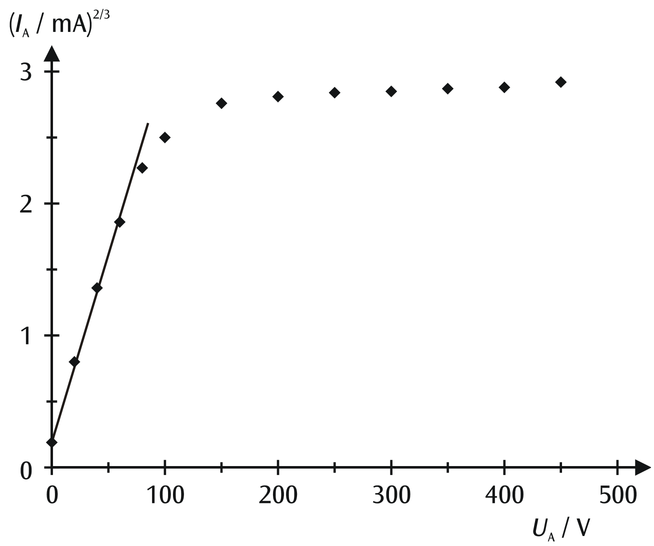

Fig. 4: Representation of $I_A^{\frac{2}{3}}$ as a function of U_A. for U_F = 6.6V.
According to the Child-Langmuir Law, the curve displays a linear characteristic in the space charge region.

The graph in Fig. 3 shows the measured values entered in Table 1. The space charge and saturation regions can be distinctly identified. The saturation current increases with rising heater voltage U_F.

The current readings I_A at heater voltage U_F = 6.6 V have been converted into the values $I_A^{\frac{2}{3}}$ in Fig. 4. According to the Child-Langmuir Law, the characteristic of the anode voltage U_A is linear up to a voltage of 50 V.

EVALUATION

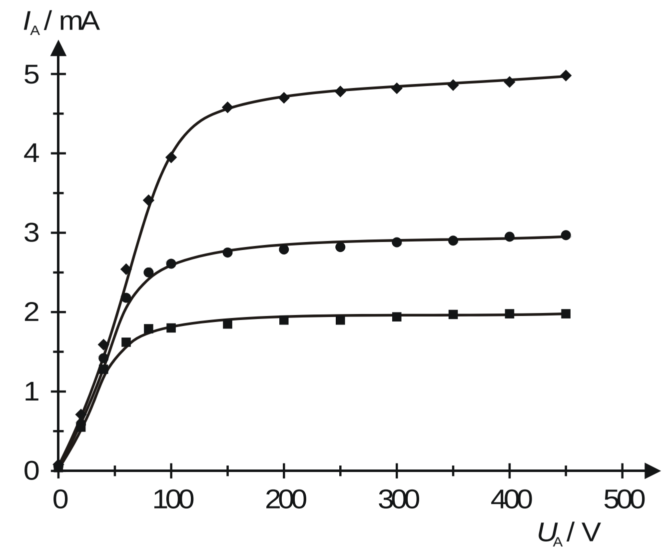

Fig. 3: Curve characteristics of a thermionic diode for the heater voltages U_F = 6.0 V (square), 6.3 V (circle) and 6.6 V (diamond).

RESULTS

Reverse-bias region and initial flow of current: since electrons are emitted from the cathode with a kinetic energy $E_{kin} > 0$, a current flows in the anode only until the voltage of the anode is sufficiently negative that even the fastest of the emitted electrons is unable to overcome the field to reach the anode.

Space charge region: for weak field strengths, not all the electrons emitted from the cathode are conveyed to the anode. They occupy the space around the cathode in a cloud thereby creating a negative space charge. When the voltage is low, field lines from the anode thus reach only as far as the electrons in the cloud and not the cathode itself. The cathode is thus shielded from the field arising from the anode. Only as the voltage increases do the field lines penetrate further into the cathode, causing the anode current to rise. The increase continues until the space charge around the cathode is dissipated, at which point the anode current is saturated.

Saturation region: in the saturation region, the anode current does not depend on the anode voltage at all. It can nevertheless be increased by increasing the number of electrons emitted from the cathode per unit time. This can be achieved by raising the temperature of the cathode. The saturation current therefore depends on the heater voltage.