Discontinuous energy emission of electrons in a gas-filled triode

Experiment objectives

- Set up a simple Franck-Hertz arrangement
- Measure the discontinuous transfer of energy in inelastic collisions between free electrons
- Interpret the measurement results as discrete energy absorption by helium atoms

Principles

Inelastic collisions between electrons and atoms result in the kinetic energy of the electron being converted into excitation or ionisation energy in the atom. Such collisions are most likely to occur when the kinetic energy closely matches the energy needed for excitation or ionisation. Since the levels of excitation in atoms are always discrete, when energy is transferred in an inelastic collision, that energy transfer is discontinuous.

To prove the discontinuous nature of energy transfer, this experiment uses a triode valve tube filled with helium, set up in a simplified Franck-Hertz arrangement. Having been accelerated by an electric field between the cathode and the grid, electrons move into a decelerating field between the grid and the anode. They can only reach the anode to contribute to the current I_A between the anode and ground if they have sufficient kinetic energy. If the electrons have gained sufficient energy before reaching the grid, they can then excite gas atoms by means of inelastic collisions.

As the accelerating voltage U is continuously increased, inelastic collisions initially occur directly in front of the grid, as that is where the kinetic energy is at its highest. After collision, the electrons can no longer combat the decelerating field. The anode current I_A therefore decreases sharply. As the accelerating voltage U increases further, the zone where excitation occurs, moves closer to the cathode, the electrons can gain more energy on their way to the grid and the current I_A rises again. Eventually the electrons are able to excite gas atoms a second time and the anode current drops again..

This experiment measures the anode current I_A as a function of the accelerating voltage between the cathode and the grid. The heater voltage at the cathode and the decelerating voltage between the grid and the anode are kept constant. The intervals between maxima are then determined and compared to quoted values.

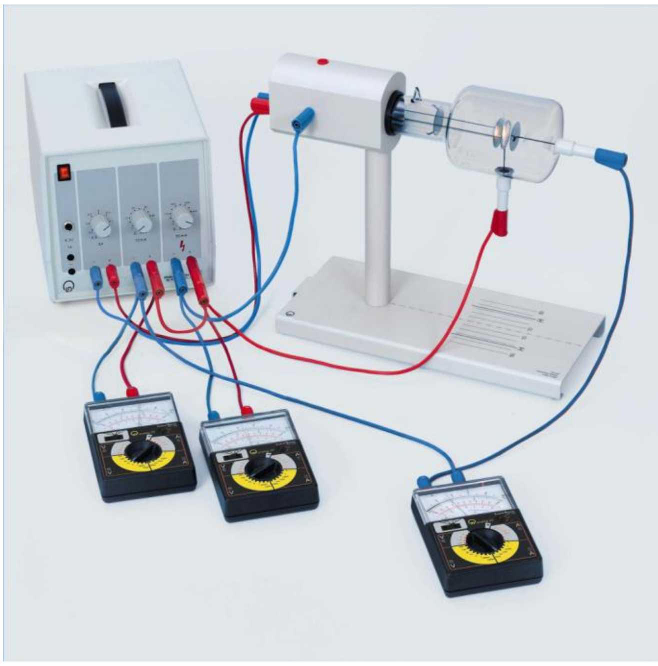

Fig. 1: Experiment set-up

Equipment

1 Gas triode	555 614
1 Tube stand	555 600
1 Tube power supply, 0...500 V	521 65
3 LDanalog 20 multimeters	531 120
1 Safety lead, 50 cm, red	500 621
4 Safety leads, 100 cm, red	500 641
6 Safety leads, 100 cm, blue	500 642

CS 2013-08

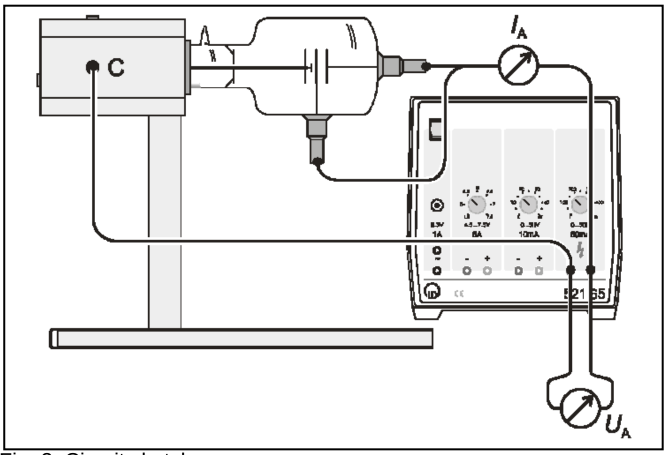

Fig. 2: Circuit sketch

Safety instructions

A gas triode is a thin-walled, evacuated glass tube. There is a risk of implosion.

- Do not put the tubes under mechanical stress.

When a gas triode is in operation, there may be situations when voltages are present with which it is dangerous to come into physical contact:

- Only use safety leads for connecting the tubes.
- Connect leads only if the power supply is switched off.

Please observe the instructions for the gas triode (555 614) and the tube stand (555 600).

Set-up

A sketch of the experiment set-up is shown in Fig. 2. In order to set up the experiment, the following steps need to be taken:

- Carefully insert the gas triode into the tube stand.
- Connect the inputs for the heating voltage, F_1 and F_2 on the tube stand, to the heater voltage output (4.5...7.5 V).
- The negative pole of the 500-V output should be connected to the cathode terminal C on the tube stand.
- Connect the positive pole of the 500-V output to the grid terminal of the gas triode.
- Connect the grid In order to measure anode current I_A, connect the anode terminal of the gas triode to the negative socket of the ammeter (531 120), with the positive ammeter socket being connected to positive of the 50-V output.
- Connect the positive pole of the 50-V output to the positive of the 500-V output.
- To measure the accelerating voltage U_1, connect a voltmeter (531 130) across the 500-V output.
- To measure the decelerating voltage U_2, connect a voltmeter (531 120) across the 50-V output.
- Turn on the tube power supply.

Procedure

- Set up the heater voltage U_H = 5 V.
- Set up the decelerating voltage U_2 = 10 V.
- Use the potentiometer knob for the 500-V output to increase the accelerating voltage U_1 in steps and read the anode current from the ammeter

Note:

The optimum value for the heater voltage may differ slightly from one tube to another. A good example of a measurement curve is shown in Fig. 3. If your curve is flatter than this, and in particular if the first maximum is not very prominent, you should increase the heater voltage in steps of 0.1 V until the best curve is achieved. If the first maximum is too prominent and U_1 is shifted to higher values, you should decrease the heater voltage in steps of 0.1 V until the best curve is achieved.

Measurement example and conclusions

$\frac{U_A}{V}$	$\frac{I_A}{mA}$	$\frac{U_A}{V}$	$\frac{I_A}{mA}$
0	0	40	64
5	0	42	66
10	0	44	66
15	37	46	65
20	48	48	64
25	79	50	62
30	100	60	53
32	80	70	49
34	68	80	44
36	62	90	36
38	62	94	14

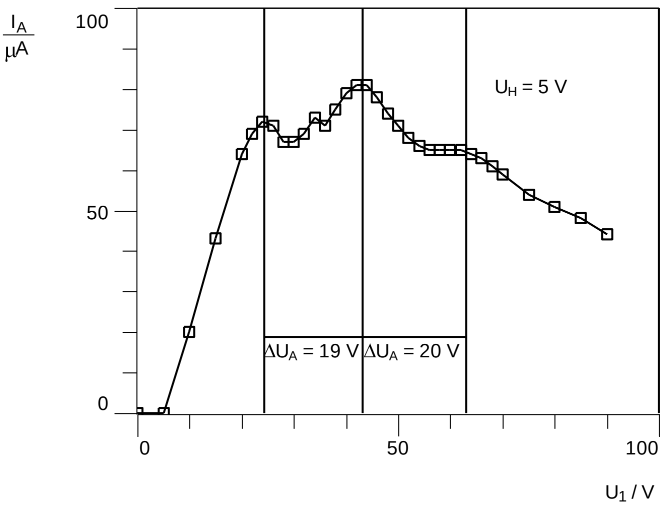

Fig. 3: Current-voltage characteristic

Results

For accelerating voltages up to 10 V it is not possible to measure any current. Since the decelerating grid voltage is 10 V, any accelerating voltage less than this leaves the electrons with too little energy to overcome the grid voltage.

As the accelerating voltage increases, the anode current initially rises. In this case, the collisions between electrons and helium atoms are elastic.

The sudden drop in the current at an accelerating voltage U_1 = 24 indicates that the electron energy is sufficient to initiate inelastic collisions with helium atoms. At each collision, the electrons lose energy to an extent that they can no longer overcome the decelerating voltage. The excited helium atoms then emit energy, partially in the form of photon emission, perceptible as a green glow between the cathode and the grid.

As the accelerating voltage is increased further, other maxima in the anode current appear at U_1 = 43 V and U_1 = 63 V. The differences in voltage between these maxima are in the region of 19 V or. 20 V. This corresponds to the excitation of helium atoms from their ground state to the first excited singlet state

Notes

The maxima and minima in the spectrum are relatively broad. As the electrons are produced by means of a heated filament, their energy distribution is relatively expansive and this is the cause of the observed broadening.

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