Atomic and Nuclear Physics

Atomic Shells

PHYSICS EXPERIMENT

Critical Potentials

DETERMINE THE CRITICAL POTENTIALS OF A HELIUM ATOM.

- Measure the collector current I_R as a function of the accelerating voltage U_A.
- Compare the positions of the current maxima with the known critical potentials of the helium atom.
- Identify the doublet structure in the term scheme of helium (ortho and para helium).

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BASIC PRINCIPLES

The expression “critical potential” is a general name for all the excitation and ionisation energies in the electron shells of an atom. The corresponding electronic states of the atom can be excited in various ways, for example by inelastic collisions with electrons. If the kinetic energy of the electron corresponds exactly to a critical potential, the electron can transfer all its kinetic energy to the atom in an inelastic collision. Using an experiment set-up originally designed by Gustav Hertz, this effect can be used to determine the critical potentials.

In a tube that has been evacuated and then filled with helium, free electrons are accelerated by a voltage U_A to form a divergent beam passing through a space at a constant potential. To prevent the walls of the tube becoming charged, the inner surface is coated with a conducting material and connected to the anode A (see Fig. 1). In the tube there is a ring-shaped collector electrode R, through which the divergent beam can pass without touching it, even though the ring is at a slightly higher potential.

However, a small current I_R, with a value in the order of picoamperes, is measured at the collector ring, and is found to depend on the accelerating voltage U_A. It shows characteristic maxima, which are caused by the fact that the electrons can undergo inelastic collisions with helium atoms during their passage through the tube. The kinetic energy E of an electron is as follows:

(1) $E = e \cdot U_A$

e: elementary electron charge

If this energy corresponds exactly to a critical potential of the helium atom, all the kinetic energy may be transferred to the helium atom. In this instance the electron can then be attracted and collected by the collector ring, thus contributing to an increased collector current I_R.

As the accelerating voltage is increased, successively higher levels of the helium atom can be excited (see the term scheme of the helium atom shown in Fig. 2), until finally the kinetic energy of the electron is enough to ionise the helium atom. As the accelerating voltage is increased further, the collector current shows a steady increase.

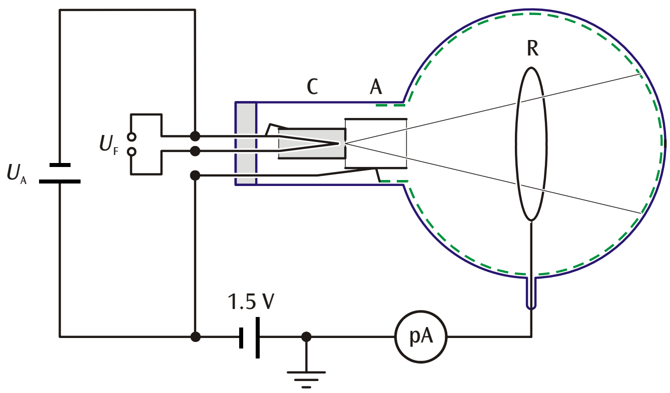

Fig. 1: Schematic diagram of critical potential tube

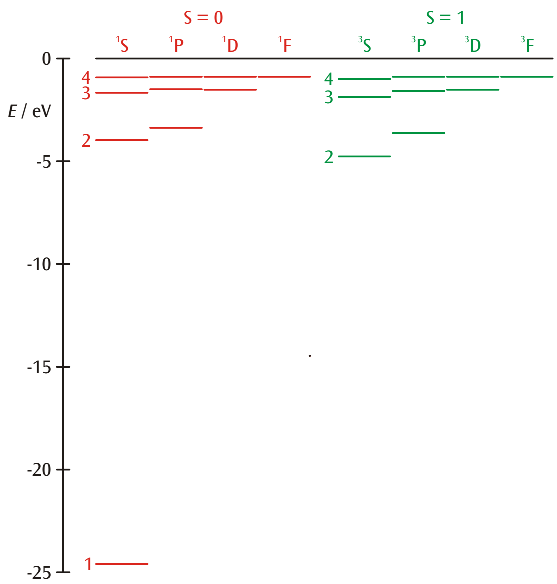

Fig. 2: The term scheme of helium
red: total spin S = 0 (para helium),
green: total spin S = 1 (ortho helium)

LIST OF APPARATUS

1 Critical Potential Tube S with He-Filling 1000620
1 Tube Holder S 1014525
1 Control Unit for Critical Potential Tubes
(115 V or 230 V) 1000633 / 1008506

1 DC Power Supply, 0–20 V, 5 A
(115 V or 230 V) 1003311 / 1003312

1 3B NET*log*™
(115 V or 230 V) 1000539 / 1000540
1 3B NET*lab*™ 1000544

1 Set of 15 Experiment Leads, 75 cm 1 mm² 1002840

1 PC with Windows 98/2000/XP, Internet Explorer 6 or later and USB connection

SAFETY INSTRUCTIONS

Hot cathode tubes are thin-walled, highly evacuated glass tubes. Treat them carefully as there is a risk of implosion!

- Do not subject the tube to mechanical stresses.
- Ensure that the connecting lead to the collector ring is not under any tension and there is no risk of it being accidentally pulled out.

SET-UP

- Fit the critical potential tube into the tube holder, ensuring that the contact pins of the tube are correctly and fully engaged in the tube socket of the holder. The central guide pin of the tube should project slightly at the back of the holder.
- Connect the sockets F3 of the tube holder to the positive terminal of the DC power supply and F4 to the negative terminal.
- Connect socket C5 of the tube holder to the negative terminal of the output V_A on the control unit and to the negative terminal of the DC power supply.
- Connect socket A1 to the positive terminal of the output V_A on the control unit and to the negative terminal of the 1.5 V battery.
- Connect the positive terminal of the 1.5 V battery to an earth socket on the control unit.
- Fit the screening frame over the tube, push its folded edge into the opening in the tube holder and connect it to an earth socket on the control unit.
- Connect the lead from the collector ring to the BNC input socket of the control unit.

EXPERIMENT PROCEDURE

Preparation:

- At the output V_A of the control unit, set the minimum voltage to about 15 V and the maximum voltage to about 28 V, by using the 3B NET*log*™ unit to measure the voltages (smaller by a factor of 1000) between socket 3 and earth and that between socket 4 and earth.
- Connect the 3B NET*log*™ unit to the computer.
- Connect the output “Fast 1” from the control unit to input A of the 3B NET*log*™ unit and the output “Fast 2” to input B.
- Switch on the 3B NET*log*™ unit and start the 3B NET*lab*™ program on the computer.
- Select the “Measurement lab” function and open a new data record.
- Select analogue inputs A and B and DC voltage mode (VDC), setting the measurement ranges to 200 mV for A and 2 V for B.
- Enter the formula I = -667 * “Input_B“ (unit: pA).
- Set the following parameters:
  Measurement interval = 50 µs,
  Measurement duration = 0.05 s
  Mode = Recorder.
- Set triggering on the input A with rising edge (20%).
- On the DC power supply, set the heater voltage to 3.5 V.

Optimising the parameters:

- Start the graph-plotting of the experimental data.
- Set up the graph with “relative time t in s” on the x-axis and the quantity I on the y-axis.
- Repeat the measurements with slightly higher heater voltages and vary the minimum and maximum accelerating voltages U_A to find the optimum graph.

Calibrating the accelerating voltage:

- In the spectrum, identify the 2^3S peak at 19.8 eV and determine its position t_1 on the time axis.
- Identify the ionisation threshold at 24.6 eV and determine its position t_2 on the time axis.
- Enter a new formula for the quantity E defined as $19.8 + 4.8 * (t - t_1)/(t_2 - t_1)$ with the unit eV; in this expression enter the numerical values for t_1 and t_2 in s determined as above.
- Set up a graph with the quantity E on the x-axis and the quantity I on the y-axis.
- Restart the plotting of the experimental data.

SAMPLE MEASUREMENTS AND EVALUATION

Table 1: Literature values of the critical potentials of helium

Term	E / eV
$2\,^3S$	19.8
$2\,^1S$	20.6
$2\,^3P$	21.0
$2\,^1P$	21.2
$3\,^3S$	22.7
$3\,^1S$	22.9
$4\,^1P$	23.7
Ionisation	24.6

- In the plot of the experimental data, identify the critical potentials listed in Table 1 (see Fig. 5).

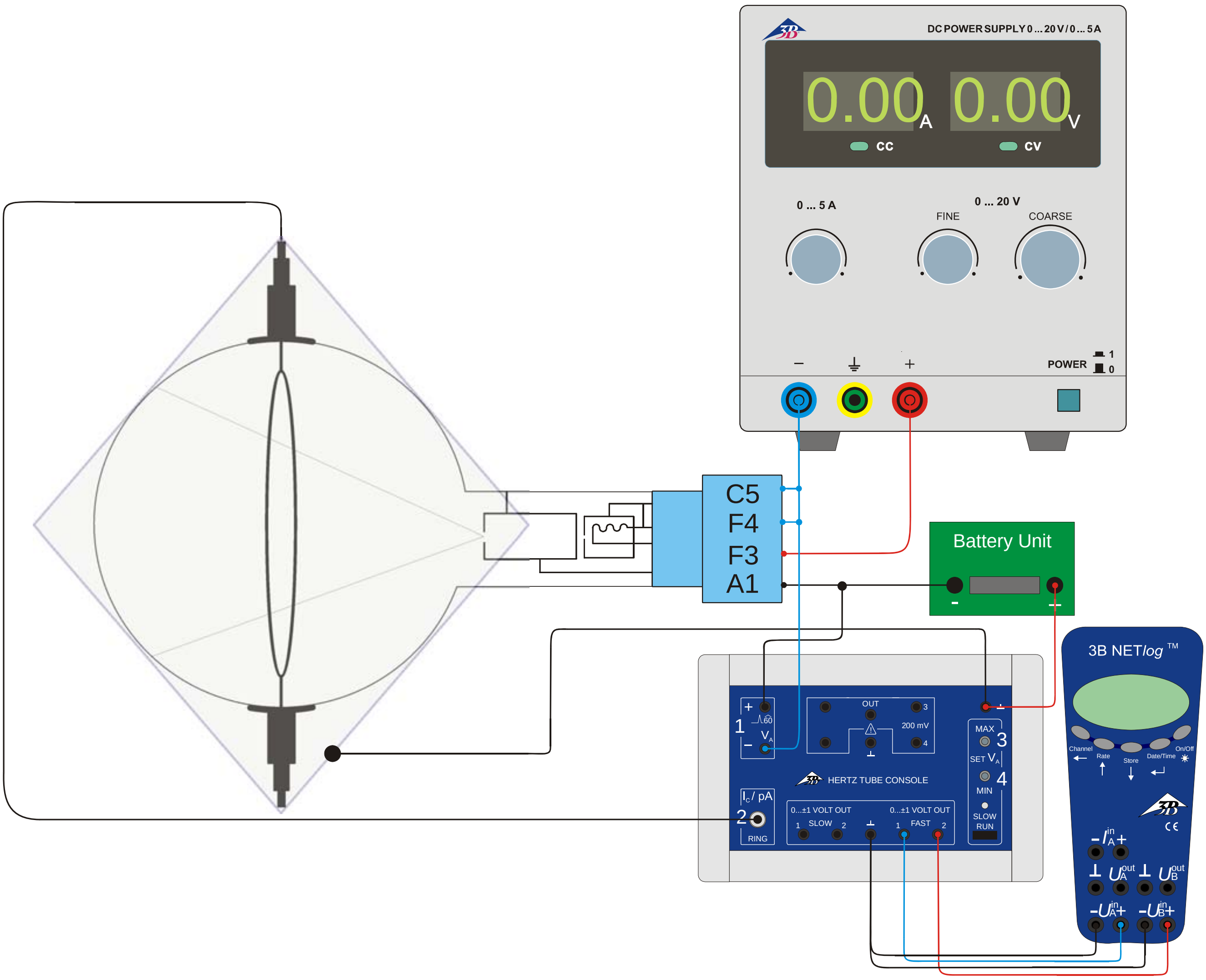

Fig. 3: Experiment set-up for measuring the critical potentials of helium

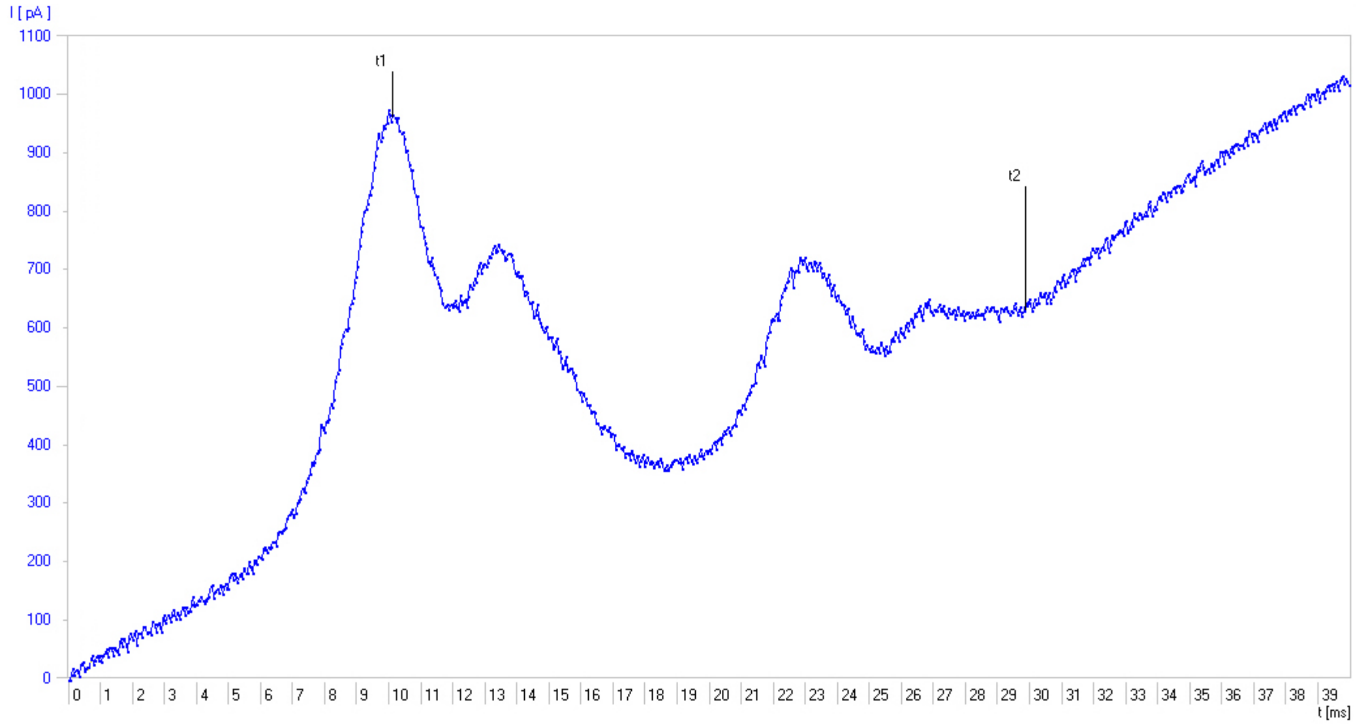

Fig. 4: Collector current I_R as a function of time t.

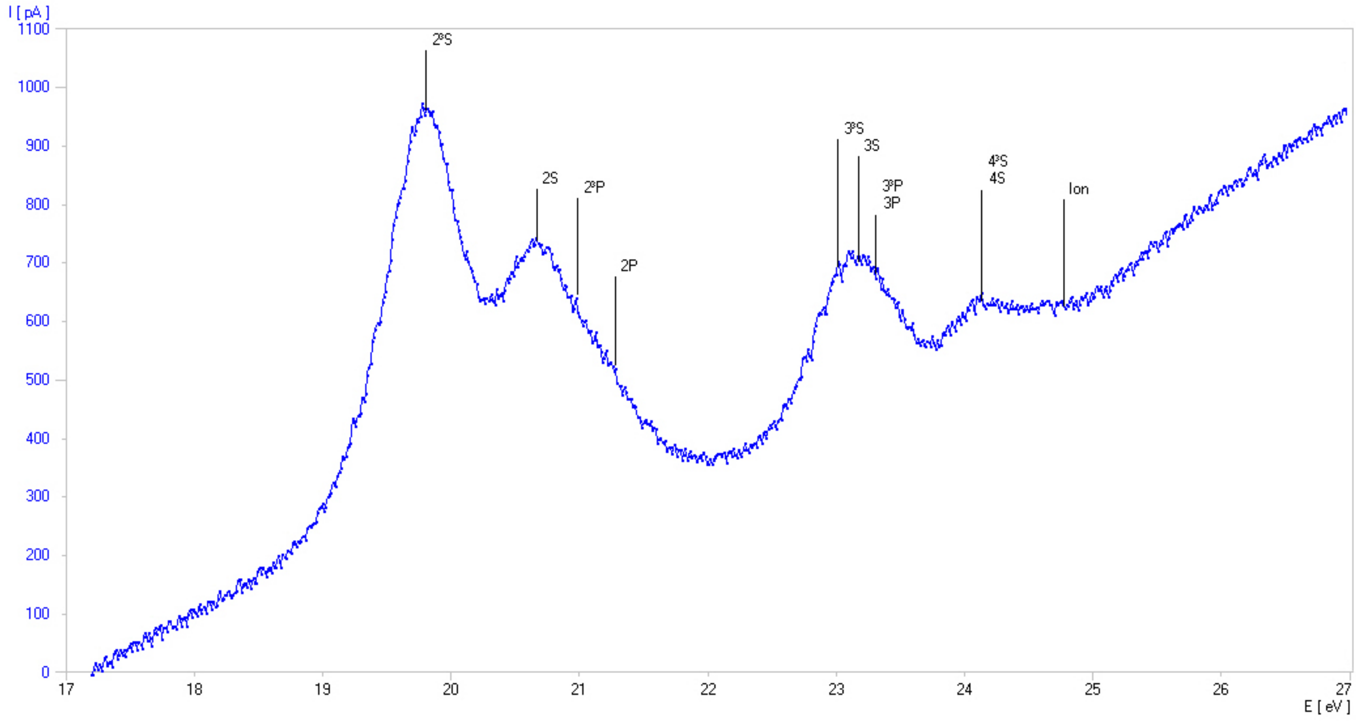

Fig. 5: Collector current I_R as a function of accelerating voltage U_A