Measurement of ionisation energy of mercury atoms

The experiment is aimed at *determination of ionisation energy of mercury atoms. The measurements are made of the intensity of ionic current (mercury ions) flowing in the anode circuit of a mercury-vapour lamp as a function of the electron accelerating voltage.*

Problems: *motion of charges in an electric field, conservative field, electron states of an atom, absorption and emission of radiation, kinetic theory of gases.*

Instruments: *mercury-vapour lamp with a power supply unit and a control panel, computer with an external (USB) acquisition card, furnace with a temperature controller.*

1. Introduction.

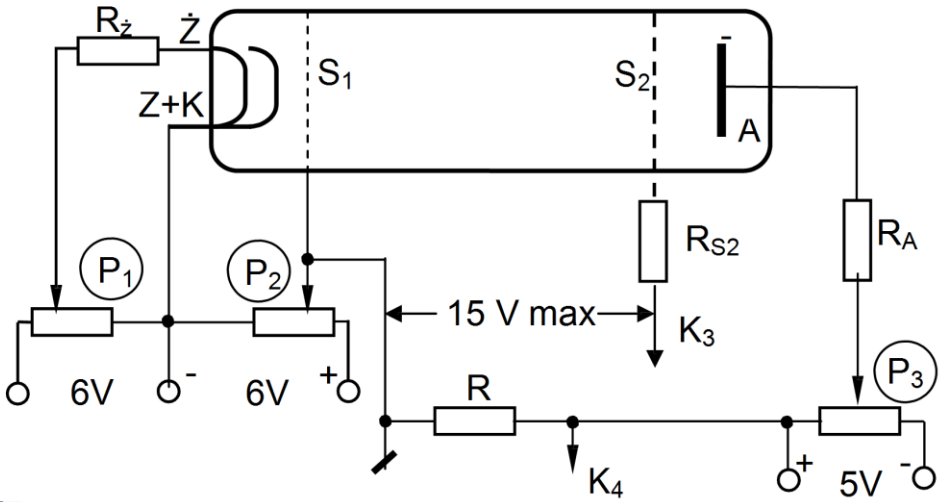


Figure 1. A scheme of connections in the mercury-vapour lamp.

The electron tube used has two grids, S_1 at the cathode and S_2 at the anode, and (except the filling) is identical to that used in Franck-Hertz experiment. The role of S_1 grid is to improve the homogeneity of electric field that accelerates electrons, while S_2 grid plays a very important role in this experiment, as explained below. The potential of S_2 is positive with respect to both S_1 grid and the anode, but in contrast to the situation in Franck-Hertz experiment, the S_2 – anode potential is higher than the electron accelerating potential so all electrons are diverted to S_2 grid and there is practically no anode current. The voltage between the grids accelerates electrons to high velocities. If the tube is filled with gas, electrons can collide with the gas atoms. If the gas concentration is high, electrons continually collide with its atoms causing an increase in the gas temperature, while the intensity of the current flowing through the lamp is low. On decreasing the gas pressure (concentration), the length of free path of electrons increases and the intensity of anodic current increases. Some of the electrons accelerated between the grids can penetrate the space between S_2 grid and anode and collide with the mercury atoms in this space. If the accelerating voltage reaches the value U_g so high that the product $U_g e$ is equal to the ionisation energy of mercury atoms, then positive ions of mercury start to appear in the lamp. This phenomenon will take place mainly near S_2 grid where the electrons have highest velocities. The mercury ions that are formed in the space between S_2 grid and anode, are attracted by the negative potential of the anode and induce the flow of anodic current but in the direction opposite to that of the anodic current in Franck-Hertz experiment (electron current).

In interpretation of results (the position of inflection point in I(U) plot) it should be remembered that the energy of electrons in the vicinity of S_2 grid also depends on the voltage between S_1 grid and the cathode (the electrons coming into the space between the grids can already have certain energy or they may need some additional energy to get to this space).

It should be mentioned that the experiment performed by James Franck and Gustav Hertz in 1914 was aimed at verification of the Bohr hypothesis on the quantum character of absorption and emission of energy by atoms. Their experiment was cleverly designed to provide the unquestionable proof for the discrete character of energy absorption by atoms, although the emission of mercury atoms was invisible. For their experiment Franck and Hertz were awarded with the Nobel Prize in 1925.

2. Experimental setup

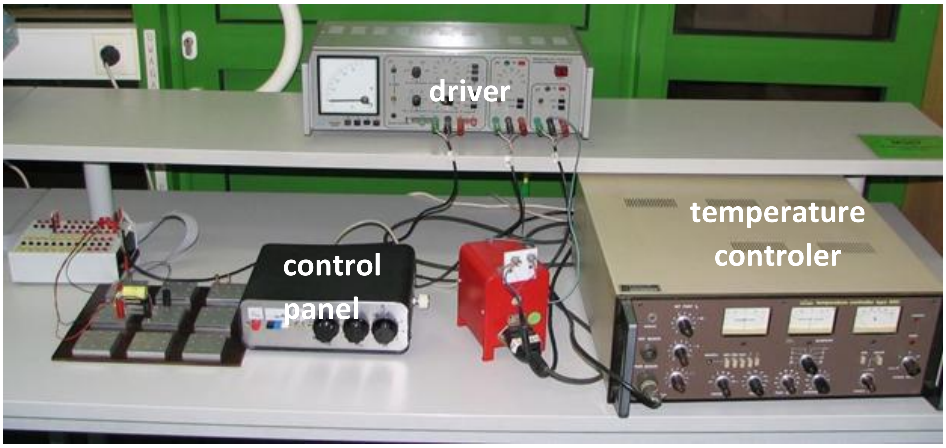
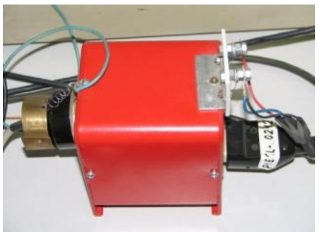


Figure 2. A view of the experimental setup without the computer.



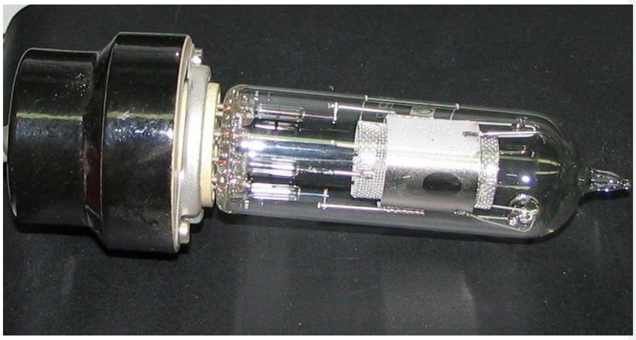


Figure 3. A furnace with a lamp inside. **Figure 4.** A mercury-vapour lamp; there is a drop of mercury in the right bottom corner.

3. Experiment

In the experimental setup used, the accelerating voltage of a maximum value close to 15 V is supplied through an RC circuit of the time constant of the order of 100 s. Thanks to the slow increase in this voltage in the lamp, it is possible to follow the changes taking place in the intensity of anodic current, measured as a drop in the voltage on the resistor connected in series in the anode circuit. Possible changes in the experiment resulting from its modifications are to be found under the tab “Informacje”(information).

Supply the accelerating voltage signal to the input ACH0, while that of electronic current to the input ACH8 in the panel of the measuring chart. Make sure that the input AISENSE is grounded (GND). Set the temperature controller to about 70°C (343 K) and supply power to the heater (the rotary knob on the far right set to 300). Make sure that the rotary knob P_1 (glowing) is set to minimum. Switch on the power supply unit without changing any of its settings. Switch the control panel of the lamp to the position "Jon" [ion] (which means that the blue button should be pressed down). Make sure that the red button "U_{S2}" informing about the supply of accelerating voltage is pressed up. On the front plate of the power supply unit, under the displaying screen, press down I_B button, then using rotary knob P_1 on the control panel set the displayed value to 0.75. In about every minute control and correct this setting until reaching a stable value. Wait till the preset temperature is reached.

Komentarz [JG1]: Ten fragment jest nieaktualny. Należałoby obejrzeć układ, zrobić mu fotkę i opisać stan aktualny.

The page "Pomiar" [measurement] of the computer program shows three windows with three plots U(t), I(t) and I(U). By pressing "Start" the new recording begins and the preceding recording is erased. By pressing "Stop" the recording stops. With the red button on the control panel of the lamp still pressed up, start measurement and with the use of a rotary knob "Zerowanie" [zeroing] on the side wall of the control panel set the anodic current to zero. Then stop the measurement and start it again but synchronise the start with pressing down the red button on the control panel of the lamp. Observe changes in the intensity of ionic current with increasing accelerating voltage. When the accelerating voltage reaches the maximum value, set it to about 13 V with the use of rotary knob P_2 (wait a few seconds for the lamp response). The voltage of 13 V is the optimum value for this experiment as it is higher than that corresponding to ionisation energy and not so high to disturb the work of the lamp. The rotary knob P_3 should be set to about 2 V. For these settings the ionic current should reach the intensity close to 0.2 nA. After the regulations, press up the red button on the control panel of the lamp and set to zero the current intensity by the rotary knob "Zerowanie" [zeroing]. Start the next measurement and record it.

The program page "Analiza" [analysis] shows the plots made on the basis of the recently measured data I(U). The cursors permit reading off the value of accelerating voltage at which the intensity of ionic current increases. With the help of two vertical slides on the page under the tab Analiza [analysis] fit the linear parts of I(U) plots with lines. Using the options "Copy Data" and "Export Simplified Image" available from the context menu (the right key of the mouse) copy the plots to clipboard of Windows system, they can be used in experiment reports.

4. Final remarks.

Besides the main result in the form of a I(U) plot and description of the lamp work, the report should also include responses to the following questions.

1. What is the optimum (for best observation of the phenomenon) free path length of an electron? In which way the optimum gas pressure should be selected?
2. What is the energy of a mercury atom excitation and to which wavelength it corresponds?
3. What is the velocity of electrons at which mercury atoms get excited? The electron mass is 9.1×10^{-31} kg, while its charge is 1.6×10^{-19} C.
4. Evaluate the validity of the assumption of weak exchange of kinetic energy between electrons and mercury atoms. Calculate the velocity that a static mercury atom gets as a result of central collision with an electron travelling at the velocity calculated in task 3. The ratio of mercury to electron masses is close to 370 000. Make use of the principle of energy and momentum conservation.

Na ekranie pojawia się napis z bledem powinno być JONIZACJI

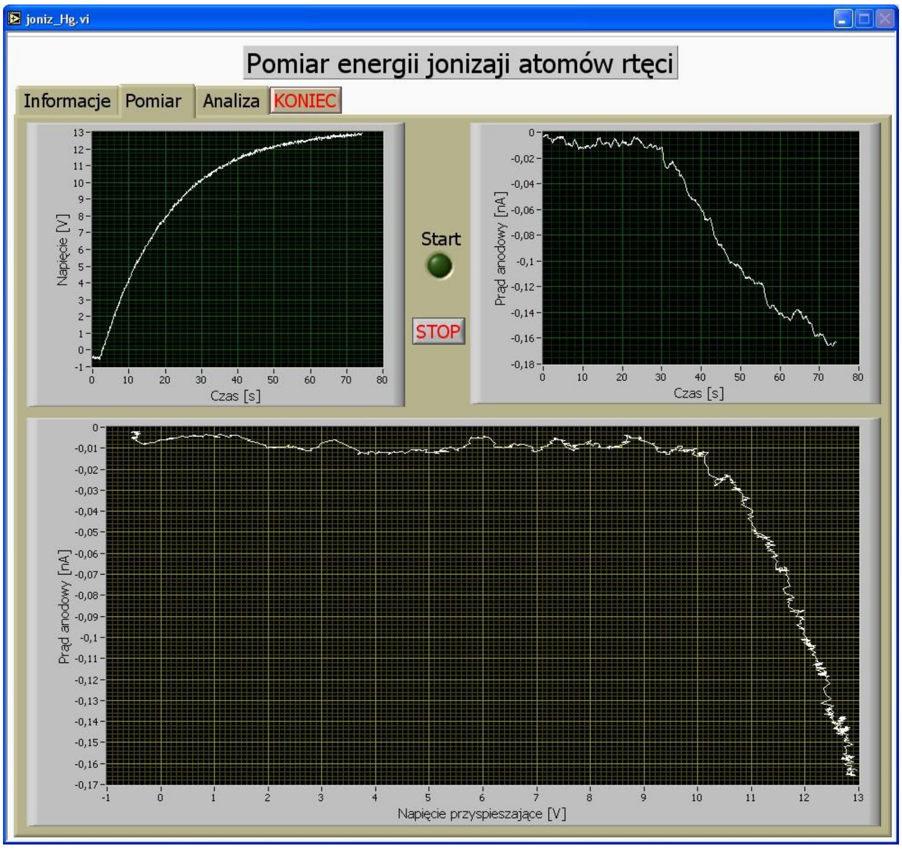


Figure 5. Exemplary results obtained in the experiment with the mercury-vapour lamp.