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Experiment 14

Determining the excitation potential of Hg and Ne atoms in the Franck-Hertz experiment

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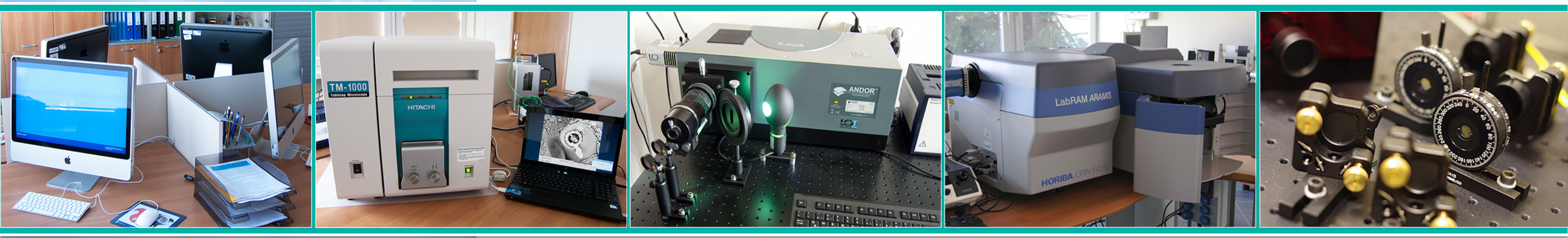
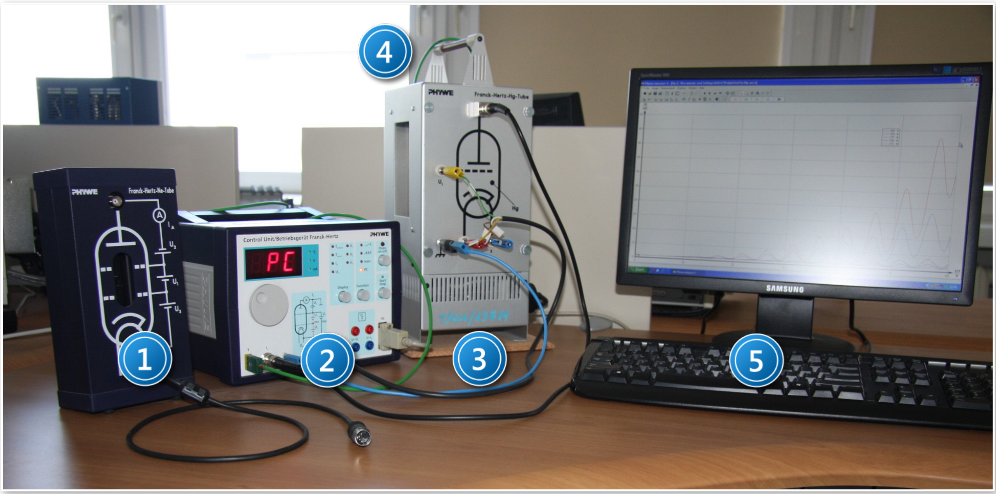


I. Background theory.

1. Planck's law.
2. Model of the atom and Bohr's quantum postulates.
3. The energy of an electron in the Coulomb field of the nucleus.
4. Electron configurations in atoms.
5. Term symbols.
6. Fine structure terms.
7. Electronic configuration and energy levels of mercury and neon.
8. Collisions of electrons with atoms:
   a) elastic collisions;
   b) inelastic collisions;
   c) mean free path of electrons in a gas.
9. Franck-Hertz experiment in mercury vapour and a neon lamp.

II. Experimental tasks.

Refer to the setup shown in *Picture 1*, the schematic connection diagrams for Ne and Hg lamps in *Figures 2* and *3* and the description of the control unit in *Appendices A* and *B*.



Picture 1. Franck – Hertz experimental setup: 1 and 3 – Franck-Hertz tubes Ne and Hg respectively ; 2 – control unit ; 4 – thermocouple; 5 – computer.

1. Measure the anode current I as a function of accelerating voltage V for both Franck-Hertz lamps – for the Ne lamp at room temperature ; for the Hg lamp in the range 175 ^{o}C – 215 ^{o}C in 10 ^{o}C intervals.

   To do this, refer to the diagrams in *Figures 2 and 3* to connect the lamps to the control unit.

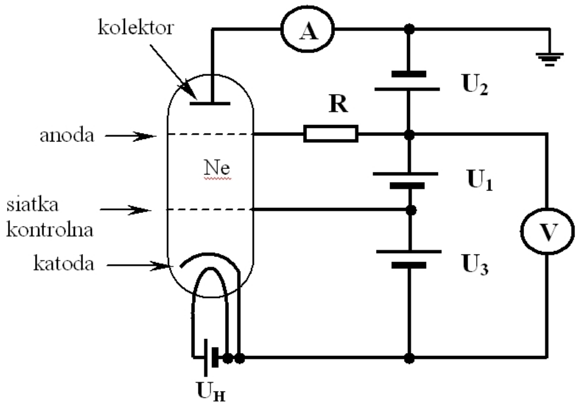


Figure 2. Ne lamp circuit diagram.

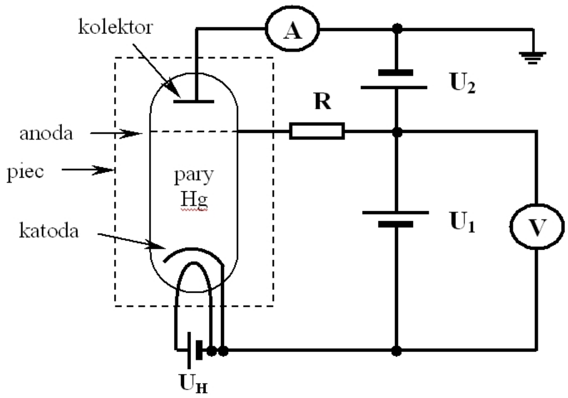


Figure 3. Hg lamp circuit diagram.

The steps which follow should be performed according to the instructions given in *Appendices A and B*.

1. Preparing measurement results.

For the neon lamp :

a) plot the dependence I = ƒ (V) of the anode current on the accelerating voltage;
b) interpret the resulting graph I = ƒ (V);
c) determine the excitation potential of Ne atoms;
d) explain the appearance of lowing layers of neon in the tube (*Picture 5*);
e) identify the transitions associated with excitations of Ne atoms (*Figure 6*);
f) calculate the wavelength emitted by Ne atoms during a ground state transition;
g) calculate the mean free path of electrons in the neon lamp.

For the mercury lamp :

a) Plot graphs of the anode current as a function of accelerating voltage I = ƒ(V) for the given range of temperatures of the mercury vapour;
b) determine the excitation potentials of mercury atoms at each temperature;
c) identify the transition to the excited state in Hg (*Figure 7*);
d) calculate the wavelength of the radiation emitted by the Hg atoms;
e) based on the plots in step a), explain the changes in the anode current for the given temperatures.

III. Apparatus.

1. Franck-Hertz neon lamp.
2. Control unit.
3. Franck – Hertz lamp with heated mercury vapour.
4. Ni Cr-Ni thermocouple.
5. Computer.

IV. Literature.

1. M. M. Kash, G. C. Shilds – "*Using the Franck-Hertz Experiment to Illustrate Quantization*", J. Chem. Educ. 71, 466, 1994.
2. H. Haken, H. Ch. Wolf – "*The Physics of Atoms and Quanta*", Springer, 2000.
3. V. Acosta, C.L. Cowan, B.J. Graham – *"Essentials of Modern Physics*", Harper & Row, Publishers, New York 1973.
4. E. W. Mc Daniel – "*Atomic Collisions – Electron & Photon Projectiles*", Wiley, N.Y. 1989.
5. A. P. Arya – "*Fundamentals of Atomic Physics* ", Allyn & Bacon Inc., Boston 1971.
6. H. A. Enge, M. R. Wehr, J. A. Richards – "*Introduction to Atomic Physics*", Addison-Wesly, Reading-Mass, 1981.
7. P. Meystre – "*Atom Optics*", Springer, Berlin-Heidelberg, 2001.

Appendix A

Instructions for the Franck-Hertz **neon lamp**

Refer to the following description of the control unit front panel in *Figure 4*.

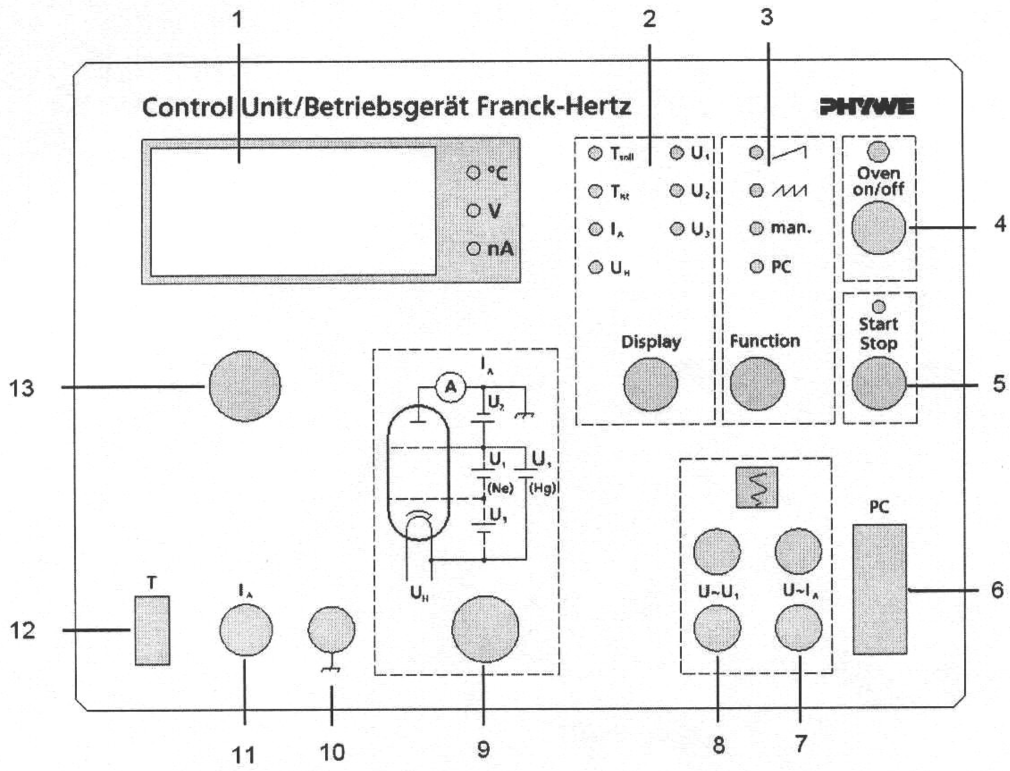
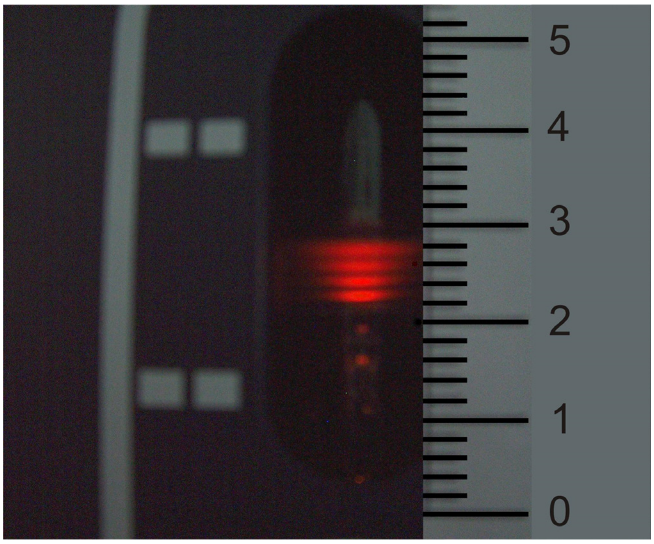


Figure 4. Front panel of the Franck-Hertz experiment control unit:

1. Digital display of chosen parameters T, I_A, U_H, U_1, U_2, U_3;
2. Display selection;
3. Measurement method function selection;
4. Switch heating in the Hg tube on/off;
5. Start/stop measurements;
6. Computer connection socket;
7. Analogue output Y (when working with oscilloscope and recorder);
8. Analogue output X (when working with oscilloscope and recorder);
9. Power supply module U_H, U_1, U_2, U_3 for the chosen Franck-Hertz lamp;
10. Earth;
11. Anode current measurement input;
12. Thermocouple connection;
13. Potentiometer for regulating temperature and voltage U_H, U_1, U_2, U_3.

Observation of neon light (with manual operation).

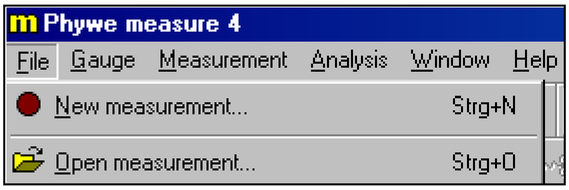
1. Turn on the Franck-Hertz control unit.
2. Press “Function” and select the option “manual”.
3. Press “Display” and select the following settings for the potentiometer:
   U_H = 8,0 [V], **U_2 = 7,0 [V]**, **U_3 =2,2 [V]**, **U_1 = 0 [V]**.
4. Press the “Start/Stop” button. Adjust the potentiometer to increase the voltage U_1 up to maximum (99,9 [V]). At the same time, observe the appearance of luminescent layers between the electrodes of the Ne lamp (as shown in *Picture 5*.).



Zdjęcie 5. Luminescent layers in the Ne lamp.

Measuring **I = f(V) for the Ne lamp (automatic measurements).**

1. Turn on the computer.
2. Start the program “measure”. Press “Function” on the control unit and select the option “PC”.
3. In the program “Phywe measure 4”, select “New measurement” :



4. Set the following measurement parameters :

   End Voltage U_1= 99,90 [V]

   Voltage U_2 = 7,0 [V]

   Voltage U_3 = 2,2 [V]

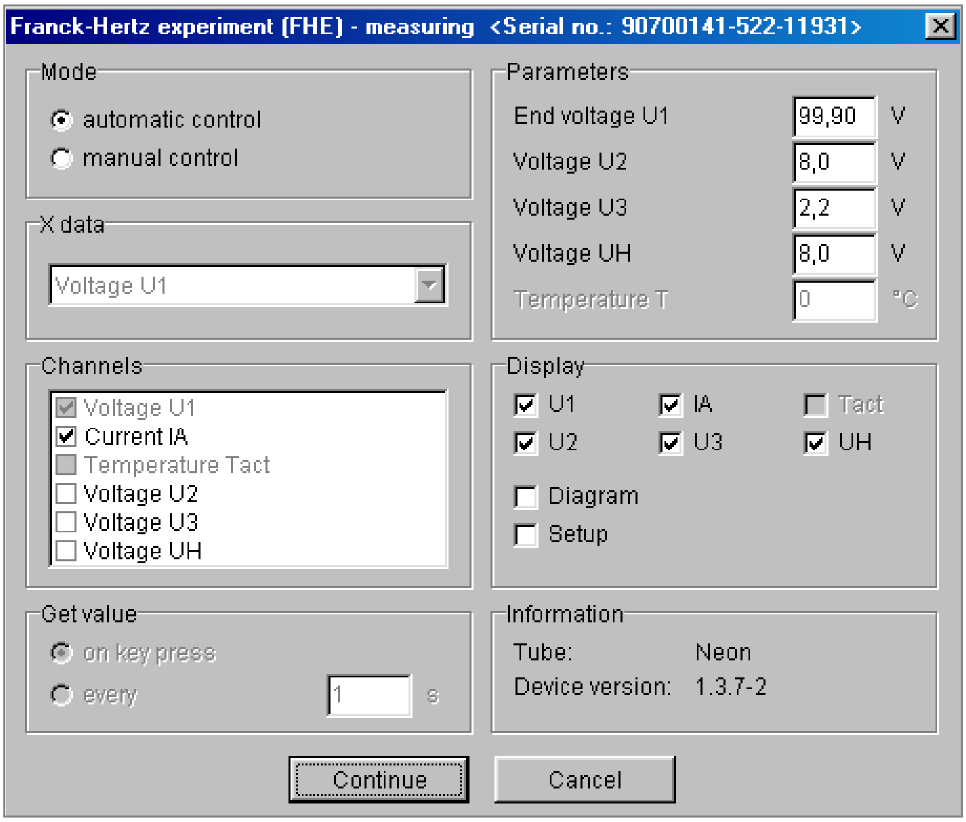
   Voltage U_H = 8,0 [V]

   In the "Display" window, tick U_1, U_2, I_A, U_3, U_H.

ATTENTION!

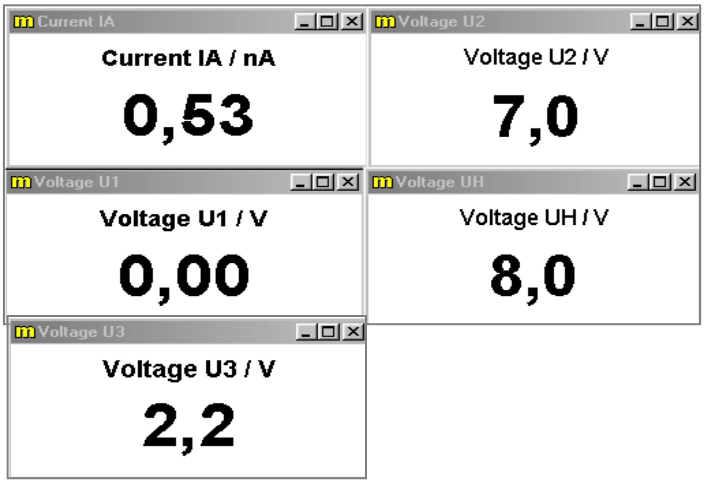
Do not exceed the following voltages:

U_1 = 99,9 [V]; U_2 = 8 [V]; U_3 = 4 [V]; U_H = 9 [V].

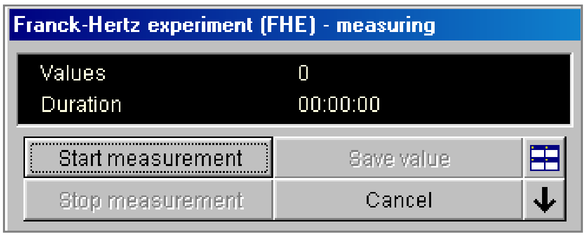


In the window "Channels", tick "Current I_A". Then click "Continue".

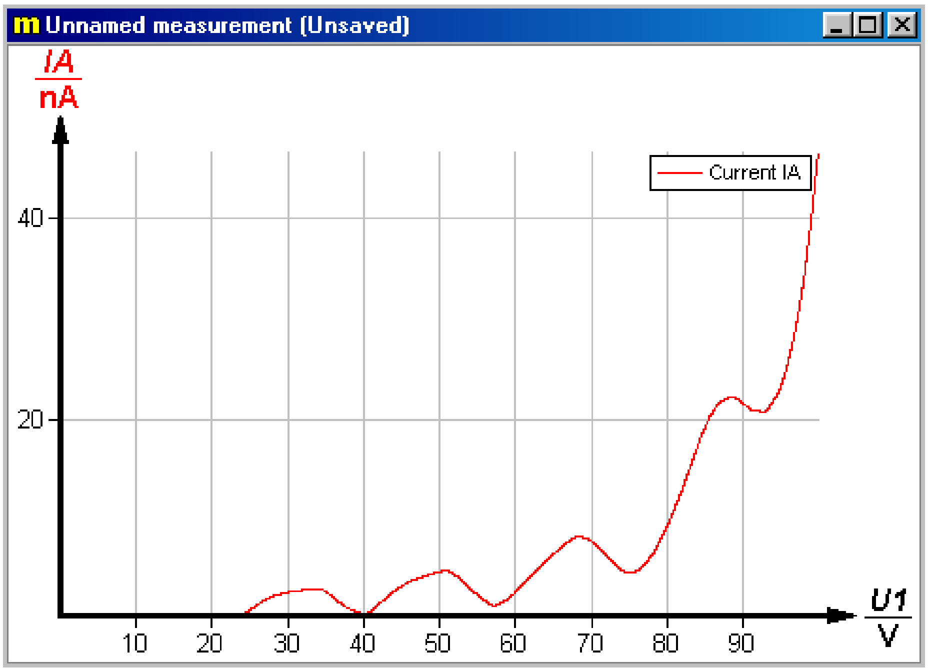
5. A measuring window will appear with the selected parameters:



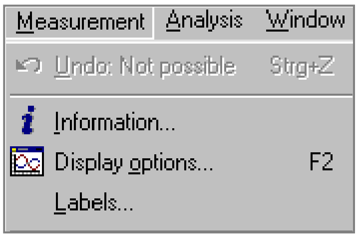
6. Click “Start Measurement”.



7. After a few moments the program will begin measuring, after which a graph will appear of $I_A = f(U_1)$.

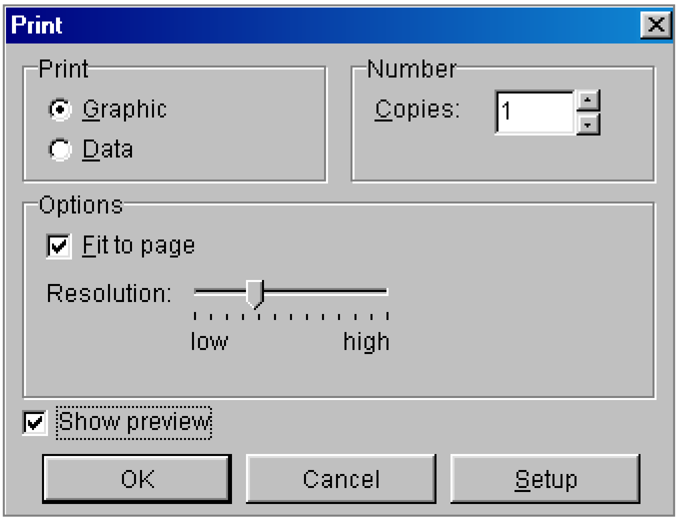


8. Select the option “Measurement” > ”Information” from the program interface



Enter the relevant description in the free field. Then go to “Display options” and set the values on the x and y axes.

9. After completing all steps, print the plot with the option “Print Measurement”. Select “Show preview” and select landscape in “Setup”.



ATTENTION!

Before turning off the control unit, set the voltage UH to O [V].

Appendix B

Instructions for the Franck-Hertz **mercury lamp**

Measuring I = f(V) for the Hg lamp (automatic measurements) at different temperatures.

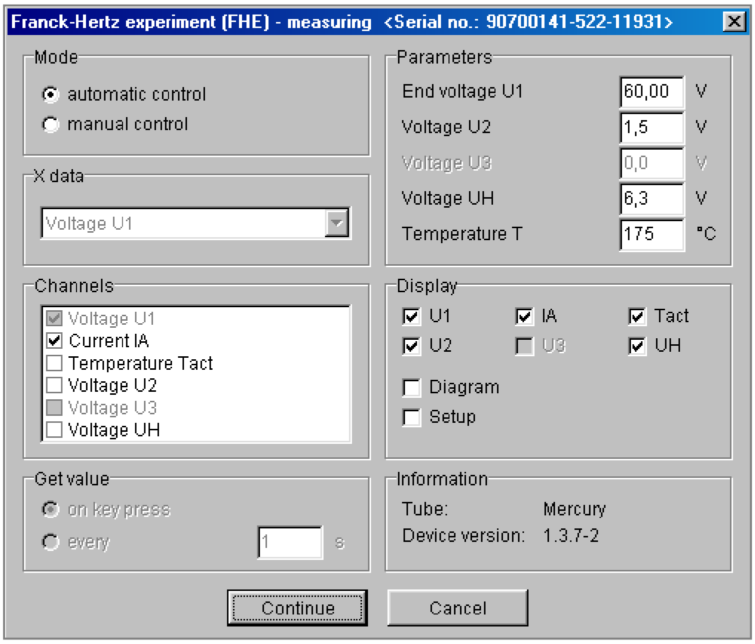
1. Familiarise yourself with the control unit functions as shown in *Figure 4*.
2. Set the heating to position 10 (maximum heating).
3. Turn on the Franck-Hertz control unit.
4. Press "Display" and choose "$T_{nominal}$". Using the potentiometer, set the temperature to 220°C. Press "Oven on/off".
5. Use the "Display" button to select the reading "T_{act}" and wait until the heating oven temperature reaches 220°C.
6. Press "Function" and select "PC"
7. Turn on the computer and start the "measure" program.
8. Select "New Measurement" from the measurement interface.
9. Select automatic control of measurements. Set the parameters as follows:

   End Voltage U_1=60,00 [V]

   Voltage U_2=1,5 [V]

   Voltage U_H=6,3 [V]

   Temperature T=175°C.

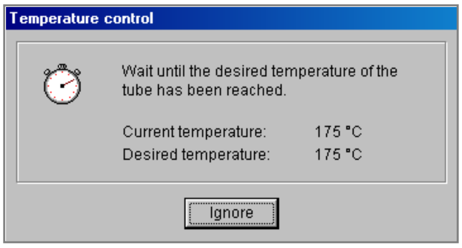


ATTENTION!

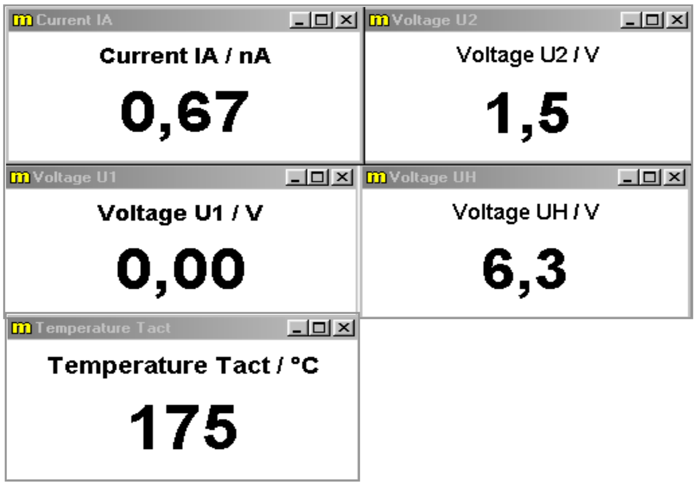
Do not exceed the following voltages: U1 = 60 [V]; U2 = 3 [V]; UH = 7 [V].

In the "Channels" window, tick "Current I_A". Then click "Continue".

10. Wait until the desired temperature is reached :

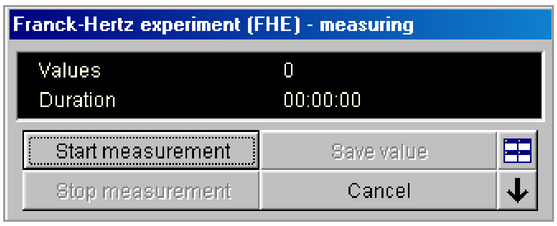


11. A measuring window will appear with the selected parameters:

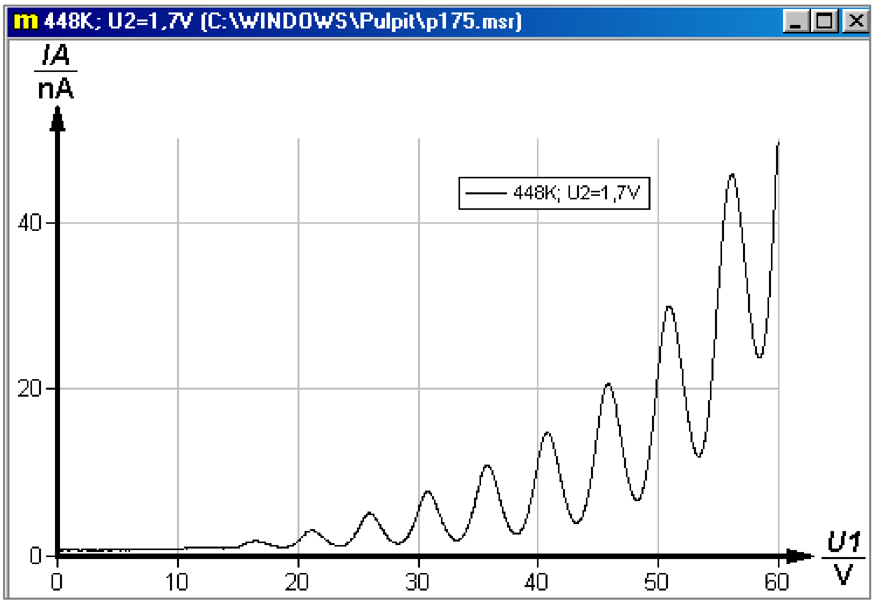


Wait about 20 minutes before starting the first measurement.

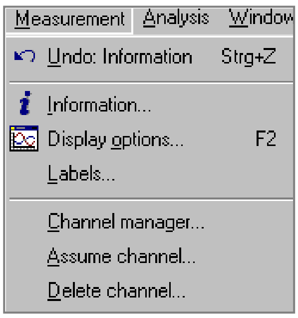
12. Click "Start Measurement".



13. After a few moments the program will begin measuring, after which a graph will appear of $I_A = f(U_1)$.

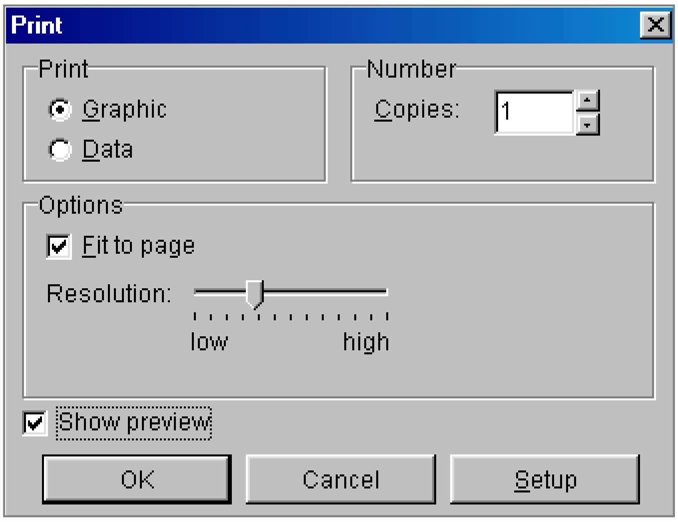


14. Record the measurements to a separate file (use "Save measurement as...")
15. Repeat the measurements for temperatures **T = 185°C, 195°C, 205°C and 215°C**, saving the results each time as in step 14.
16. Before each measurement, select "Information" and write a description of the measurement and then in "Channels" under "Name", enter the measurement parameters. Under "Display options", set the graph scale (**x-axis from 0 to 60 [V]; y-axis from 0 to 50 [nA]**) and choose a different colour for each measurement. Repeat these procedures for each successive measurement. Remember **not to close** the windows for each measurement.
17. After all measurements are complete, plot a combined graph. To do this, select "Measurement" and then "Assume channel".



Include all the sequential measurements.

18. Print the plot after following all steps. Use the function "Print Measurement". Tick "Show preview" and in "Setup", select landscape.



ATTENTION!

Before turning off the control unit, set the voltage UH to 0 [V].

Appendix C

Supplemental figures for Experimental tasks II

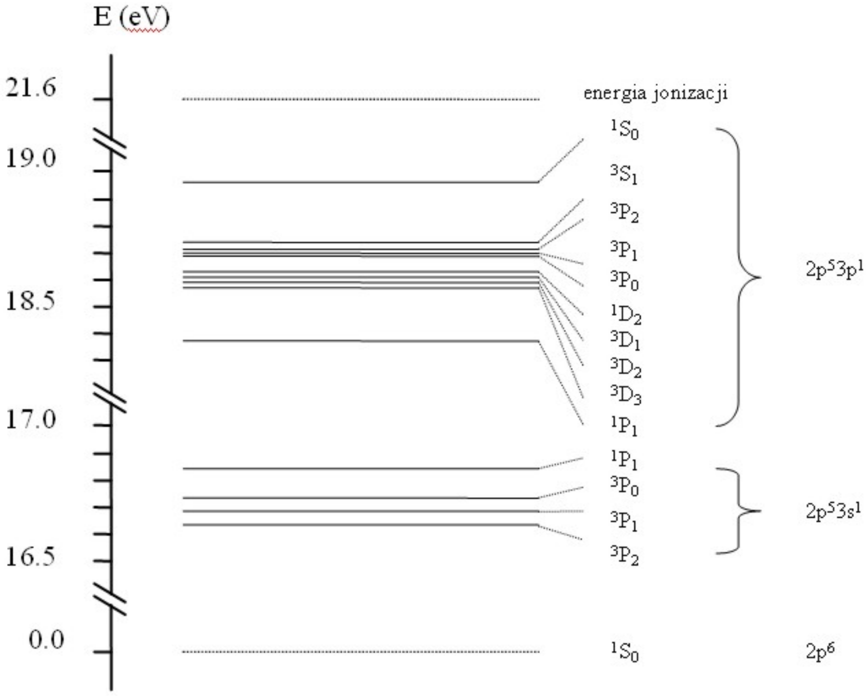


Figure 6. Ne energy level diagram.

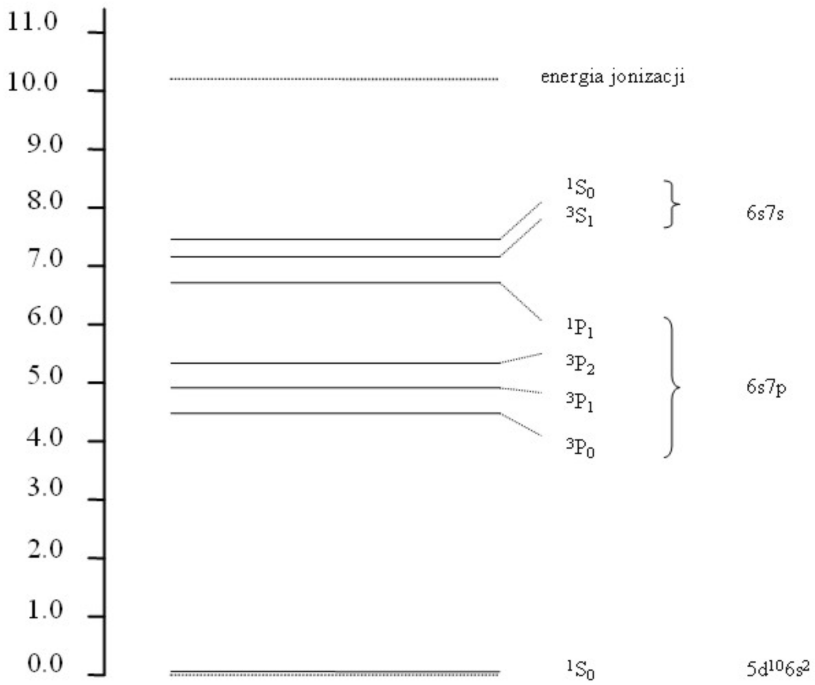


Figure 7. Hg energy level diagram.