PHYS 360/460: Advanced Physics Laboratory
Experiment 8: The Franck-Hertz Experiment

I. BACKGROUND

Before coming to the lab, you should familiarise yourself with the background to the Franck-Hertz experiment. This can be found in most introductory textbooks on Quantum Mechanics, for example "Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles" by Eisberg and Resnick.

You should also read the (somewhat dated) description of the experiment from Melissinos and Napolitano which is provided on the UW-ACE website. The experiment you will perform will not proceed exactly as outlined in this handout, but it will provide valuable information on how the apparatus operates.

You will also need a copy of the following paper:
Gerald Rapier, Klaus Sengstock and Valery Baev, "New features of the Franck-Hertz experiment", *American Journal of Physics*, **74**, 423, (2006)

II. APPARATUS

Control Unit for Franck - Hertz Tube
Franck - Hertz tube
Oven for Franck - Hertz tube
Temperature sensor for oven
Digital voltmeter
USB data acquisition card for LabView
Connecting wires

The equipment used is similar to that described in the description mentioned above, however, a complete control and measurement unit is used to operate the tube and obtain the results. The output U_A is connected to the computer via a data acquisition card. The LabView program may be used to obtain plots of anode current (actually, a voltage U_A proportional to I_A) vs the electron accelerating potential U_2. To save any data to a file use the STOP button on the front panel to terminate data acquisition. This automatically opens a window for file saving. The tube itself is housed in a specially designed oven to allow you to obtain plots in the operating region of the tube (145 - 200C). It is fitted with a thermocouple temperature sensor which is connected to the control unit. For the following instructions please refer to the picture of the control unit in figure 1. θ_S is the set point temperature, and can be varied by adjusting the knob 3 on the left-hand side, labeled θ_S. θ is the actual temperature of the oven as read by the thermocouple device. Note that for $\theta < \theta_S$ the LED on the front panel will be yellow, when $\theta = \theta_S$ it will switch to green, although you should use the temperature as measured and displayed by θ. The selector knob 1 changes which item is being shown on the digital display 2. Selector knob 4 is to change the method by which the accelerating potential U_2 is varied. Reset sets U_2 to be 0 V. The Manual position allows you to manually adjust the potential using knob 5. For plotting purposes, the ramp sweep option (indicated by the ramp icon on knob 4) should be used. This varies U_2 internally as a function of time and can be recorded on the computer.

III. PROCEDURE

The background information will have revealed that information on the spectrum of energy levels in mercury atoms is determined by examining the periodic nature of the anode current as a function of the kinetic energy of the bombarding electrons controlled by the accelerating voltage, U_2.

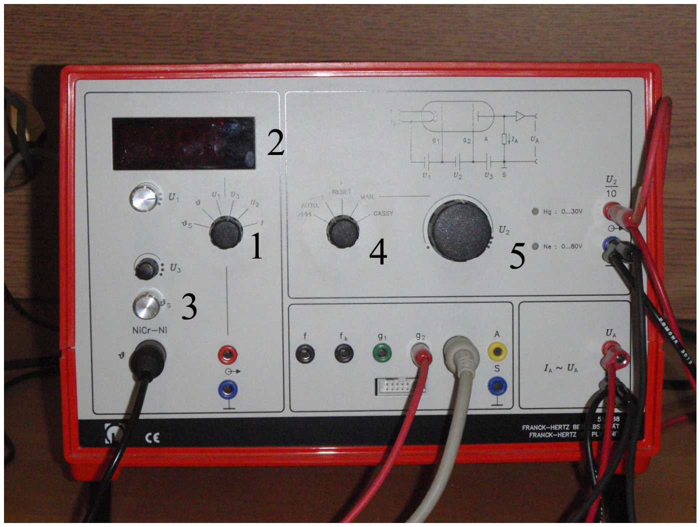

FIG. 1: The control unit for the Franck-Hertz experiment.

A. Preliminary

Familiarise yourself with the control unit and the LabView data acquisition software. Make sure you know how to set up a voltage sweep and record the data to a file on the computer.

B. Tube performance

One of the important parameters to be measured in this experiment is the kinetic energy of the bombarding electrons. However, the circuit diagram of the tube shows that the electrons are in fact subjected to electric fields in three distinct regions as determined by U_1, U_2 and U_3. Clearly, the electrons are mainly accelerated in the region controlled by U_2, but what is the role played by U_1 and U_3 and what is their effect on your data?

You should determine this empirically and provide data in your report to justify your claims.

C. Temperature

Having established the effect of varying the voltages U_1 and U_3, you should use this information to collect optimised data for V_A as a function of U_2 for a range of temperatures between 140° C and 200° C. The temperature controls the vapour pressure of the mercury in the tube. Use the vapour pressure of mercury as a function of temperature to determine the distribution of your temperature values. The results from this part of the experiment will be used for the bulk of the analysis to follow.

IV. ANALYSIS

You should follow the analysis described by Rapior *et al*. In this article, a model is presented for the inelastic collisions between mercury atoms and electrons with energies that exceed the minimum excitation energy for mercury and a method is described for obtaining a value of the first excitation level in the spectrum for mercury denoted E_a.

Use this method and your data for different temperatures to obtain a value for E_a with appropriate error analysis. To improve your ability to accurately detect the maxima and minima in the anode current (I_A) curves, it is recommended that you fit and subtract the background variation in I_A. The current versus acceleration curve for a regular diode is well approximated by the Child-Langmuir law.

The same analysis for E_a will also yield a value for the mean free path of the electrons, λ, as a function of temperature. Theoretically, this should vary inversely with the density of mercury atoms with a proportionality constant that is the inverse of the cross-section for scattering.

V. DISCUSSION

1. Discuss the use of the volatges the U_1 and U_3. What is the effect of varying these voltages on the anode current curves? How does it affect your ability to determine E_a? Give reasons as to why you observe what you do.

2. Discuss the Child-Langmuir law and the background dependence of your curves

3. Discuss your value for E_a in the context of values determined by other experimental techniques. What is you main source of error? Is it a systematic or random error?

4. Discuss your values for λ and its variation with temperature. Is it as predicted theoretically? Compare your value of the cross-section for scattering with that obtained via other techniques. An approximation used in the analysis to determine E_a is that $\lambda << L$. Is this appropriate?