Physikalisches Institut der Universität Bern

Experimental Lab Sheet for

Franck-Hertz Experiment

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Supervisor:

Prof. Dr. Ingo Leya

Assistants:

Dr. Tamer Tolba Dr. Lucian Ancu

Introduction:

In 1915 Niels Bohr proposed his model of the atom, known as "Bohr model", assuming that electrons can lose or gain energies only by jumping from one orbit to another, i.e. the electron energy in Bohr's model is restricted to discrete values (the energy is quantized). Shortly after Bohr's theory, in 1914 James Franck and Gustav Hertz published the results of an experiment which provided strong evidence that Bohr's model of the atom with quantized energy levels was correct. In their experiment, Franck and Hertz accelerated electrons in a tube filled with mercury vapor. They had observed that the electrons lose their energies in quantized steps as they inelasticaly interact with and excite the mercury atoms. This experiment yielded a remarkable results that were key in the early development of quantum theory.

Theory:

In the Frank-Hertz experiment (illustrated schematically in Figure 1) a Platinum filament cathode (C) is heated and thus releases some of its conduction electrons. The released electrons are accelerated with potential the U1 towards the grid (G). The accelerated electrons hit Hg vapor atoms and lose some of their energies. After the electrons pass the grid they are decelerated by counter potential U2 before they are finally collected on the anode (An). The whole setup is maintained in a low pressurized tube, which is placed within an oven that controls the tube temperature and thus the Hg vapor pressure.

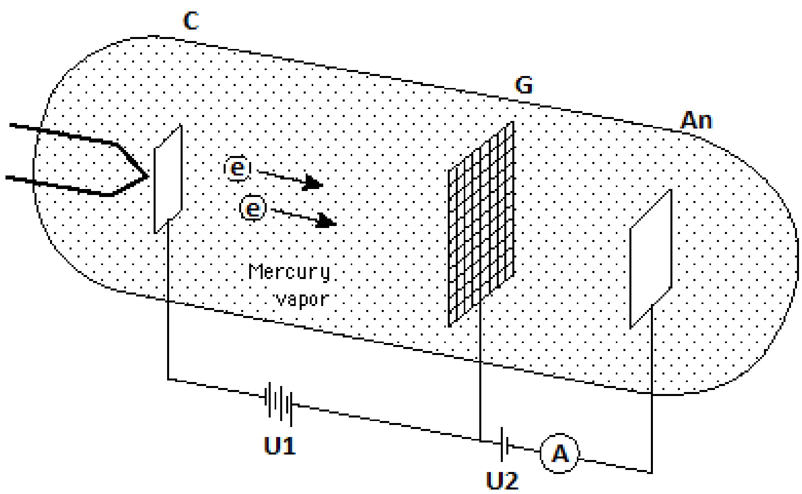


Figure 1: Schematic diagram for the Frank-Hertz experiment setup. C indicates the Cathode filament, G indicates the positively charged Grid, An indicates the Anode, A represents the Ammeter measuring the current at the anode, and U1 and U2 indicate the power supply of the accelerating voltage and anode voltage, respectively.

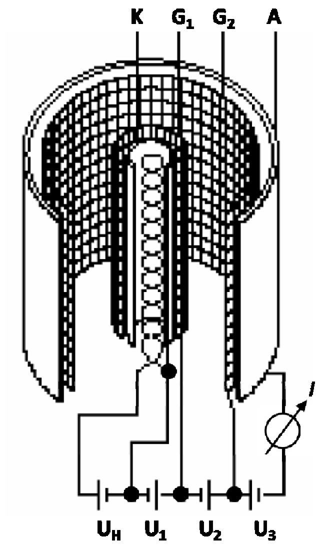


Figure 2: Schematic diagram for Hg tube.

Franck-Hertz data for Mercury tube:

Figure 2 shows a schematic diagram for Franck-Hertz Hg tube used in this lab. The glass tube contains a cylindrically symmetric system of four electrodes. The cathode K is surrounded by a grid-type control electrode G_1 at a distance of few tenth of millimeter, an acceleration grid G_2 at greater distance and finally the collector electrode A outermost. The cathode is heated indirectly, in order to prevent a potential difference along K.

During the experiment the evacuated tube kept at constant pressure ~ 15 hPa of Mercury vapor by controlling the oven temperature in which the tube is contained in. Inside the glass, the cathode (K) is heated and hence some of its conduction electrons are released. The released electrons leave the cathode metal and accelerated with the deriving potential U1 between the cathode and the grid G_1. the electrons then punch-through G1 and accelerated by the acceleration potential U_2 between G_1 and G_2. A breaking voltage U_3 is present between G_2 and the collector A. Only electrons with sufficient kinetic energies to overcome the counter potential U_3 can reach the collector A.

The acceleration voltage U_2 , between G_1 and G_2, is increased from 0 to 30 V while U_1 and U_3 are held constant, and the corresponding collector current is measured (the left raising tail of the first peak of Figure 3). When the accelerated electrons gain energy enough to excite the Hg vapor atoms E_e , they lose energy equal to the excitation energy $E_{ex} = E_e$ (= 4.9 eV) and proceed further with $E_f = E_e - E_{ex}$. The collector current drops off dramatically, as after collision the electrons can no longer overcome the counter voltage U_3 (the falling tail of the first peak of Figure 3). As the acceleration voltage U_2 increases, the electrons gain more energy $E_e > E_{ex}$, and hence the recorded current starts to raise up again until it reaches $E_e = 2E_{ex}$ (the raising tail of the second peak of Figure 3). Again the current drops off, because the electrons transferred all their energy E_e to excite the electrons in the gas atoms. This procedure is repeated for each excitation levels of the Hg atoms. Thus this experiment shows that the vapor atoms can be only excited at specific (quantized) energies.

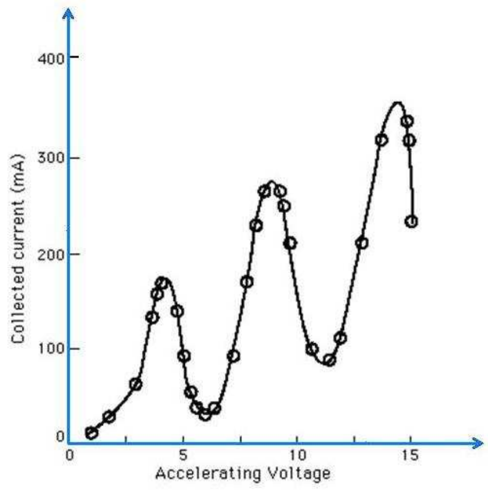
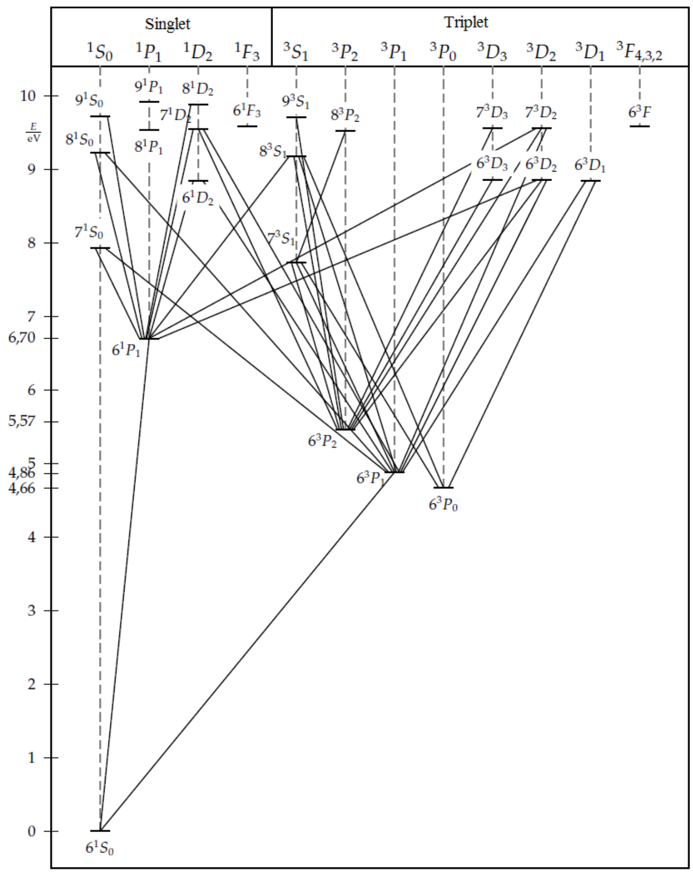


Figure 3: Frank-Hertz curve for Mercury.



Transition	λ / nm
$6^1S_0 \leftrightarrow 6^1P_1$	184,95
$6^1S_0 \leftrightarrow 6^3P_1$	253,65
$6^3P_1 \leftrightarrow 7^3D_2$	265,20
$6^3P_1 \leftrightarrow 7^1D_2$	265,51
$6^3P_0 \leftrightarrow 8^3S_1$	275,28
$6^3P_1 \leftrightarrow 8^1S_0$	285,69
$6^3P_1 \leftrightarrow 8^3S_1$	289,36
$6^3P_2 \leftrightarrow 9^3S_1$	292,54
$6^3P_0 \leftrightarrow 6^3D_1$	296,72
$6^3P_2 \leftrightarrow 7^3D_3$	302,15
$6^3P_2 \leftrightarrow 7^3D_2$	302,35
$6^3P_2 \leftrightarrow 7^1D_2$	302,75
$6^3P_1 \leftrightarrow 6^3D_2$	312,57
$6^3P_1 \leftrightarrow 6^3D_1$	313,16
$6^1D_2 \leftrightarrow 6^3P_1$	313,18
$6^3P_2 \leftrightarrow 8^3S_1$	334,15
$6^3P_2 \leftrightarrow 6^3D_3$	365,02
$6^3P_2 \leftrightarrow 6^3D_2$	365,48
$6^1P_1 \leftrightarrow 8^1D_2$	390,64
$6^3P_0 \leftrightarrow 7^3S_1$	404,66
$6^3P_1 \leftrightarrow 7^1S_0$	407,78
$6^1P_1 \leftrightarrow 9^1S_0$	410,81
$6^1P_1 \leftrightarrow 7^3D_2$	433,92
$6^1P_1 \leftrightarrow 7^1D_2$	434,75
$6^3P_1 \leftrightarrow 7^3S_1$	435,83
$6^1P_1 \leftrightarrow 8^1S_0$	491,61
$6^1P_1 \leftrightarrow 8^3S_1$	502,56
$6^3P_2 \leftrightarrow 7^3S_1$	546,08
$6^1P_1 \leftrightarrow 6^3D_2$	576,96
$6^1P_1 \leftrightarrow 6^1D_1$	579,07
$8^3P_2 \leftrightarrow 7^3S_1$	690,75
$6^1P_1 \leftrightarrow 7^1S_0$	1013,98

Reference:
NIST Atomic Spectra Datab
v3.1.3

Figure 4: Energy level diagram for Mercury.

Franck-Hertz data for Neon tube:

For Neon gas (see Figure 5), the process of energy absorption from electron collisions is clearly much easier to observe: when the accelerated electrons excite the electrons in neon to upper states, they de-excite in such a way as to produce a visible glow in the gas volume in which the excitation is taking place. There are about ten excited levels in the range 18.3 to 19.5 eV. They de-excite by dropping to lower states at 16.57 and 16.79 eV, figure 6 shows the energy level diagram for Neon atom. This energy difference gives light in the visible range. If the accelerating voltage is high enough, they can undergo a series of inelastic collisions between electrons and neon gas. Almost similar pattern is observed in the case of neon gas at intervals of approximately 19 eV.

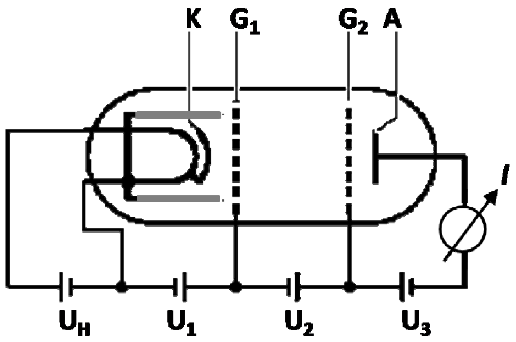


Figure 5: Schematic diagram for the Ne tube

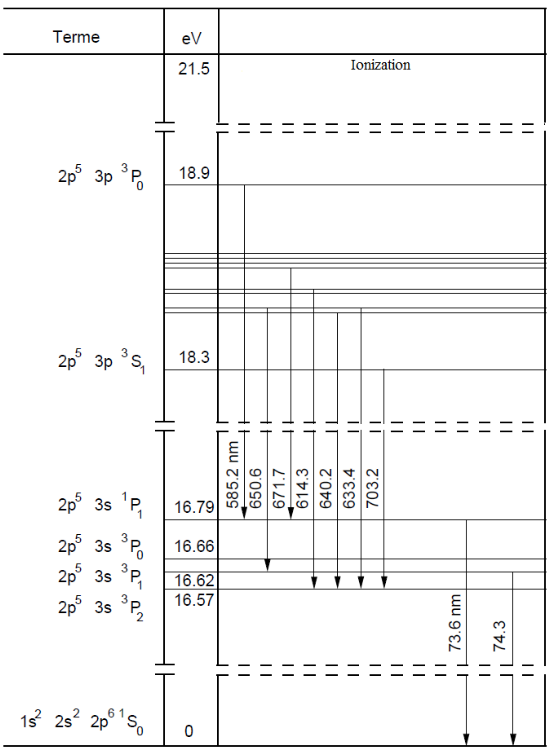


Figure 6: Energy level diagram for Neon.

Setup/Apparatus:

Figure 7 shows a diagram illustrating the components of the Franck-Hertz experiment setup:

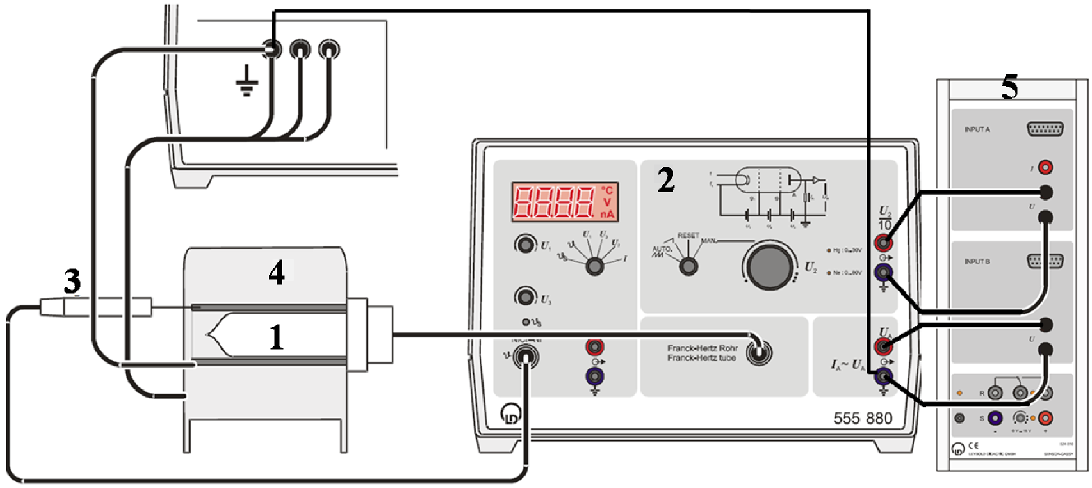


Figure 7: Schematic diagram for Franck-Hertz experiment setup.

1- Hg Franck-Hertz tube.

2- Frank Hertz supply unit.

3- NiCr-Ni temperature sensor.

4- Electrical oven 230 V.

5- Recording interface CASSY

Description of input/output controllers on the parameter, display and operation panels can be found in the Franck-Hertz Instruction sheet 555 880 (always near to the PC in the lab).

Getting started:

1- Make sure that all connections are correct as shown in Figure 7.

2- Switch ON the supply unit from the rear push button switch and the CASSY interface by connecting the power cable to the S pin.

3- Make sure that all voltages and temperatures read 0. Bare-in-mind that the actual Temp. display (ϑ) is reading the room temperature (20-25 ^{o}C) depending on the outer environment temperature.

4- Make sure that the Operating mode switch is set to RESET.

5- Open the "CASSY Lab 2" program from the computer desktop and set the operating parameters as follows:

- At **settings** node - open **CASSYs** sub-node: check boxes for **Input A_1 (left) - Voltage U_{A1}** and for **Input B_1 (left) - Voltage U_{B1}**.

- At **Voltage U_{B1}** node set the measured voltage **range** (e.g. 0 V... 30 V), Set **Record Measured Values** (e.g. Instantaneous values) and the **origin** (left, middle or right).

- Set **Meas. time** and **interval** (depends on the measurement) and set **trigger values** for U_{A1} and U_{B1} (e.g. 0.01 V).

6- Start to set the operational parameters (e.g. U_1, U_3 and ϑ_s) for each Franck-Hertz tube separately. U_2 is controlled by the PC, the CASSY interface knows automatically which tube is connected once you connect it to the supply unit. You can check that by monitoring the Status LEDs on the operational panel, when you attach the Hg tube, the Hg: 0...30V LED will turn light ON and when you attach the Ne one the other LED will turn light ON.

Things to measure:

- For Mercury Franck-Hertz tube:

- Make sure to put the temperature sensor in the hole in the back of the cylinder oven body NOT between the oven and the Hg tube.

- DO NOT apply voltages (U_1 and U_3) before you reach the desired temperature on the tube (ϑ value) by varying the temperature potentiometer ϑ_s, default is ϑ_s = 180 ^{o}C (check the instruction sheet). Wait 15-20 minute till the system reaches thermal equilibrium. Now ϑ_s and ϑ must refer to the same temperature value.

- Set the emitting grid voltage U_1 to 0.35 V and the counter voltage U_3 to 1.50 V.

- Move the Operating mode switch (in the Operation panel) to **AUTO** position.

- Start the measurement (from the CASSY-Lab 2 program) and record the Franck-Hertz curve.

- Optimize the Franck-Hertz curve by fine tuning U_1, U_3 and the temperature values.

- Investigate the influence of the Hg vapor density on the behavior of the anode current. This can be done by fixing the U_1 and U_3 values and varying the oven temperature from 170 ^{o}C to 190 ^{o}C. Repeat the same test but for the reverse case (i.e. 190 ^{o}C to 170 ^{o}C). Explain what you observe.

- Investigate the influence of U_1 on the anode current: fix the temperature ϑ_s to 180 ^{o}C and U_3 value and record the curve at different U_1 values.

- Investigate the influence of U_3 on the anode current: fix the temperature ϑ_s to 180 ^{o}C and U_1 and record the curve at different U_1 values.

- Explain/compare the effect of each of U_1 and U_3 on the anode current.

- For Neon Franck-Hertz tube:

- The Neon tube works at room temperature.

- Set the emitting grid voltage U_1 to 1.40 V and the counter voltage U_3 to 8.00 V (fine tuning may be needed in order to get better curve).

- Start the measurement (from the CASSY-Lab 2 program) and record the Franck-Hertz curve.

- Move the Operating mode switch (in the Operation panel) to **AUTO** position.

- How many light zones you can record and which transitions are involved in the luminous phenomena?

- Theoretical requirements:

A bibliography with suggestions for the study of the literature for the theoretical principles of this experiment is included in the end of this sheet.

• The first part of the report should briefly summarize the essential theoretical principle of this experiment. Important figures, tables, etc. can be copied to it with referring to the source references. The explanation, however, of the physical processes must be in your own words. The report is expected to cover the following concepts:

Hydrogen-Atom, Schrödinger equation, coupling mechanisms, vector backbone model, selection rules, Level diagram of Hg, lifetime of excited states, kinetic theory of gases, mean free path, energy transfer during elastic and inelastic collision, the cross section, Excitation function, thermal electron emission, mercury vapor lamp, Space charge law, Franck-Hertz experiment setup.

• tasks to the theory: Before performing the test, the following tasks have to be solved and to discussed:

1- Determine the mean velocity, the mean free path and the Impact frequency of atoms in the mercury vapor at the temperature T = 170 ° C, 180 ° C, 190 ° C.

2- Determine the cross section for Hg - atoms.

3- how can the cross section for inelastic collisions be estimated from the characteristic profile of the current-voltage relationship of Hg Franck-Hertz experiment?

Literature:

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