FRANCK - HERTZ EXPERIMENT

1 AIM

- To check the energy quantization of the atoms through the Frank-Hertz experiment.
- To determine the first excitation energy of the mercury atoms,E_a from the positions of the minima of the electron current, I_A, in a variable opposing electric field, U_1.

2 THEORETICAL BACKGROUND

In 1913, Bohr presented the first quantum model of the atom, based on Rutherford's atom. One of the main features of this model is the quantization of the electron orbits around the nucleus: electrons can only describe certain orbits, at given distances from the nucleus, and in which their energy remains constant (stationary orbits). **According to the Bohr model, the orbits and energies of the electrons in the atoms are quantized.** Soon, great efforts were dedicated to trying to experimentally confirm this quantization of the energy of the electrons in the atom. The initial experiments used light, which at that time was already known to be made up of energy quanta, the photons. For this reason, it was claimed that Bohr's results on the quantization of the electron orbit (and its energy) were due to the quantization of light.

In 1914, James Franck and Gustav Hertz conducted a series of experiments that demonstrated the existence of excited states in mercury atoms. This experiment did not use light, but a beam of accelerated electrons to measure the energy required to lift electrons in the ground state of a gas of mercury atoms to the first excited states. **Therefore, Bohr's quantum theory was confirmed through the Franks-Hertz experiment, as the absence of light proved irrefutably the quantization of the energy in the atoms.**

3 DESCRIPTION OF THE EXPERIMENT

The sketch of the experiment is illustrated in Figure 1. Electrons are emitted by the cathode C because of the application of a voltage U_H to the filament that acts as an electron source. Such electrons are accelerated by a voltage U_1 towards a positively charged grid (the anode A), inside a glass tube full of mercury vapor. Therefore, the idea behind the experiment is that the accelerated electrons collide with the mercury atoms and undergo elastic (without any energy loss) or inelastic (with energy loss) scattering.

Beyond the grid, there is a collector plate S, maintained at a small negative retarding voltage U_2 with respect to the grid. Electrons that reach the collector plate S contribute to the collector current I_A.

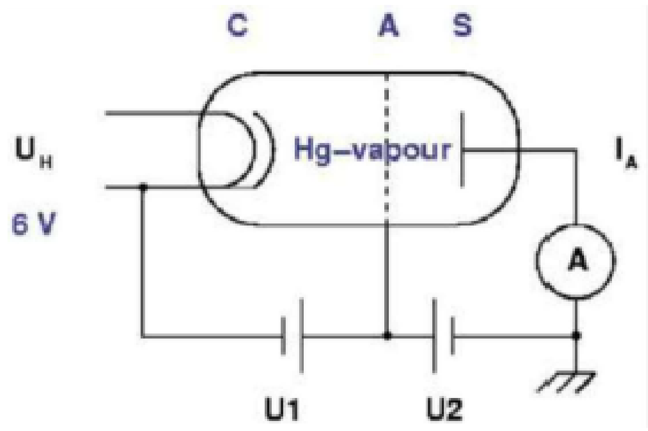

Figure 1: Principle of the measurement.

The experiment consists of recording the electron current I_A as a function of the steadily increasing accelerating potential U_1. What is observed is that first the current increases with the voltage U_1; when the energy of the impinging electron is smaller than the energy separation of the Hg states, there is no energy transfer so the collision is elastic, and therefore the accelerated electrons will reach the collector plate S and a current I_A is measured. After that, the current decreases abruptly; once the threshold energy is reached (the one required for lifting one electron of the Hg atom from the ground to the first excited state), accelerated electrons collide inelastically giving their energy to the electrons in the Hg atoms, so they remain trapped between the grid A and the collector plate S, and the current I_A sharply drops.

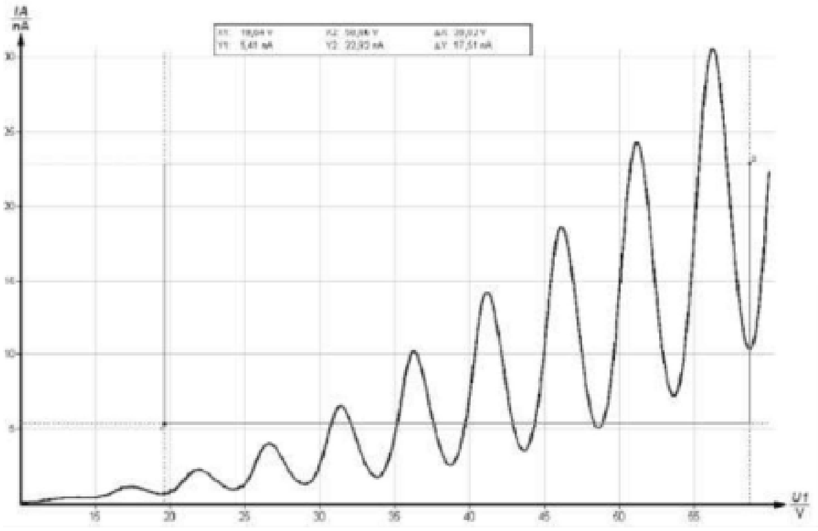

Figure 2: Example of a Franck-Hertz curve.

When the voltage U_1 continues increasing, the current increases again until the energy of the electrons coming from the cathode C is twice the excitation energy of the electrons in the Hg atoms: then, each electron can excite two atomic electrons, and afterward the current decreases again; the same happens when their energy increases to three, four, etc, times the excitation energy of the electrons in the Hg atoms, which corresponds to the successive maxima and minima of the current I_A as a function of the voltage U_1, as illustrated in Figure 2. From the spacing between U_1 minima values, the energy difference between the ground state and the first excited state of the Hg atoms, E_a, can be calculated.

4 EXPERIMENTAL SET UP AND PROCEDURE

The experiment for the observation of the atomic spectra is formed by:

- Franck - Hertz Hg-tube.
- Oven for the Franck - Hertz tube.
- Franck - Hertz control unit.
- Thermocouple NiCr-Ni, -50..1100°C.
- Computer and software for the Franck - Hertz experiment.
- Connection cables.

Proceed now using the following steps:

1. The experiment will be already set up and the oven running, as some stabilization time (around 30 minutes) is required before starting. The unit control is connected to the Franck-Hertz system and the computer. Select "*PC mode*" in that unit.
2. On the computer, select "*Sensor*" and "*Franck-Hertz Experiment*". A window will appear to select the experiment parameters (see Figure 3).

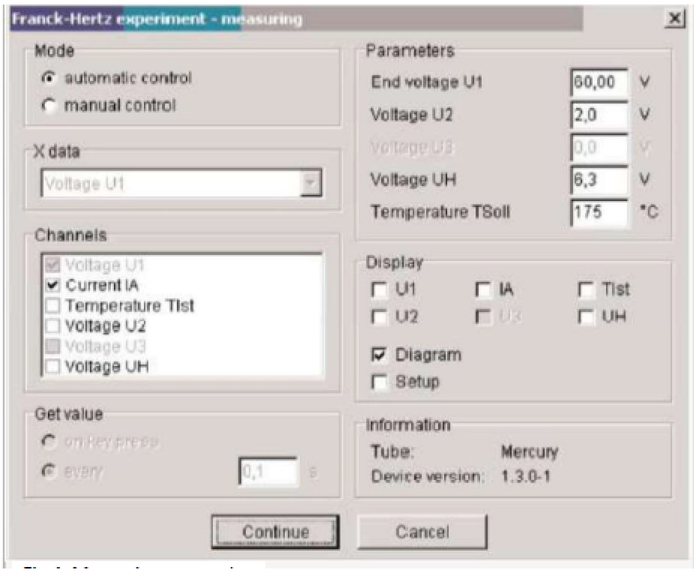

Figure 3: Example of measuring parameters.

3. Check that the temperature of the Franck-Hertz tube oven is set at $175^o\ C$ on the program and that such temperature has been reached.
4. Use these parameters for the first running of the experiment: voltage $U_H = 6.3\,V$, end voltage $U_1 = 60\ V$, and voltage $U_2 = 2\ V$. When ready, press "*Continue*". The current curve, I_A, will be shown on the computer screen as a function of U_1. Click the printer icon to save both "*Gráfico*" and "*Valores*" as *pdf* files or another format that you can later open on your computer.
5. Repeat the experiment now changing the voltage U_2 to $U_2 = 1\ V$.
6. Assure that you upload your files to your Drive account or some other cloud hosting service.

5 TASK AND QUESTIONS

- Collect all data needed according to the procedure described above.
- Determine the values of the voltage U_1 minima for the series of observed minima of I_A vs U_1 using the data of the first running of the experiment ($U_2 = 2\ V$).
- Use the U_1 minima values just obtained to determine the value of the excitation energy of the Hg atoms, E_a, by calculating the potential difference between each consecutive pair of minima and computing the average between them.
- Determine the value of E_a from the slope of the least square fitting of the relationship $U_{1,n} = E_a \cdot n + b$, where n is the order of the minima.
- Discuss the accuracy of the results obtained by both methods and the possible sources of error.
- Using the known values for electron charge, light velocity, and Plank's constant, find the wavelength of a photon associated with the calculated excitation energy. How well does it correspond to the first line of the Hg spectrum?
- Compare both graphs, the first one taken at $U_2 = 2V$ and the second one at $U_2 = 1V$. Comment on the similarities and differences that you see between them, and relate them to the purpose of the U_2 parameter.