The Franck-Hertz Experiment

1   Introduction

This is a classic experiment which provided strong evidence against classical mechanics and in the favor of the Bohr model of quantized energy states. In 1914, James Franck and Gustav Hertz bombarded mercury atoms with a beam of electrons and showed that the electrons lost discrete amounts of energy as they interacted by colliding with larger atoms. Franck and Hertz were able to show that collisions could lead to optical emission at the known spectral energies. Historically, the Franck-Hertz experiment provided one of the experimental bases for the quantum theory. Within the Bohr model, the experiment demonstrated that excitation of one of the discrete energy levels is followed by a transition back to the ground state with emission of light.

2   Apparatus Notes

The essential apparatus is an electron emitting filament, grids for accelerating the electrons to the desired (variable) energy, and an anode at which the electrons are collected. These are contained in a tube that is evacuated except for some mercury vapors. The auxiliary apparatus consists of various power supplies for heating the filament and producing the accelerating voltages, an oven (for heating the tube to produce an appropriate vapor pressure of mercury), some other apparatus for maintaining the oven at a specific temperature, an electrometer and a voltmeter. A schematic circuit diagram of the apparatus is shown in Figure 1.
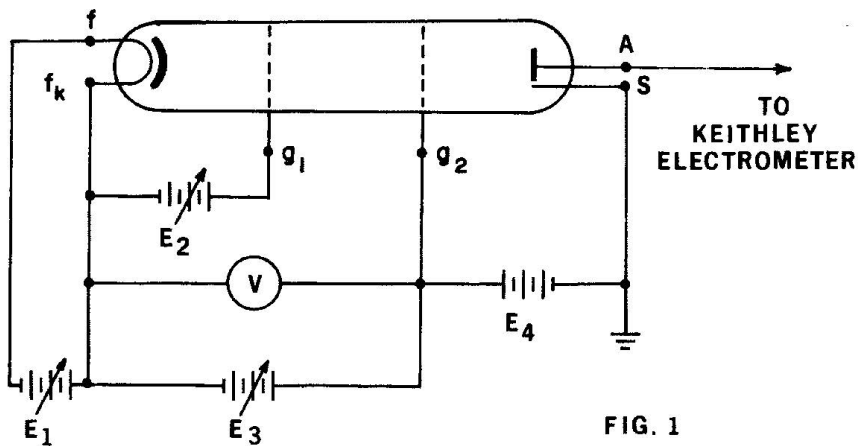

Figure 1: The Frack-Hertz apparatus

Four DC voltages are required, and these are all mounted on the same panel with their terminals and controls clearly labeled. The connections to these power supplies can be worked out from the figure:
- E1 is the filament supply,
- E2 is the screen grid voltage,

- E3 is the accelerating voltage,
- E4 is a fixed voltage to repel low energy electrons.
Electrons are emitted by the hot filament and accelerated through the E3 voltage. When an electron hits a vaporized Hg atom, it will transfer its energy. Because of the large mass difference between the electron and the atom, collisions will be inelastic and will result in energy changes internal to the atom. If the accelerating voltage is large enough and there is no energy loss in collisions, electrons will pass through the grid and continue to the collector electrode S. The electrometer measures this electron flow. Electrons which have undergone an inelastic collision will reach the grid with a lower kinetic energy and will be captured there, thus diminishing the current through the collector and electrometer. We should expect several, equally spaced current dips as we increase the accelerating voltage. They are due to the lowest energy transitions the electrons can excite in the Hg atoms.

The labels f, fk, g1, g2, and s are on the leads attached to the Franck-Hertz tube. Voltmeter V is connected to E3. The Keithley electrometer is a sensitive current meter. The Keithley output may be connected to the computer ports from the panel in the *Data acquisition* part of the experiment. Voltage E3 may be derived either from the appropriately labeled adjustable voltage supply or from the panel sweep circuit. The later provides a ramp voltage which scans (uniformly in time at a rate which is set by panel controls) through a voltage starting at 0V and finishing at 30V. You will find that at different parts of the experiment you will have to switch from one of these sources of E3 to the other.

Before any of these power supplies are turned on, the tube and oven must be heated to the operating temperature. The electrical connections for this are on a separate rack panel. The optimum values of E1 and E2 and the oven temperature will have to be determined by trial and error. It is most likely that E1 will be between 4V and 6V and E2 between 1V and 2V.

Important! Under no conditions should the tube be heated above 210^oC. When the operating temperature is reached it must be maintained constant throughout the experiment.

Important! The filament supply must be turned on before E2 and E3 are turned on. Do not turn the filament on and off!

When the apparatus is functioning correctly the anode current will show sharp dips at specific values of E3. The extremely sensitive Keithley electrometer permits measurements as small as 10^{-12} A. In general, however, the anode current will be in the range 10^{-8} A to $10^{-10}A$. The data consists of values of anode current as a function of electron energy (E3). Well-defined minima depend on the grid bias E2, and also on the temperature of the oven. If the tube has been overheated, the emission current is small, and maxima and minima can hardly be recognized or seen at all. For checking purposes, remove the tube from the oven for approximately 30 seconds. Then, if the tube was overheated before, maxima can be found. In this case, the oven temperature should be lowered. On the other hand, when the tube is not sufficiently heated, the emission current is large and the maxima, especially those of a higher order, can hardly be seen. This is because at the low mercury pressure in the tube, discharge can take place even at small voltages. When this is the case, the tube must be heated to a higher temperature. In general, the adjustment of the heating temperature is not difficult. One should change the temperature of the heater only after you are certain than there are no mistakes in the connections and that the facts observed indicate that the temperature is either too high or too low. If in doubt, check with your TA.

3   The Experiment

Part 1 Manual check
Connect the E3 voltage to the *Manual* panel ports. Slowly sweep the accelerating voltage, monitoring the electrometer reading. Adjust E1 and E2. You should observe smooth and regularly spaced raises and decreases of the electrometer readings. If not, check again the electric connections, switch the electrometer on a more sensitive scale. Move to *Data acquisition* only after you verified your setup through a manual check.

Part 2 Data acquisition

Connect E3 to the the X computer ports from the instrument panel and the the Keithley electrometer to the Y computer ports. Click on *FranckHertz.vi* shortcut located on the desktop. By default the acquisition starts immediately. Click on Clear Graph (if any graph was developed on the screen) and STOP. To start a recording, switch the Sweep Circuit to RESET then RUN. At the end of each sweep click STOP and switch to RESET in order to allow the electrometer to go back to zero. To change the graph axis, highlight the end of scale number and type another value. To read the positions of the relative maxima/minima use the two cursors.

⟹ **Questions**:

1) What is the amount of energy (in eV) transferred from an electron to an Hg atom in an inelastic collision?

2) Calculate the wavelength associated with photons emitted by Hg atoms when decaying from the first excited state to the ground state.

3) Why did Franck and Hertz use vaporized mercury and not hydrogen gas?

4) Why the dips from the current vs. accelerating voltage graph are not sharp sawtooth patterns? How did this affect your results?

What to submit: Answers to all questions; a printout of the LabView acquisition plot.

This guide sheet was revised by Ruxandra M. Serbanescu in 2017. Larry Avramidis programmed the LabView application.