Franck-Hertz Experiment

Introduction:

In 1914, James Franck and Gustav Hertz discovered in the course of their investigations an "energy loss in distinct steps for electrons passing through mercury vapor", and a corresponding emission at the ultraviolet line (λ= 254 nm) of mercury. As it is not possible to observe the light emission directly, demonstrating this phenomenon requires extensive and cumbersome experiment apparatus. They performed this experiment that has become one of the classic demonstrations of the quantization of atomic energy levels. They were awarded the Nobel Prize for this work in 1925. In this experiment, we will repeat Franck and Hertz's energy-loss observations, using argon, and try to interpret the data in the context of modern atomic physics. We will not attempt the spectroscopic measurements, since the emissions are weak and in the extreme ultraviolet portion of the spectrum.

Principle of the Experiment:

The Franck-Hertz tube is an evacuated glass cylinder with four electrodes (a "tetrode") which contains argon. The four electrodes are: an indirectly heated oxide-coated cathode as an electron source, two grids G1 and G2 and a plate A which serves as an electron collector (anode A). Grid 1 (G1) is positive with respect to the cathode (K) (about 1.5 V). A variable potential difference is applied between the cathode and Grid 2 (G2) so that electrons emitted from the cathode can be accelerated to a range of electron energies. The distance between the cathode and the anode is large compared with the mean free path length in the argon in order to ensure a high collision probability. On the other hand, the separation between G2 and the collector electrode (A) is small. A small constant negative potential UG2A ("retarding potential") is applied between G2 and the collector plate A (i.e. A is less positive than G2). The resulting electric field between G2 and collector electrode A opposes the motion of electrons to the collector electrode, so that electrons which have kinetic energy less than e•UG2A at Grid 2 cannot reach the collector plate A. As will be shown later, this retarding voltage helps to differentiate the electrons having inelastic collisions from those that don't.

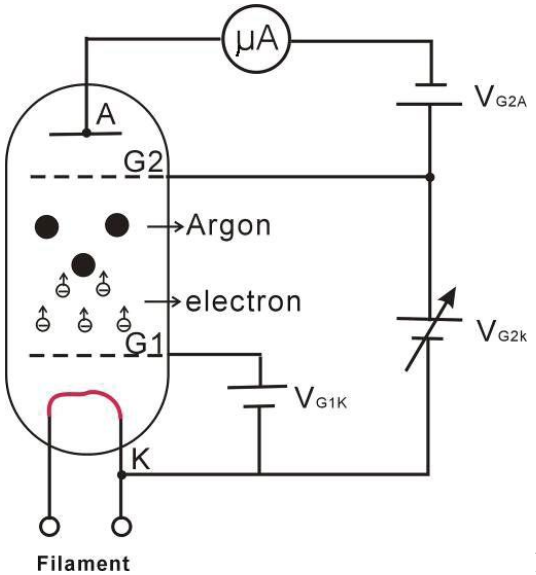


Figure 1

A sensitive current amplifier is connected to the collector electrode so that the current due to the electrons reaching the collector plate may be measured. As the accelerating voltage is increased, the following is expected to happen: Up to a certain voltage, say V1, the plate current IA will increase as more electrons reach the plate. When the voltage V is reached, it is noted that the plate current, IA, takes a sudden drop. This is due to the fact that the electrons just in front of the grid G2 have gained enough energy to collide inelastically with the argon atoms. Having lost energy to the argon atom, they do not have sufficient energy to overcome the retarding voltage between G2 and collector electrode A. This causes a decrease in the plate current IA. Now as the voltage is again increased, the electrons obtain the energy necessary for inelastic collisions before they reach the anode. After the collision, by the time they reach the grid, they have obtained enough energy to overcome the retarding voltage and will reach the collector plate. Thus IA will increase. Again when a certain voltage V2 is reached we note that IA drops. This means that the electrons have obtained enough energy to have two inelastic collisions before reaching the grid G2, but have not had enough remaining energy to overcome the retarding voltage. Increasing the voltage again, IA starts upward until a third value, V3, of the voltage is reached when IA drops. This corresponds to the electrons having three inelastic collisions before reaching the anode, and so on. The interesting fact is that V3 - V2 equals V2 - V1, etc., which shows that the argon atom has definite excitation levels and will absorb energy only in quantized amounts.

When an electron has an inelastic collision with an argon atom, the kinetic energy lost to the atom causes one of the outer orbital electrons to be pushed up to the next higher energy level. This excited electron will within a very short time fall back into the ground state level, emitting energy in the form of photons. The original bombarding electron is again accelerated toward the grid anode. Therefore, the excitation energy can be measured in two ways: by the method outlined above, or by spectral analysis of the radiation emitted by the excited atom.

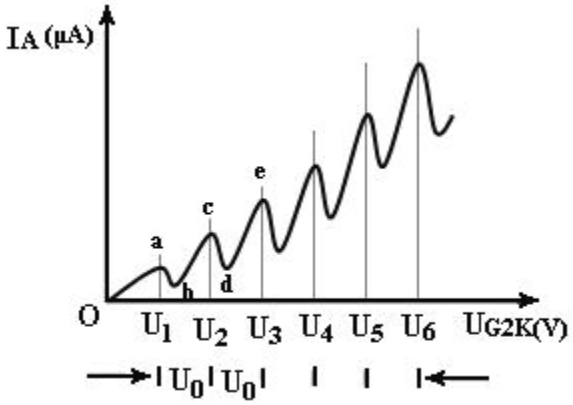


Figure 2

Figure 2 displays a typical measurement of the anode current, IA, as a function of the accelerating voltage. As soon as $V_{G2K} > V_{G2A}$ the current increases with rising V_{G2K}. Notice that the current sharply decreases for a voltage U_1 and then increases up to U_2, and then this pattern recurs. The interpretation of these observations is successful with the following assumptions:

- Having reached energy of about $e \bullet U_0$, electrons can transmit their kinetic energy to a discrete excitement state of the argon atoms.
- As a result of the inelastic collision, they pass the braking voltage.

- If their energy is twice the required value, or 2 e•U_0, they can collide two times inelastically and similarly for higher voltages.
- As a matter of fact, a strong line can be found for emission and absorption corresponding to an energy of e•U_0, the excitation energy of argon, in the optical spectrum (108.1 nm).

In figure 2, the resonance voltage is denoted by U_0.

$E \cdot U_0 = hf = hc/\lambda$ or

$h = e\lambda(U_0/c)$

where e is the charge on an electron, h is Planck's Constant, and c is the speed of light.

Procedure:

Note: Before connecting any cords or cables, be sure that all power switches on the Interface, Power Supplies, and Current Amplifier are in the OFF position and all voltage controls are turned fully counterclockwise.

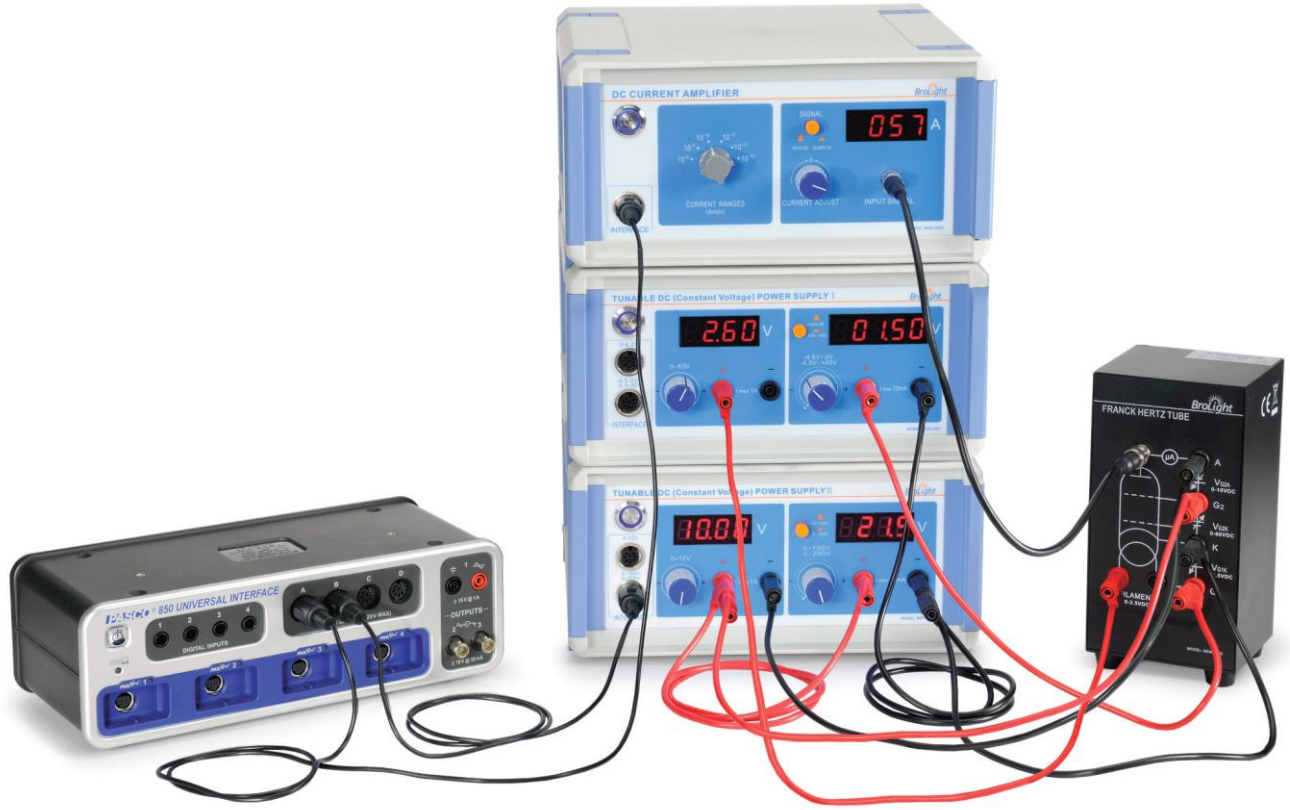


Figure 3: Frank-Hertz experimental setup

1. Connect all the cables and cords between the argon tube enclosure and the power supplies and current amplifier.
2. Connect one 8-pin DIN Extension Cable (UI-5218) from the INTERFACE port on the DC Current Amplifier to ANALOG INPUT A on the Universal Interface (UI-5100).

3. Connect a second 8-pin DIN Extension Cable from the 0 - 100V / 0 - 200V INTERFACE port on Power Supply II to ANALOG INPUT B on the Universal Interface.

4. Turn ON the power for the Universal Interface, the power supplies, and the current amplifier.

5. On the DC Current Amplifier, turn the CURRENT RANGES switch to 10-10 A. To set the current amplifier to zero, press the SIGNAL button in to CALIBRATION. Adjust the CURRENT CALIBRATION knob until the current reads zero. Press the SIGNALbutton to MEASURE.

6. On the DC (Constant Voltage) Power Supply I, set the Voltage Range switch to -4.5 – +30 V ( ). On Power Supply II, set the Voltage Range switch to 0 – 100 V ( ).

7. On Power Supply I, rotate the 0 – 6.3 V adjust knob until the voltmeter reads 2.8 V. This sets **VH** = 2.8 V (Filament Voltage). Note: The Argon Tube Enclosure may have a different suggested filament voltage. If so, use it instead of 2.8 V.

8. On Power Supply I, rotate the -4.5 – +30 V adjust knob until the voltmeter reads 1.5 V. This sets **VG1K** = 1.5 V (the voltage between the first grid and the cathode)

9. Rotate the 0 – 12 V adjust knob until the voltmeter reads 10.0 V to set **VG2A** = 10.0 V (Retarding voltage).

10. Rotate the 0 – 100 V adjust knob until the voltmeter reads 0 V. This sets **VG2K** = 0 V (Accelerating voltage).

11. Remember, allow the argon tube and the apparatus to warm up for 15 minutes.

12. When you have finished the above steps, check that **VH** = 2.8 V (Filament voltage), **VG1K** = 1.5 V (the voltage between the first grid and cathode), and **VG2A** = 10.0 V (voltage between the second grid and anode – "retarding voltage"). If so, the equipment is ready for the experiment. Note: These are suggested settings for the experiment, but other values could be tried. You can do the experiment by parameters that are marked on the Argon Tube Enclosure.

Recording Data
1. Start the PASCO Capstone software.
2. Make sure the accelerating voltage VG2K is zero.
3. After the filament has warmed up for about 15 minutes, click **Record** and slowly increase the accelerating voltage (take about two minutes to go from 0 V to 85 V). Do not exceed 85 V.

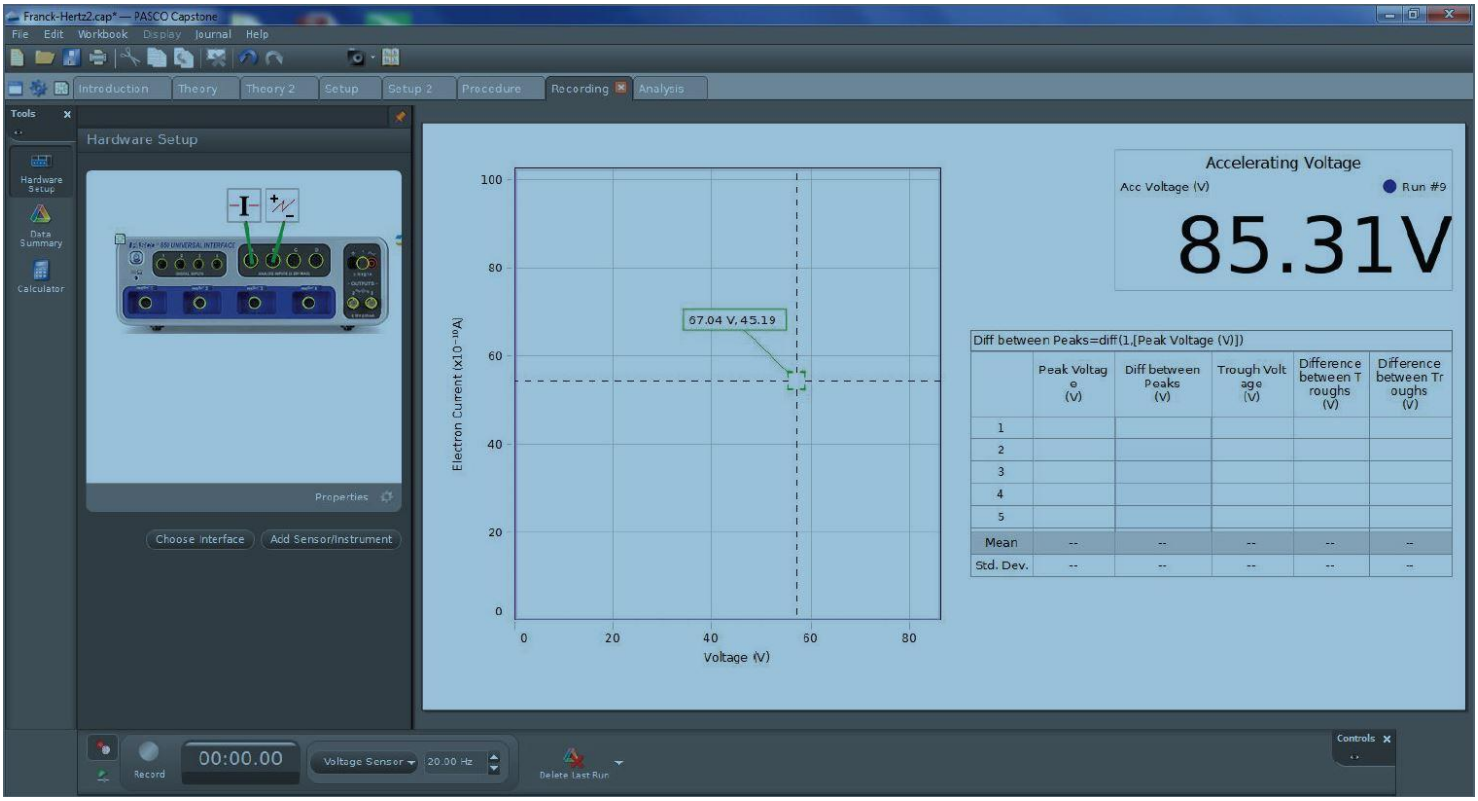
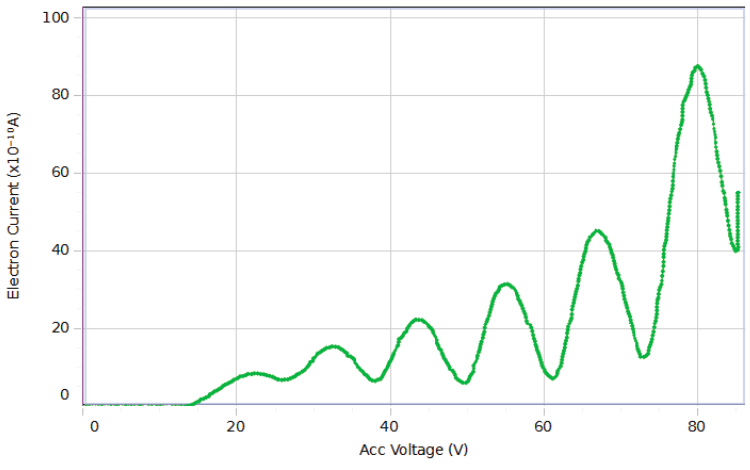


Figure 4. PASCO Capstone template

Sample Data: Using a PASCO Interface
Filament voltage (V) = 2.8 V
V_{G1K} = 1.5 V
V_{G2A} = 11.0 V

	Run #9
	All ΔV (V)
2	11.08
3	11.34
4	11.88
5	11.44
6	12.09
7	11.13
8	11.94
Mean	11.44
Std. Dev.	0.50



Diff between Peaks=diff(1,[Peak Voltage (V)])

	Peak Voltage (V)	Diff between Peaks (V)	Trough Voltage (V)	Difference between Troughs (V)
1				
2				
3				
4				
5				
Mean				
Std. Dev.				

CAUTION: While you are increasing the voltage, if you see the current suddenly increase, immediately return the voltage to zero and decrease the filament voltage slightly, Wait for a few minutes for it to cool, and repeat the recording.

Analysis

1. Using the coordinates tool on the graph, find the voltage of each of the peaks and troughs and record them in the table in the **Peak Voltage** and Trough Voltage columns respectively.

2. The voltage differences between adjacent peaks and the voltage differences between adjacent troughs will be calculated automatically in the table. Record the mean and standard deviations for the differences. The standard deviations give the uncertainties in the difference measurements.

3. Use the mean voltage difference (V_0) to calculate the value of Planck's Constant, *h*:
where **e** = 1.602 x 10^{-19} C, λ= 108.1 nm and **c** = 3 x 10^{8} m/s. The answer will be in J•s.

4. Calculate the percent difference between the experimental value and the accepted value (h_o = 6.626 x 10-34 J•s).

5. Estimate the uncertainty in the experimental value of Planck's Constant using the uncertainty in the voltage difference.

Questions

Please provide answers to the following questions at the end of the lab report.

1. Should you use the positions of the peaks or of the valleys to determine the excitation energy? Or both? Explain.

2. Why are the peaks and valleys smeared out rather than sharp?

3. How precisely can you determine the peak/valley position? Explain and justify your estimates.

4. How would molecular contaminants in the tube affect your results?