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An Exploration of The First Excitation Energy of Argon Using The Frank-Hertz Method

Evan Henderson, Monte Mahlum

McGill University Department of Physics

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Abstract

The purpose of this experiment was to determine the first excitation energy of Argon using the Franck-Hertz method. By applying a voltage across an Argon tube and analyzing the resulting current for peaks and troughs. Dips in current will occur at multiples of the first excitation energy where one or more inelastic collisions with vaporized argon atoms prevent some electrons from reaching the end of the Argon tube and registering as current. The first excitation energy of Argon was found to be 11.50 ± 0.08 eV. A value for Planck's constant was then calculated as $(4.15 \pm 0.03) * 10^{-15}$ eVs using the measured value of excitation energy. Both determined quantities are in strong agreement with known values, validating the importance of the Franck-Hertz method to the early discoveries of quantum physics.

1 Introduction

In the early 20th century, physicists began to explore the quantum nature of the atom. One of the first things noticed was that valence electrons of atoms would only absorb and emit discrete amounts of energy. Figure 1 describes these energy levels in the Hydrogen Atom. The purpose of this experiment was to determine the first excitation energy of gaseous Argon by replicating the famous Franck Hertz experiment.

First, electrons are accelerated across a potential difference and then collide with gaseous atoms as they pass through a decelerating field. Finally, the electrons with great enough kinetic energy to overcome the reverse bias strike the anode and register as current. As electrons collide with the gaseous atoms, many are deflected elastically, as they do not have the specific discrete amount of energy required to excite valence electrons. Those that do collide inelastically, lose most of their kinetic energy. These slowed down electrons then do not have sufficient kinetic energy to overcome the reverse bias and cannot collide with the anode. It is then possible to measure at which accelerating voltages these inelastic collisions are occurring because the current is observed to decrease sharply at these voltages. It was expected that these dips in current would occur periodically, where the electrons have kinetic energy equal to some multiple of the first excitation energy of argon. This is because after making one inelastic collision, the electron still has sufficient energy to make another inelastic collision, hence decreasing the odds that it reaches the anode and registers as current. Absorption energy (E) is characterized by the equation:

$$E = h * \frac{c}{\lambda}, \tag{1}$$

where h is plank's constant, c is the constant of the speed of light in a vacuum, and λ is the wavelength of the photon emitted during the absorption.

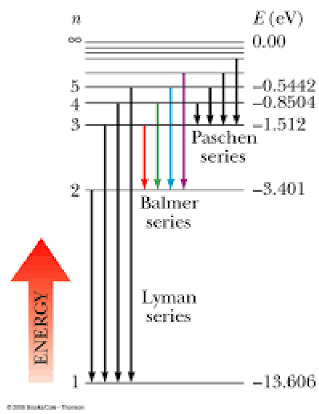


Figure 1: Emission series of Hydrogen demonstrating discrete energy of valence electrons. [1]

2 Materials

SE-9650 Argon Tube Enclosure, SE-6621 Current Amplifier,SE-6615 Power Supply I, SE-9644 Power Supply II, Pasco, Computer, Conductive Wires (5 red, 4 black).

3 Methodology

1. First, lab setup was prepared in the same way as shown in figure 3 in Appendix C.
2. Next the Pasco, the DC Current Amplifier, the Power Supply I and the Power Supply II were all turned on.
3. Current was calibrated to be as close to zero as possible (on the order of 10^{-15} amps).
4. Voltage values were initially set to $V_{G1K} = 1.5$ V, $V_{G2A} = 9.5$ V, $V_{G2K} = 0$ V and $V_H = 2.3$ V.
5. Argon tube was given 15 minutes to warm up.
6. Current was measured at intervals of 0.3 V as V_{G2K} was increased from 0 V to 80 V.
7. Step 6 was repeated for $V_{G2A} = 10.5$ V.
8. Step 6 was repeated for $V_{G2A} = 9.5$ V, $V_H = 2.8$ V.

4 Results

In this experiment, electrons were passed through Argon gas three times under different initial conditions. In each trial, the electron-accelerating voltage was increased and the current, measuring the amount of electrons that reached the back panel, exhibited oscillatory behavior as seen in figure 2. These oscillations were quantified by finding the average change in voltage between peaks, and between troughs, independently (Table 1). These values act as the period of these oscillations. Because the voltage periods from all trials were in strong agreement with each other, it appears that the initial conditions did not effect the outcome. Because of this, the voltage periods were then averaged between all trials and scaled by a factor of e to obtain a value for Argon's first excitation energy, E, in eV. Lastly, Planck's Constant, h, was calculated through equation 1 using the experimental value for E, along with literature values for λ (wavelength from Argon's first excitation) and c, the speed of light (Table 2).

Figure 2: Example Oscillatory Behavior of Current Over Voltage In Frank-Hertz Argon Tube, Taken From Trial 2

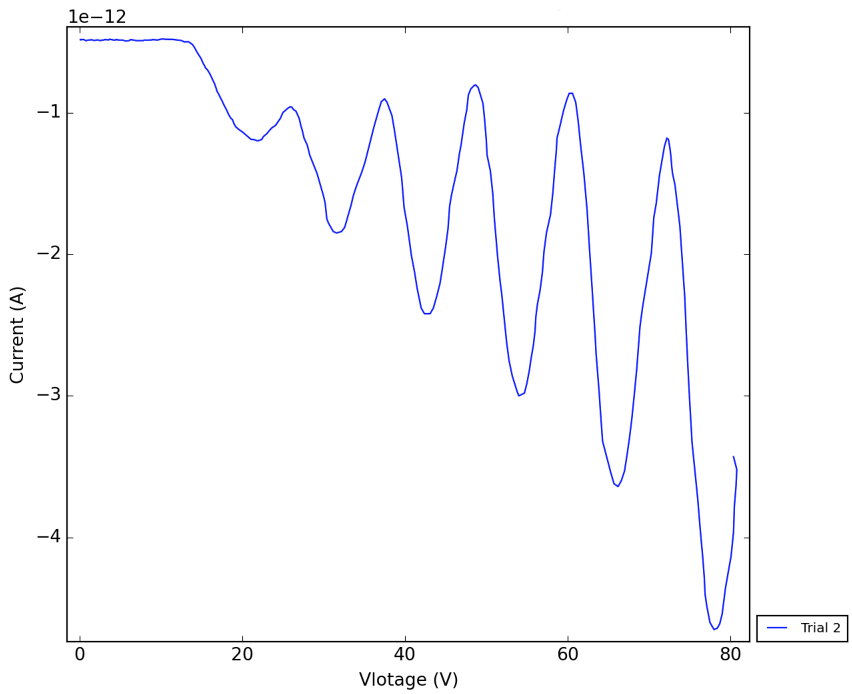


Table 1: The Average Change In Voltage Measured Between Peaks(ΔV_P), and Between Troughs (ΔV_T) of Oscillatory Current

	ΔV_P (V)	$\sigma_{\Delta V_P}$($\pm$ V)	ΔV_T(V)	$\sigma_{\Delta V_T}$($\pm$ V)
Trial 1	11.4	0.2	11.6	0.2
Trial 2	11.3	0.2	11.5	0.2
Trial 3	11.5	0.2	11.7	0.2
Average	11.50 ± 0.08			

Table 2: Planck's Constant h And The Relevant Values Used In Calculation

	Energy (eV)	λ(nm)	c (ms^{-1})
Value:	11.50 $\pm$ 0.08	108.1 [2]	299792458 [3]
Experimental h (eVs)	$(4.15 \pm 0.03) * 10^{-15}$		
Literature h (eVs)	$4.1357 * 10^{-15}$ [4]		

5 Discussion

This experiment measured the first excitation energy of Argon to be 11.50 $\pm$ 0.08 eV. This value was then used to calculate Planck's Constant h, which was found to be (4.15 $\pm$ 0.03)$*10^{-15}$ eVs. Both values are in strong agreement with the literature values (11.4694 eV [4]), and (4.135667696...$*10^{-15}$ [4]) respectively. A discussion of all uncertainties used in these derivations can be found in *Second Appendix: Uncertainties*. This experiment is also in support of the Bohr Model of the atom. As accelerating voltage increased, the current shows oscillatory behavior. These oscillations imply that despite an increase in voltage, the electrons' ability to reach the back panel dipped periodically. From this it can be inferred that Argon accepts electrons only once they have a specific energy. When the voltage creates any multiple of this excitation energy, many electrons then have enough kinetic energy to provide the required excitation energy to multiple atoms which explains why multiple dips occur. This inference is what allowed for the excitation energy to be deduced from the voltage period as described in *Results*.

The data from this experiment does not show any evidence of interference coming from other energy levels. This could be a result of either the accelerating voltage not becoming high enough for the other energy levels to become relevant or the other energy levels could be close enough to the first excitation energy such that their interference is indistinguishable under this precision. The latter explanation seems more likely because Bohr's model predicts that the change in energy between each level decreases with each new one. Therefore, more precise data should be taken near the peaks and troughs of figure 2 to investigate possible interference. While the experimental values are in strong agreement with the accepted ones, they do deviate slightly from ideal and the interference coming from other energy levels provides one explanation for this deviation.

6 Conclusions

It has been seen that Argon atoms accept only specific kinetic energies of p

The Franck-Hertz method identified the first excitation energy of Argon to be 11.50 ± 0.08 eV. From this Planck's constant was found to be to be $(4.15 \pm 0.03)*10^{-15}$ eVs. Both are in strong agreement with literature values. This reinforces the usefulness of the Frank-Hertz setup in determining the first excitation energy of any vaporized atom and its historical importance of confirming the quantization of valence electron energy. This experiment confirmed the basics of the Bohr model over one hundred years ago, leading to a barrage of new experiments to more rigorously explore the new field of quantum physics.

References

[1] UC San Diego. (2007, October). Physics 1C - Lecture 29A. Retrieved Feburary 1, 2022, from Physics UCSD: https://courses.physics.ucsd.edu/2011/Fall/physics1c/Lectures/F11Physics1CLec29A.pdf 2

[2] Pasco. (2015) Franck-Hertz Experiment. Model SE-9639 Instruction Manual 4

[3] Speed of light in a vacuum. (n.d.) Collins Dictionary of Astronomy. (2006). Retrieved February 2 2022 from https://encyclopedia2.thefreedictionary.com/Speed+of+light+in+a+vacuum 4

[4] "2018 CODATA Value: Planck constant". The NIST Reference on Constants, Units, and Uncertainty. NIST. 20 May 2019. Retrieved 2021-04-28. 4

A First Appendix: Author Contribution Statements

Monte Mahlum

M.M contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

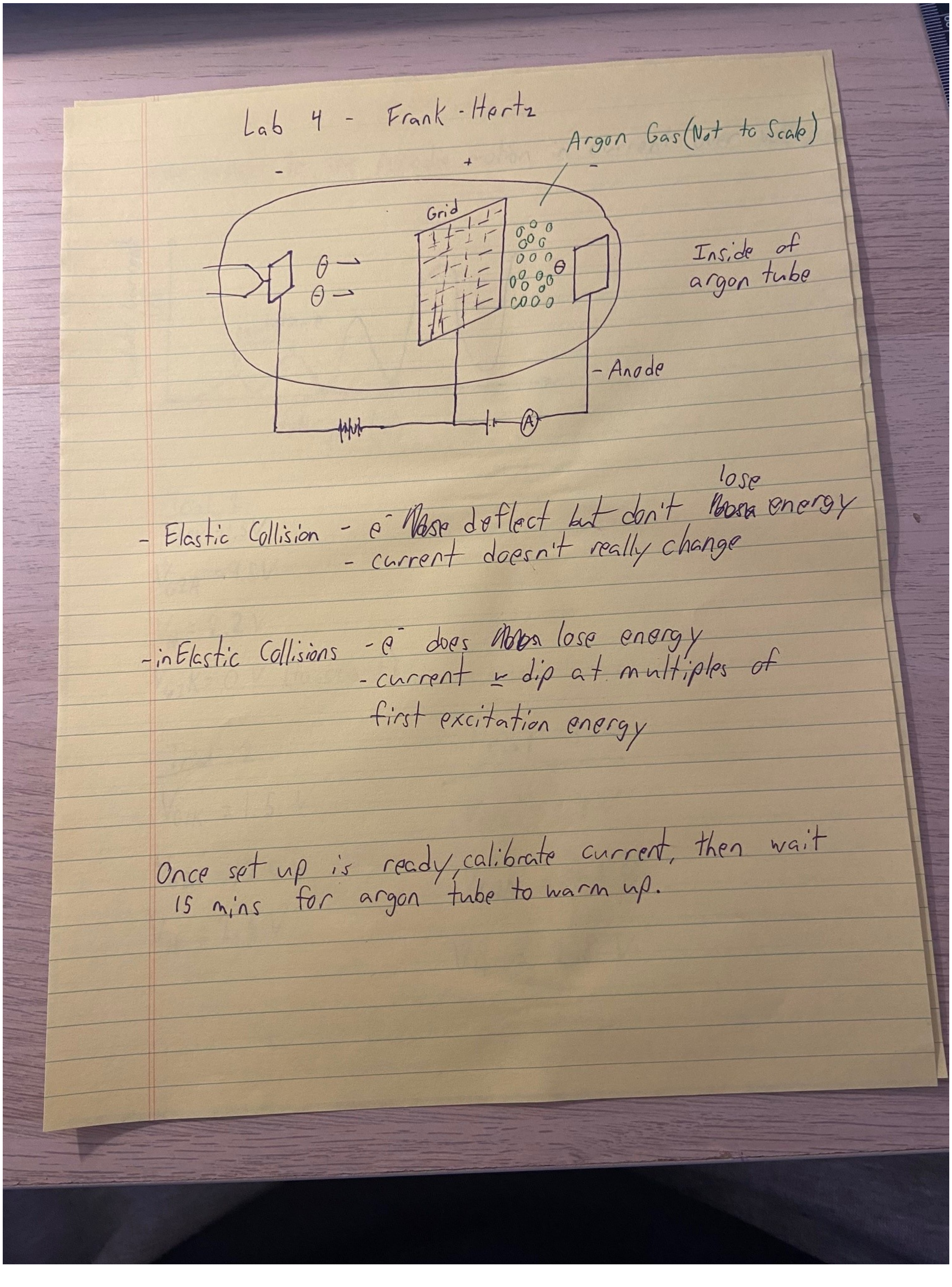
Evan Henderson

E.H contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

B Second Appendix: Uncertainties

The uncertainty on excitation energy comes directly from the uncertainty on Voltage. This value was taken to ± 0.2 V which was the average ΔV between each data point. This error was reduced by averaging multiple measurements. It was then propagated through equation 1 to obtain uncertainty on h.

C Third Appendix: Lab Book



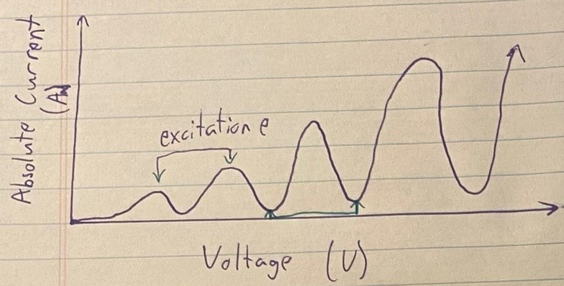
Lab 4 - Frank-Hertz

- Elastic Collision - e^- deflect but don't lose energy
  - current doesn't really change

- inElastic Collisions - e^- does lose energy
  - current $\simeq$ dip at multiples of first excitation energy

Once set up is ready, calibrate current, then wait 15 mins for argon tube to warm up.

- we expect to see periodic motion in current over voltage



Trial 1

$V_{G1K} = 1.5 V$

$V_{G2A} = 9.5 V$

$V_H = 2.3 V$

$V_{G2K} = 0 V$ (to start)

Trial 2

$V_{G1K} = 1.5 V$

$V_{G2A} = 10.5 V$

$V_H = 2.3 V$

Trial 3

$V_{G1K} = 1.5 V$

$V_{G2A} = 9.5 V$

$V_H = 2.8 V$

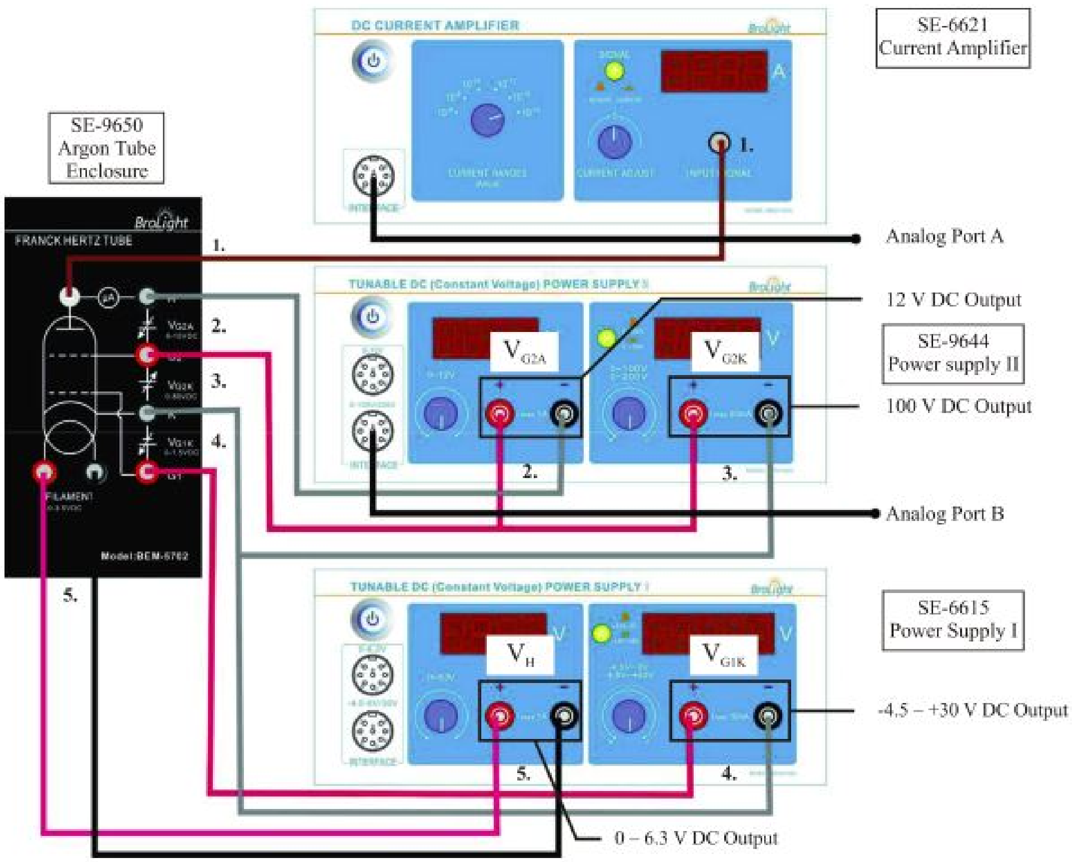


Figure 3: Lab setup of Franck-Hertz Experiment. (Pasco. 2015)