Excitation and Ionization of Helium Experiment

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CONTENTS

I Introduction 1

II THEORETICAL BACKGROUND 1
- II-A Atoms Quantum Nature 1
- II-B Elastic and Inelastic collisions 1

III EXPERIMENTAL DESIGN AND PROCEDURE 1
- III-A Description of the apparatus 1
- III-B Description of the experimental procedure 2
  - III-B1 Helium excitation 2
  - III-B2 Helium Ionization 2

IV ANALYSIS 2
- IV-A Method of analysis 2
- IV-B Discussion of results 3

V Conclusion 3

VI Appendix I 3

References 5

LIST OF FIGURES

1 Elastic and Inelastic collisions 1
2 The circuit Diagram 1
3 V_f= 2.6V, Helium excitation 3
4 V_f= 2.6V, Helium excitation 3
5 V_f= 2.3V, Helium excitation 3
6 V_f= 2.3V, Helium excitation 3
7 V_f= 2.1V, Helium excitation 4
8 V_f= 2.1V, Helium excitation 4
9 V_f= 1.8V, Helium excitation 4
10 V_f= 1.8V, Helium excitation 4
11 V_f= 2.6V, Helium Ionization 4
12 V_f= 2.3V, Helium Ionization 4
13 V_f= 2.1V, Helium Ionization 5
14 V_f= 1.8V, Helium Ionization 5

LIST OF TABLES

I Calculated Critical Potentials for Helium 5
II Calculated correction values using ionization potentials 5
III Corrected critical potentials for Helium 5
IV % Difference between the Average corrected values and the Actual Values of Helium 5

Excitation and Ionization of Helium Experiment

***Abstract*—The purpose of the experiment is to confirm that electrons occupy only discrete, quantized energy states, according to the quantum theory. This is achieved by recording the excitation and the ionization potentials of helium gas. In the experiment, accelerated electrons are emitted with varying voltage in the helium gas tube, the electrons which undergo inelastic collisions will be collected from the collector ring and a current peak results in the data recorder. The obtained graphs show that only certain energies are absorbed and released.**

I. Introduction

In 1913, Bohr introduced his atom model, which shows that toms have quantized specific energy levels. Bohr formulated that the change in energy levels is $\Delta E = hf$, were f is the frequency and h is planck's constant. Bohr's equation shows that the absorption of discrete energies transferred by these photons, happens only at certain light's frequencies. Also, Planck explained black body radiation, based on the idea that atoms have quantized energy levels. In 1914, James Frank and Gustav Ludwig Hertz designed this experiment to confirm Bohr's quantum model of atoms.

Franck and Hertz experiment achieves its goal by making helium atoms collide with electrons in a tube, some of these electrons will collide elastically and some will collide inelastically according to their energies, and then they observed if the electrons – same idea as photons- lost their kinetic energy at certain quantized energies. We have to mention that the experiment we performed uses a different method from Franck and Hertz's experiment. In the experiment we performed, we are collecting electrons that have lost energy in inelastic collisions and then recording the current that shows peaks when these electrons are collected. However, In the Franck-Hertz experiment, a decrease of the current is recorded as a result of the electrons energy loss. [2]

II. THEORETICAL BACKGROUND

A. Atoms Quantum Nature

The assumptions of the Bohr model of Atom [1]:

1) The electron moves in circular orbits around the nucleus
2) Only certain orbits are stable, which are ones in which the electrons don't radiate, such that the energy is stationary in time.
3) Radiation is emitted (or absorbed) by the atom when electrons gain and lose energy by jumping from one allowed orbit to another. The frequency f of the absorbed or emitted radiation is determined by the energy difference of the levels, Planck-Einstein's equation:

$$E_i - E_f = hf$$

B. Elastic and Inelastic collisions

When the electrons are emitted by the heated filament (cathode), they then are accelerated toward a ring which has a slightly positive potential. If electrons have sufficient energy and undergo an elastic collision, there will be no change in the total kinetic energy when the electrons collide with helium atoms. Those electrons will reach the glass envelope of the tube, and then they will pass through the conductive layer on the glass.

However, if the electrons have just the right amount of energy, they will undergo an inelastic collision, where the travelling electrons lose some of their kinetic energy which in return, is deposited into the helium atom. The atom is now is an excited state, eventually, the atom will emit light, and return to its ground state. The electrons which undergo inelastic collisions will be attracted to the collector ring.

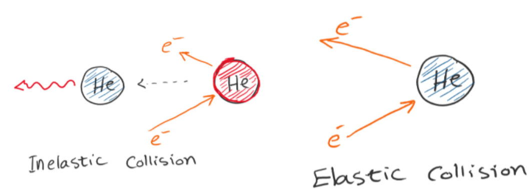

Fig. 1. Elastic and Inelastic collisions

III. EXPERIMENTAL DESIGN AND PROCEDURE

A. Description of the apparatus

The used apparatus consists of :

1) Filament Vf supply: 30V supply of the TEL 2800(LV)
2) Helium Tube: Cathode Filament, Anode, and Collector ring.
3) Va Supply: 60V supply of TEL 2801 (HV)
4) Picoamplifier
5) Data Recorder
6) Battery

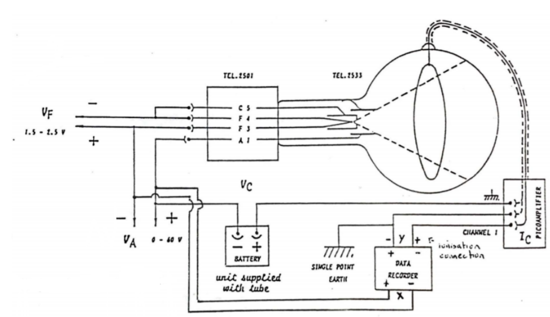

Fig. 2. The circuit Diagram

The circuit was wired according to Figure 2. The tube is filled with Helium Gas and it consists of a cathode filament, an node, and a collector ring. The filament is connected to Power supply V_f and when it's heated, the electrons are emitted and then accelerated by an anode with a small hole in it which is connect to a varying potential Va. The battery is connected to the collector ring to give it a slightly positive potential or a negative potential depending on if we are doing excitation or ionization parts.

Some of these accelerated electrons will collide elastically and some will collide inelastically according to their energies, the electrons which collided elastically will go through the tube and then eventually will go back to the anode through a conductive layer, on the other hand, the electrons which lost their energies in the inelastic collisions will be attracted to the collector ring. Using the data recorder, we can chart the Va against the collected current, and the peaks show when the electrons that collided inelastically and lost their energies are collected. The data recorder had two inputs to chart X against Y. X axis is connected directly to the anode voltage supply, while Y is connected to the output voltage that is coming from the picoamplifier.

B. *Description of the experimental procedure*

We divided this experiment in two part: Excitation part and Ionization part.

1) Helium excitation:

1) We adjusted V_f supply to 2.6V
2) We connected the battery with the right polarity such that the collector is at a positive potential relative to the cathode, the electrons are attracted to the ring after they collide with the gas's atoms.
3) We adjusted the chart recorder such that the scan range is 0-50V such that the electrons with have sufficient energy to cause excitation two times.
4) We examined the lower critical region in detail by adjusting the data recorder to scan in the range 0 – 26V.
5) We repeated the same procedure for V_f = 1.8V, 2.1V and 2.3V

2) Helium Ionization:

1) In this case, we reversed the battery potential because we are detecting the positive ion current, so that the collecting ring is at a negative potential negative to the cathode.
2) We then reversed the Y axis leads inputs on the back of the data recorder.
3) We examined the ionization by adjusting the data recorder to scan in the range 0 – 30V for V_f = 1.8V, 2.1V and 2.3V.

IV. ANALYSIS

A. *Method of analysis*

The primary method used to analyze the data was to find the ratio between the acceleration voltage and the length of the plot. By doing so, determining the critical potentials were made possible while minimizing the error.

The following is a sample calculation used to determine the first critical potential when the filament voltage is approximately 2.6V:

$$P = \frac{V_{acc}}{L} = \frac{50.1V}{18.2cm} = 2.75\frac{V}{cm}$$

$$P_{crit} = x_1 P = \left(6.2cm \times 2.75\frac{V}{cm}\right) = 17.1V$$

The following is a sample error calculation for the determined critical potential when the filament voltage is approximately 2.6V:

$$\Delta P_{crit} = P_{crit}\sqrt{\left(\frac{\Delta V_{acc}}{V_{acc}}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta x_1}{x_1}\right)^2}$$

$$\Delta P_{crit} = 17.1V\sqrt{\left(\frac{0.1V}{50.1V}\right)^2 + \left(\frac{0.1cm}{18.2cm}\right)^2 + \left(\frac{0.1cm}{6.2cm}\right)^2}$$

$$\Delta P_{crit} = 0.293V$$

Since the calculated critical potential is not similar to the actual value, we need to add the correction value. The correction term is found from the ionization scan of Helium. The correction value is calculated by taking the difference between the points where the electrons start to ionize completely and the points where the excited electrons ionize prior to the actual ionization.

The following is a sample calculation used to determine the correction value for the ionization potential and its error range when the filament voltage is approximately 2.6V:

$$P_{ion} = P_{complete} - P_{prior} = \left(\frac{36.3V - 4.5V}{15.8cm}\right)(8.9cm - 6.4cm)$$

$$P_{ion} = 5.0V$$

$$\Delta P_{ion} = P_{crit}\sqrt{\left(\frac{\Delta V_{acc}}{V_{acc}}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta x_1}{x_1}\right)^2}$$

$$\Delta P_{ion} = 5.0V\sqrt{\left(\frac{0.1V}{31.8V}\right)^2 + \left(\frac{0.1cm}{15.8cm}\right)^2 + \left(\frac{0.1cm}{2.5cm}\right)^2}$$

$$\Delta P_{ion} = 0.203V$$

The following is a sample calculation used to determine the corrected first critical potential when the filament voltage is approximately 2.6V:

$$P_{corr} = P_{crit} + P_{ion} = 17.1V + 5.0V = 22.1V$$

$$\Delta P_{corr} = P_{corr}\sqrt{\left(\frac{\Delta P_{crit}}{P_{crit}}\right)^2 + \left(\frac{\Delta P_{ion}}{P_{ion}}\right)^2}$$

$$\Delta P_{corr} = 22.1V\sqrt{\left(\frac{0.293V}{17.1V}\right)^2 + \left(\frac{0.203V}{5.0V}\right)^2}$$

$$\Delta P_{corr} = 0.974V$$

The %error between the actual critical potential and the corrected critical potential is:

$$\%error = \frac{|22.1V - 19.80V|}{19.80} \times 100\% = 11.62\%$$

B. Discussion of results

In general, the data matched the theory and most of the critical potentials were very close to the actual value. Looking at Table 1 in Appendix 1 (located at the end of the report), we see that the measured potentials are fairly close to the actual values and Table 2 shows that the correction value is around 5 V on average. However, in Tables 3 and 4, we see that the measured third excitation is almost twice as big as the actual excitation value. This tells us that there was a measurement error for all third excitations. The % difference of the ionization potentials are around 11% on average and were the most accurate measurements done in this experiment. The % difference of the excitation potentials were 12.7% for the first excitation, 18.5% for the second excitation and 96.9% for the third excitation.

V. Conclusion

In conclusion, this experiment was a success as most of the excitation and ionization potentials were measured accurately and matched the theory. The % difference of the ionization potentials are around 11% on average and were the most accurate measurements done in this experiment. The % difference of the excitation potentials were 12.7% for the first excitation, 18.5% for the second excitation and 96.9% for the third excitation due to a human error.

VI. Appendix I

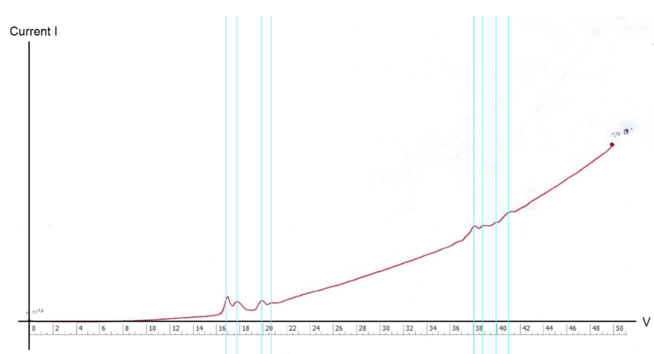

Fig. 3. V_f= 2.6V, Helium excitation

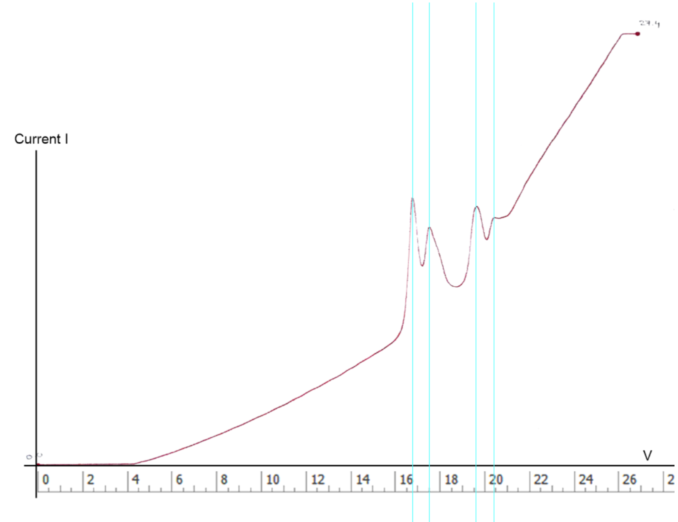

Fig. 4. V_f= 2.6V, Helium excitation

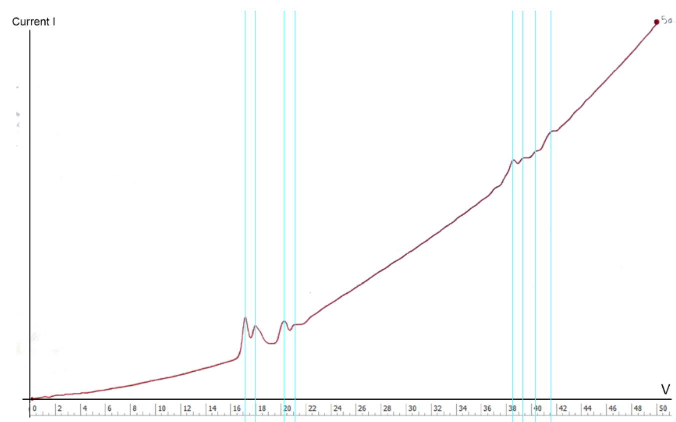

Fig. 5. V_f= 2.3V, Helium excitation

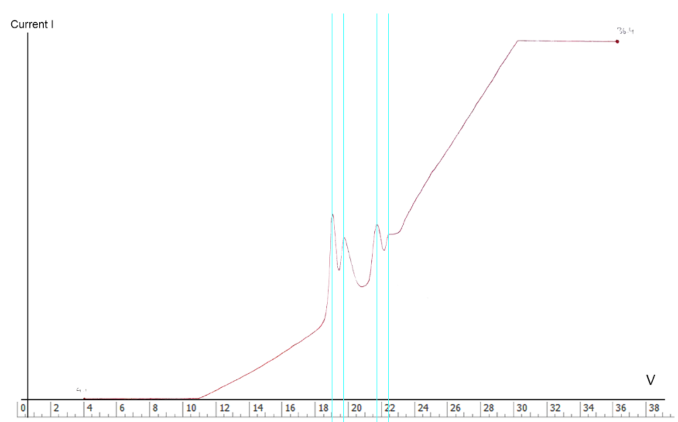

Fig. 6. V_f= 2.3V, Helium excitation

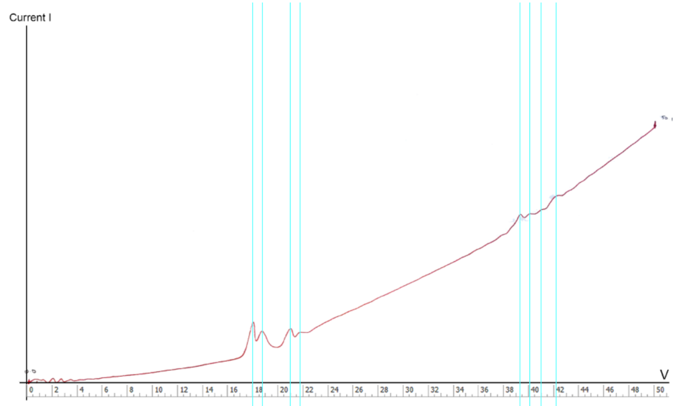

Fig. 7. V_f= 2.1V, Helium excitation

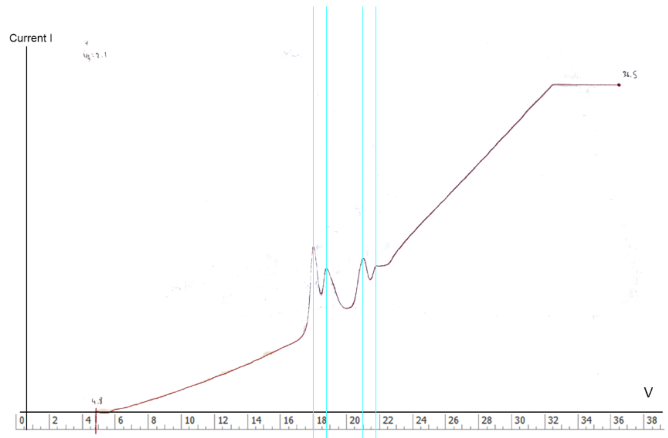

Fig. 8. V_f= 2.1V, Helium excitation

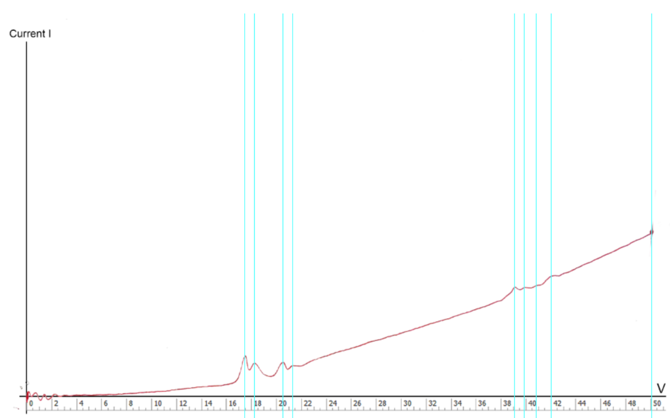

Fig. 9. V_f= 1.8V, Helium excitation

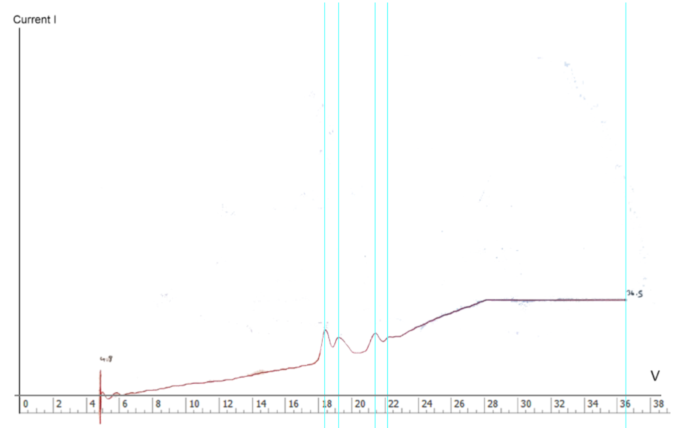

Fig. 10. V_f= 1.8V, Helium excitation

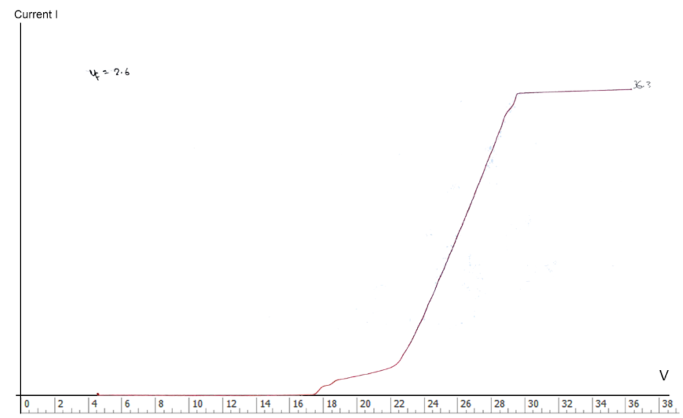

Fig. 11. V_f= 2.6V, Helium Ionization

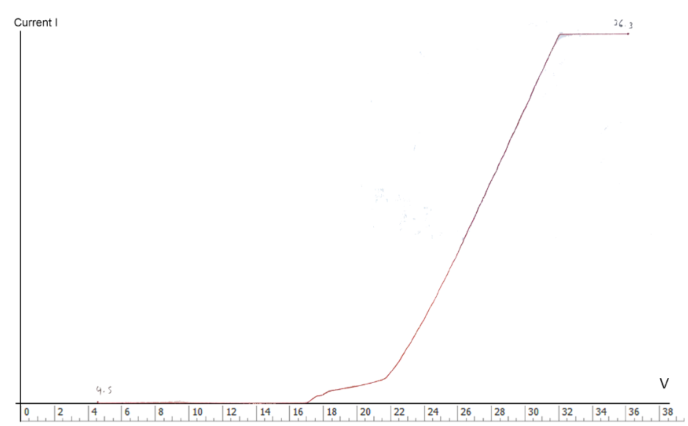

Fig. 12. V_f= 2.3V, Helium Ionization

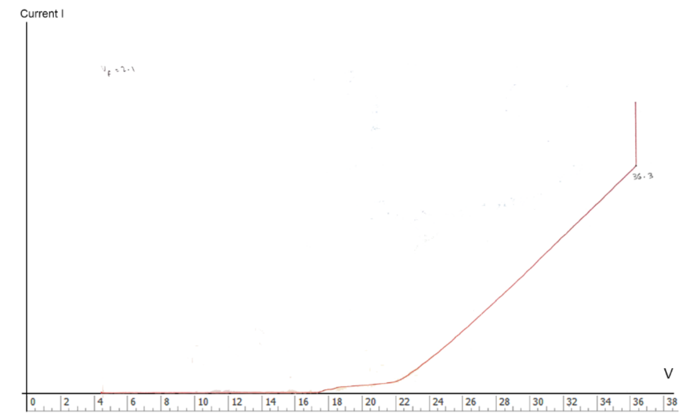

Fig. 13. V_f= 2.1V, Helium Ionization

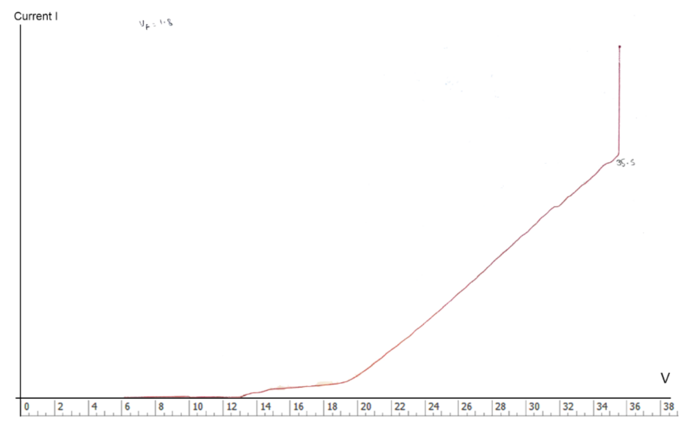

Fig. 14. V_f= 1.8V, Helium Ionization

TABLE I. CALCULATED CRITICAL POTENTIALS FOR HELIUM

V_f(V)	1^{st} Excitation (V)	$\pm\Delta V$	2^{nd} Excitation (V)	$\pm\Delta V$	3^{3d} Excitation (V)	$\pm\Delta V$
2.6	17.07	0.29	17.89	0.29	37.99	0.35
			19.82	0.30	38.81	0.36
			20.65	0.30	39.91	0.36
					41.02	0.37
2.3	16.95	0.27	17.95	0.27	38.39	0.32
			20.19	0.27	39.38	0.33
			20.94	0.27	40.38	0.33
					41.63	0.33
2.1	17.30	0.32	17.89	0.32	38.47	0.38
			20.28	0.32	39.36	0.39
			20.88	0.33	40.26	0.39
					41.45	0.40
1.8	16.91	0.33	17.54	0.33	38.83	0.40
			20.04	0.34	39.77	0.41
			20.67	0.34	40.71	0.41
					41.96	0.42

TABLE II. CALCULATED CORRECTION VALUES USING IONIZATION POTENTIALS

V_f (V)	Correction Values (V)	$\pm\Delta V$	Ionization Potentials (V)	%diff. of ionization
2.6	5.00	0.20	22.91	7%
2.3	4.86	0.21	22.28	9%
2.1	4.60	0.20	22.20	10%
1.8	6.54	0.22	20.06	18%

TABLE III. CORRECTED CRITICAL POTENTIALS FOR HELIUM

V_f(V)	1^{st} Excitation (V)	$\pm\Delta V$	2^{nd} Excitation (V)	$\pm\Delta V$	3^{3d} Excitation (V)	$\pm\Delta V$
2.6	22.07	0.97	22.89	1.00	42.99	1.79
			24.82	1.08	43.81	1.82
			25.65	1.11	44.91	1.87
					46.02	1.91
2.3	21.81	0.98	22.81	1.02	43.25	1.86
			25.05	1.11	44.24	1.91
			25.80	1.14	45.24	1.95
					46.49	2.00
2.1	21.90	1.04	22.49	1.07	43.07	1.94
			24.88	1.17	43.96	1.98
			25.48	1.19	44.86	2.02
					46.05	2.08
1.8	23.45	0.90	24.08	0.92	45.37	1.58
			26.58	0.99	46.31	1.61
			27.21	1.01	47.25	1.64
					48.50	1.68

TABLE IV. % DIFFERENCE BETWEEN THE AVERAGE CORRECTED VALUES AND THE ACTUAL VALUES OF HELIUM

Average corrected values		
First Excitation	Second Excitation	Third Excitation
18.31	17.82	39.67
	20.08	40.58
	20.78	41.56
		42.76
Actual Values		
First Excitation	Second Excitation	Third Excitation
19.8	20.61	22.71
	20.96	22.91
	21.21	23.00
		23.08
Difference Between Average and Actual Values		
7.5%	13.6%	74.7%
	4.2%	77.1%
	2.0%	80.7%
		85.3%

REFERENCES

[1] Serway, R., Moses, C., & Moyer, C. (2005). Modern physics. Belmont, CA: Thomson Brooks/Cole.

[2] Franck–Hertz experiment. (2018). — Wikipedia, The Free Encyclopedia. Retrieved from https://en.wikipedia.org/wiki/Franck–Hertz_experiment