Determining Argon Ionization Potential

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***Abstract*—In this paper, the ionization potential of argon gas is determined using the Langmuir Child equation. The voltage of a flux tube containing argon gas was set to different values and the current recorded. The calculated ionization potential for bulb#1 and bulb#2 was found to be 17.00 ev and 15.70ev respectively , which has a percentage error of 7.87% and 0.38% respectively from the accepted value of 15.76 ev.**

I. Introduction

Among the many properties that gaseous substances have, the ionization potential is one of the most important, since with it known, substances can be exploited for their electrical properties, and even beyond their practical use, much of the quantum mechanical structure of the atom can be understood by studying the ionization potential. Therefore methods of determining ionization potentials is essential.

In this experiment, the ionization potential of argon is found using the Langmuir Child equation. Within a vacuum flux tube, the Langmuir Child equation dictates that the voltage will be linear to the current to the exponent of (2/3). In the case of an ionized gas however, this relation is no longer valid.

By varying the voltage and plotting the voltage against the current to the power of (2/3), we may find the ionization potential as the specific voltage when the Langmuir Child equation is violated.

II. THEORETICAL BACKGROUND

In order to derive the Langmuir Child equation, first consider a vacuum tube with a potential difference V across two plates, and a current J flowing from the anode to the cathode. The kinetic energy of the electrons in the tube would be given by the following where m is the mass of an electron, and e is the charge of an electron. [1]

$$\frac{1}{2}mv^2 = Ve \tag{1}$$

The charge density is then given by

$$\rho = \frac{J}{v} \tag{2}$$

Recall the one dimensional Poisson equation

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon_0} \tag{3}$$

By plugging in ρ and eliminating v from our expression, this becomes:

$$\frac{d^2V}{dx^2} = -\frac{J}{\varepsilon_0\sqrt{\frac{2Ve}{m}}} \tag{4}$$

In order to integrate this, consider the following trick

$$\int \frac{d^2V}{dx^2}\frac{dV}{dx}dx = \left(\frac{dV}{dx}\right)^2 - \int \frac{d^2V}{dx^2}\frac{dV}{dx}dx \tag{5}$$

$$\left(\frac{dV}{dx}\right)^2 = 2\int \frac{d^2V}{dx^2}\frac{dV}{dx}dx \tag{6}$$

The integral then becomes

$$\left(\frac{dV}{dx}\right)^2 = \frac{4J}{\varepsilon_0}\sqrt{\frac{2e}{m}}\sqrt{V} + C \tag{7}$$

The constant in this corresponds to the derivative of the voltage at $x = 0$. If we assume that is zero, the solution to this equation turns into the following

$$V = \left(\frac{3}{2}\right)^{\frac{4}{3}}\left(\frac{J}{\varepsilon_0}\right)^{\frac{2}{3}}\left(\frac{m}{2e}\right)^{\frac{1}{3}}x^{\frac{4}{3}} + C \tag{8}$$

Again, the constant corresponds to the voltage at $x = 0$. If we assume it is zero, we may ignore it. Using the boundary condition at $V(D)$, this becomes the following:

$$J = \frac{4}{9}\varepsilon_0\sqrt{\frac{2e}{m}}\frac{V^{3/2}}{D^2} \tag{9}$$

Rearranging for the voltage V

$$V = J^{2/3}\left(\frac{4}{9}\frac{D^2}{\varepsilon_0}\sqrt{\frac{m}{2e}}\right)^{2/3} \tag{10}$$

Thus, we clearly see that there must be a linear relation between the voltage V and the current J to the power of $(2/3)$. Now, consider the same flux tube, now filled with an inert gas. If we assume that electrons do not scatter, this same relation should hold until the voltage is equal to the ionization potential of the gas, after which the ions created by the splitting of the gas will flood the current reaching the cathode, causing a rapid increase in the current.

By varying the voltage of the system, and measuring the current, a determination of the ionization potential can be made by finding the voltage at which the current to the two thirds power is no longer linear, but rather increases rapidly.

III. EXPERIMENTAL DESIGN AND PROCEDURE

A. *Description of the apparatus*

- AC source
- DC source
- Simpson multimeter
- Taylor multimeter
- Two 884 Thyratrons
- 47 Ω resistor

- 1000 Ω resistor

The two 884 Thyratrons are tubes filled with Argon gas. The circuit used in the experiment is as follows:

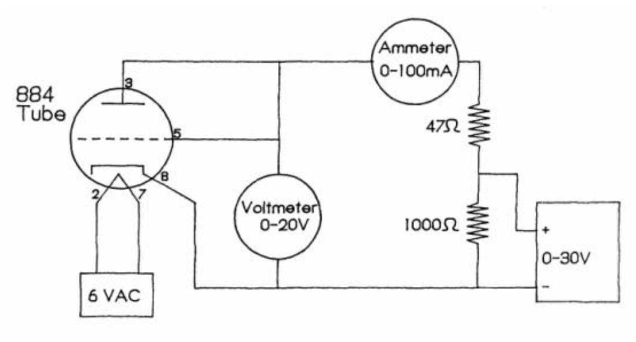

Fig. 1. Design of the Circuit

B. Description of the experimental procedure

The voltage of the DC source was set to zero , then increased in interval of $0.5V$, and the current measured until the approximate range of the ionization potential was reached. Once the approximate range was found, further measurements were made near the range in intervals of $0.1V$.

This is then repeated for both tubes. A full summary of the data collected can be found in the Analysis section of this paper.

IV. Analysis

A. Method of analysis and Presentation of results

After obtaining the data for each bulb, We plotted anode voltage vesus the current (to the power 2/3) for both bulbs which are filled with argon gas, however, as we noticed an exponential increase in the collected current, we decreased the step increment to get more points around the ionization area.

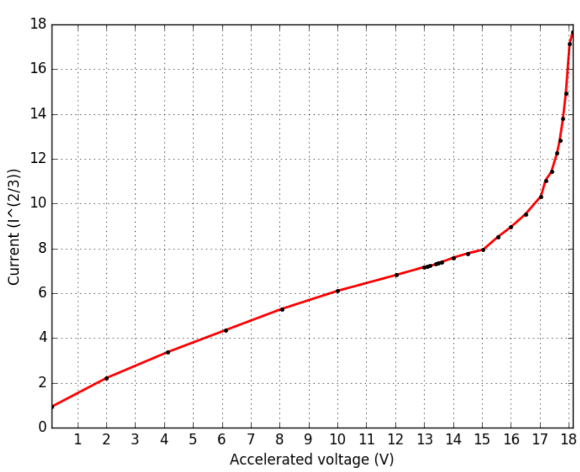

Fig. 2. Argon Ionization for bulb #1

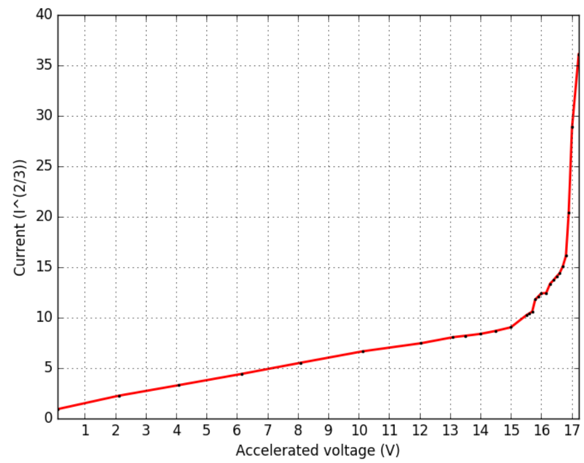

Fig. 3. Argon Ionization for bulb #2

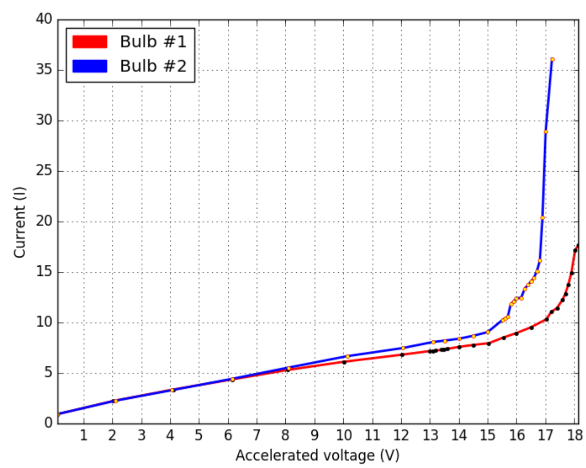

Fig. 4. Argon Ionization for bulb #1 and #2

To determine where the critical point happens, we take the derivative of the data and then we plotted it:

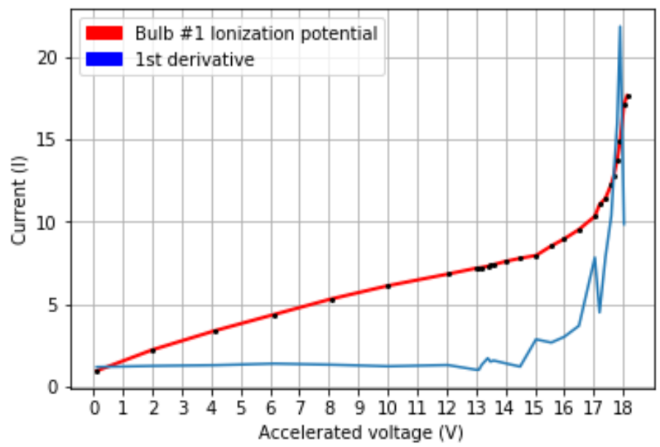

Fig. 5. Argon Ionization for bulb #1 and it's 1st derivative

From figure 5, we found that the ionization potential for bulb#1 is around 17.0ev

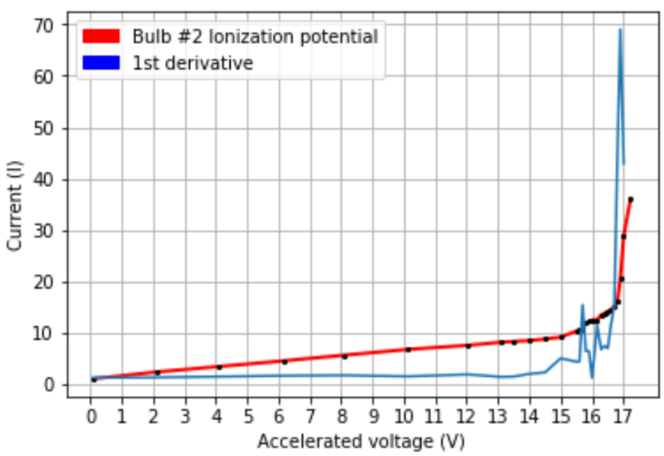

Fig. 6. Argon Ionization for bulb #2 and it's 1st derivative

From figure 6, we found that the ionization potential for bulb#1 is around 17.00 ev

We found that the ionization potential for Argon [2] 15.70 ev, to find the experimental error in our experimental data:

$$\%error = \frac{|ApproximateValue - ExactValue|}{ExactValue} \times 100\%$$

For bulb #1:

$$\%error = \frac{|17.0ev - 15.76ev|}{15.76ev} \times 100\% = 7.87\%$$

For bulb #2:

$$\%error = \frac{|15.7ev - 15.76ev|}{15.76ev} \times 100\% = 0.38\%$$

Error difference between bulb #1 and bulb #2 Ionization potential:

$$\%error = \frac{|FirstValue - SecondValue|}{(FirstValue + SecondValue)/2} \times 100\%$$

$$\%error = \frac{|15.7ev - 17.0ev|}{(15.7ev + 17.0ev)/2} \times 100\% = 7.95\%$$

B. *Discussion of results*

Referring to figure 2, the first bulb seemed to have a systematic error. The ionization potential of bulb #1 happened around 17.0 ev, however, it was supposed to happen around 15.76ev, We found that it has %error of 7.87% compared to the known Argon ionization potential; As the setup of the experiment is exactly the same for both bulbs, so we can safely assume that that the error arises from the bulb itself. After doing some research, we found that the possible parameters that could shift the data with the correction value we found in the analysis section, might be due to an increased residence in the system. However, as the wires in the system are the same for bulb #2, then we can assume that there is something wrong with the resistance inside bulb #1.

For the second bulb, we found that we have %error of 0.38% compared to the known Argon ionization potential; so we consider bulb#2 trial is more accurate because it's very close to the actual Argon ionization potential.

V. Conclusion

In conclusion, we successfully confirmed the quantum theory of atoms by showing that there is a minimum ionization potential through which an electron must have to be able to produce ionization. We found that bulb#1 and bulb#2 has %error of 7.87% and 0.38% respectively compared to the known Argon ionization potential. For bulb #1, we concluded that there must have been a defect with the bulb itself.

References

[1] Umstattd, R., Carr, C., Frenzen, C., Luginsland, J., & Lau, Y. (2005). A simple physical derivation of Child–Langmuir space-charge-limited emission using vacuum capacitance. American Journal Of Physics, 73(2), 160-163. doi: 10.1119/1.1781664

[2] Kenneth Barbalace https://klbprouctions.com/. Periodic Table of Elements - Sorted by 1st Ionization Potential (eV). EnvironmentalChemistry.com. 1995 - 2018. Accessed on-line: 10/21/2018 https://EnvironmentalChemistry.com/yogi/periodic/1stionization.html