Ionization Potential

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Bulb 1					
Trial 1		Trial 2		Trial 3	
Voltage (V)	Current (mA)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
-0.1±0.05	0.00089	-0.01±0.0	0.00089	-0.1±0.0	0.0009
1.3±0.05	0.00239±0.5 μA	1.2±0.05	0.00229±0.5 μA	1.1±0.05	0.0022±0.5 μA
2.2±0.05	0.00357±0.5 μA	2.1±0.05	0.00351±0.5 μA	2.3±0.05	0.00371±0.5 μA
3.4±0.05	0.0051±0.5 μA	3.3±0.05	0.00501±0.5 μA	3.4±0.05	0.00519±0.5 μA
4.4±0.05	0.00633±0.5 μA	4.2±0.05	0.00623±0.5 μA	4.1±0.05	0.00608±0.5 μA
5.4±0.05	0.00761±0.5 μA	5.4±0.05	0.00789±0.5 μA	5.4±0.05	0.00778±0.5 μA
6.6±0.05	0.00925±0.5 μA	6.4±0.05	0.0093±0.5 μA	6.5±0.05	0.00934±0.5 μA
7.4±0.05	0.01038±0.5 μA	7.5±0.05	0.01096±0.5 μA	7.1±0.05	0.01018±0.5 μA
8.7±0.05	0.01217±0.5 μA	8.3±0.05	0.01217±0.5 μA	8.2±0.05	0.01187±0.5 μA
9.7 ±0.05	0.01351±0.5 μA	9.5±0.05	0.0138±0.5 μA	9.9±0.05	0.01404±0.5 μA
10.7±0.05	0.01473±0.5 μA	10.5±0.05	0.01507±0.5 μA	10.3±0.05	0.01458±0.5 μA
11.4±0.05	0.01561±0.5 μA	11.6±0.05	0.01649±0.5 μA	11.1±0.05	0.01555±0.5 μA
12.5±0.05	0.01678±0.5 μA	12.7±0.05	0.01816±0.5 μA	12.2±0.05	0.01698±0.5 μA
13.7±0.05	0.01831±0.5 μA	13.8±0.05	0.01966±0.5 μA	13.1±0.05	0.01818±0.5 μA
14.6±0.05	0.01932±0.5 μA	14.9±0.05	0.02119±0.5 μA	14.1±0.05	0.01957±0.5 μA
15.6±0.05	0.02128±2 μA	15.4±0.05	0.02186±0.5 μA	15.1±0.05	0.02093±0.5 μA
16.4±0.05	0.02427±3 μA	16.4±0.05	0.0261±0.5 μA	16.2±0.05	0.02452±0.5 μA
17.4±0.05	0.03223±5 μA	17±0.1	0.0302±5 μA	17±0.1	0.0267±5 μA
17.9±0.1	0.051157±15 μA	17.5±0.1	0.03767±15 μA	17.5±0.1	0.0355±15 μA

Bulb 2					
Trial 1		Trial 2		Trial 3	
Voltage (V)	Current (mA)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
-0.01±0.05	0.00089±0.5 μA	-0.01±0.05	0.00095±0.5 μA	-0.1	0.00092±0.5 μA
0.08±0.05	0.00186	0.08±0.05	0.0019±0.5 μA	1.4±0.05	0.00258±0.5 μA
2.7±0.05	0.00412±0.5 μA	2.7±0.05	0.00417±0.5 μA	2.7±0.05	0.00423±0.5 μA
3.5±0.05	0.00507±0.5 μA	4.3±0.05	0.00639±0.5 μA	4.2±0.05	0.00615±0.5 μA
4.5±0.05	0.00658±0.5 μA	5.4±0.05	0.00813±0.5 μA	5.3±0.05	0.00787±0.5 μA
5.3±0.05	0.00776±0.5 μA	6.6±0.05	0.0101±0.5 μA	6.7±0.05	0.0104±0.5 μA
6.3±0.05	0.00954±0.5 μA	7.6±0.05	0.01207±0.5 μA	8.2±0.05	0.01326±0.5 μA
7.7±0.05	0.01207±0.5 μA	8.6±0.05	0.01402±0.5 μA	8.8±0.05	0.01464±0.5 μA
8.7±0.05	0.01431±0.5 μA	9.8±0.05	0.01657±0.5 μA	9.7±0.05	0.01642±0.5 μA
9.8±0.05	0.01652±0.5 μA	10.9±0.05	0.01842±0.5 μA	10.7±0.05	0.01808±0.5 μA
11.0±0.05	0.01851±0.5 μA	11.7±0.05	0.01966±0.5 μA	11.6±0.05	0.01961±0.5 μA
12.3±0.05	0.02089±0.5 μA	12.7±0.05	0.02165±0.5 μA	12.7±0.05	0.02176±0.5 μA
13.5±0.05	0.02335±0.5 μA	13.7±0.05	0.02382±0.5 μA	13.7±0.05	0.02381±0.5 μA
14.7±0.05	0.02567±0.5 μA	14.8±0.05	0.02626±0.5 μA	15±0.05	0.02693±0.5 μA
15.4±0.05	0.03053±3 μA	15.7±0.05	0.03852±3 μA	15.6±0.05	0.03222±3 μA
16.4±0.05	0.0487±5 μA	16.5±0.05	0.05161±5 μA	16.2±0.05	0.04604±5 μA
16.9±0.1	0.07762±15 μA	16.9±0.1	0.07955±15 μA	16.8±0.1	0.06927±15 μA
17±0.1	0.11704±15 μA	.	.	.	.

Bulb 1		Bulb 2	
Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
13.4±0.05	0.0193±0.5 μA	12.8±0.05	0.02195±0.5 μA
13.7±0.05	0.01965±0.5 μA	13.6±0.05	0.02355±0.5 μA
14.3±0.05	0.0203±0.5 μA	14.1±0.05	0.02457±0.5 μA
14.7±0.05	0.0207±0.5 μA	14.5±0.05	0.02537±0.5 μA
15±0.05	0.02075±0.5 μA	14.7±0.05	0.02593±0.5 μA
15.3±0.05	0.02121±0.5 μA	15±0.05	0.02683±0.5 μA
15.6±0.05	0.02253±0.5 μA	15.2±0.05	0.0286±0.5 μA
16±0.05	0.02397±0.5 μA	15.4±0.05	0.03084±0.5 μA
16.2±0.05	0.025±10 μA	15.6±0.05	0.03233±10 μA
16.6±0.1	0.0269±15 μA	15.7±0.1	0.03859±15 μA

Table 1: Table of Bulb 1 and 2 close up around Ionization Voltage

Abstract

In this lab we used Child's law to calculate the ionization potential of argon gas. In the Langmuir-Child equation the current $I^{\frac{2}{3}}$ is almost linear with the voltage V. As a result the ionization potential can be calculated as the difference between the breaking point of linearity on a $I^{\frac{2}{3}}$ vs V graph the x-intercept. In our lab we found that bulb 1 had an ionization potential of $17.8 \pm 0.1V$ and for bulb 2: $17.1 \pm 0.09V$. This leads to a 13% and 9% error from the accepted value of 15.69V. We concluded that the main contributor to this deviation is from deciding where the break-point is located since the break point in turn effects the x-intercept.

Introduction

In this experiment, a graph of anode current vs. voltage for two light bulbs. The type of gas in the lightblub is Argon gas. From the anode current vs. voltage graphs, the breaking point of Argon gas can be determined. This breaking point is the point at which Argon gets Ionized.

Ionization is when electrons are removed from some atom. The ionization energy is the lowest energy required for the release of the electrons.(Helmanstine, n.d.) Now a question is, why is ionization and ionization energy important? Ionization energy is important because it is the lowest energy required to ionize, and using the minimum energy will save power. It is also important because it helps determine the reactivity of the atoms and the strength of chemical bonds that form with the bonds. Also, ionization causes the gas to glow, so this can help with making lights with different colours at the lowest energy required.

The experiment consist of a circuit system. The system has DC and AC power going into a lightbulb, by adjusting the DC voltage, you can determine the voltage and current through the lighbulb. With the current and voltage, a graph can be made to determine the ionization potential.

Background

Argon has three ionization potentials. The first ionization potential is at 15.7596eV. The second and third potential is 27.629eV and 40.74eV. In this lab, only the first potential is going to be explored. (ChemGlobe, 2015c) When Argon gets ionized, the gas turns violet or purple. (Purdue University, n.d.)

The graph of the current vs. voltage should start off as a (mostly) straight, until it hits the ionization potential, then the current should increase dramatically (Singhal, June 2013)

The voltage when the current dramatically increases should be the potential equal to the ionization potential for the first ionization level of Argon (15.7596eV). At this potential,the lightbulb should turn purple or violet. Although the density of the gas would not change the potential energy, the density of the gas would effect the intensity of the light. The intensity of the light would be lower because their would be less gas atoms to ionize. Another effect of density of the gas would be the change in resistance. Depending whether the resistance of argon is higher or lower then the air, would effect the current of the anode because of the relationship:

$$I = R * C$$

Procedure

Apparatus:
- 6.3 Voltage source
- 0-¿30V DC source
- Simpson multimeter
- Taylor multimeter
- 884 Thyratron
- 47 O resistor
- 1000 O resistor
- 2 Argon light bulbs

The first step of the experiment is to step up the circuit correctly, the diagram below is how the circuit was step up. The voltmeter is step up to determine DC current from the DC power source. The power source range is 0-30V.

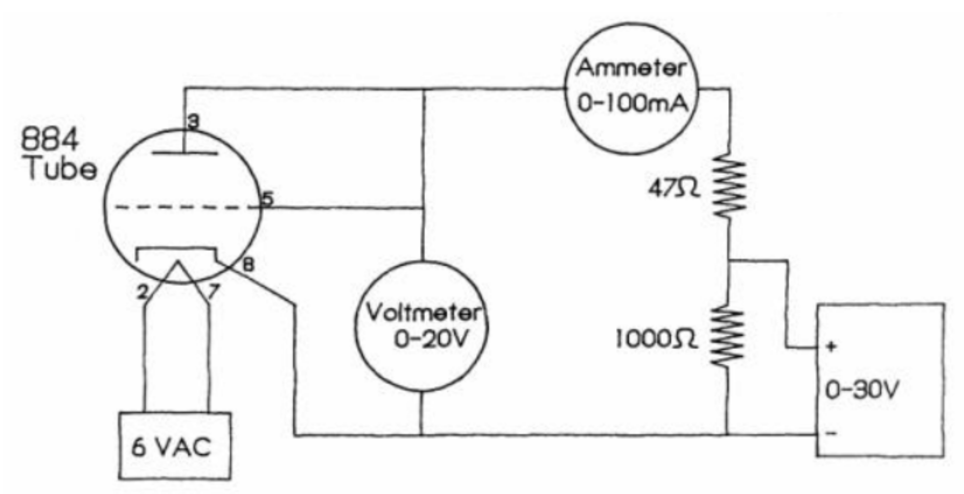

Figure 1: Circuit Diagram. (Gardiner, n.d)

After the set up is done, the data is then collected. The initial potential starts at 0V and the current through the lightbulb and the voltage was recorded. After it was increased by about 2V each time and then again, the potential and current was recorded. This was done until the voltage source hit 30V. This was done 3 times to give a good set of data. After the three trials, there was another trial that started around the voltage that the light changed to violet. For this trial, the voltage went up by 0.3V to give a clear image of what happens around the ionization potential.

After all of that, the lightbulb was changed to the other bulb and then redone with the three trials from 0-30V and a single trial from around the ionization potential upwards.

Analysis

To begin a qualitative description of data would be discussed. For both the bulbs once the voltage hits a certain value a purple light can be seen within the bulb. The purple light is most likely due to the argon ionizing and emitting a wavelength in the purple range. As the voltage increases the light also gets brighter and this is most likely due to more argon gas being ionized result in more light emissions. For the first bulb in the three trials the light can be seen in around 15.7V while the second bulb was around 15.4V.

Next a more quantitative discussion about the results. The raw data values along with the error of bulb 1 and bulb 2 can be seen in table 1 and table 2 respectively. In table 3 is the data for bulb 1 and bulb 2 close up around the ionization voltage. Therefore for each bulb the data consist of three trials and also a close up on the voltages surrounding cut-off point. In figure 1 the two graph shows the combination of all our data for bulb 1 and bulb 2.

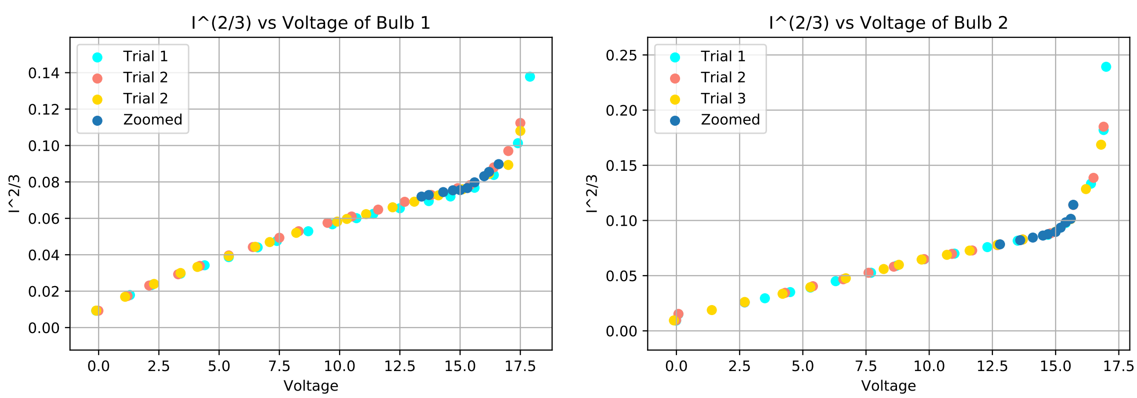

Figure 2: Bulb 1 and 2 Combined 3 Trials and break close-up

The three individual trials for both bulbs seem to be consistent. Before the ionization both bulbs shows an almost linear relation between voltage and current to the $\frac{2}{3}$ power. Another key takeaway is that the "linear" section isn't completely straight as it is a bit concave down agree with ARTICLE(Van Atta et al. 1940). Next from a visual inspection of these two graphs it seems that both bulb has a break-point around the 15V mark however a more accurate number will be derived from the graphs of the individual trials. In figure 2 and 3 shows the three trials of bulb 1 and bulb 2 respectively. For each trial the break off point was decided by comparing the approximate location of all three trials and also looking at the break off point in the close-up figure. By looking at the close-up graph it seems that the point of ionization is the inflection point of the graphs. For example in bulb 1 the first four points seem linear however the fifth point drops a bit and then the points starts to become concave up. Likewise in bulb 2 the fifth point is the inflection point. Therefore from the data the break-off point would be the values that have a voltage of less than 15V fr bulb 1 and 14.7 for bulb 2. To linearize the three trials for each bulb all values below the cut-off voltage is used to calculate the least square polynomial fit of degree 1. To calculate the error in the slope, the formula from Phys 360B error note(Treatment of Errors):

$$\frac{\Delta S}{S} \approx \frac{S_{max} - S_{min}}{2S} \tag{1}$$

For each trial the upper and lower bound of Voltage and Current was calculated. From that the maximum and minimum slope was calculated using the method of least square. Following the equation the error of the slope would just be $\frac{S_{max}-S_{min}}{2}$. For example using the data from trial 1 of bulb 1:

Plugging in the error for both current and voltage would give 4 lists. 2 voltage list with the error added and subtracted and 2 current list with errors added and subtracted. Then graphing $I^{\frac{2}{3}}$ vs V there would be two charts. To maximize the slope voltage with the added error is paired with $I^{\frac{2}{3}}$ where error was subtracted to the current. To get the minimum slope voltage was subtracted while current was added. This gives two values where the maximum slope is 0.004189160746560695 and 0.0041889389441177385. Using the equation calculating ΔS gives $1.1090122147830103x10^{-7}$ which rounds to $1x10^{-7}$.

The table below gives the error of the slope and y-intercept of bulb 1 and bulb 2.

Bulb 1		Bulb 2	
Slope $\frac{(mA)^{\frac{2}{3}}}{V}$	y-intercept $(mA)^{\frac{2}{3}}$	Slope $\frac{(mA)^{\frac{2}{3}}}{V}$	y-intercept $(mA)^{\frac{2}{3}}$
$(4.20 \pm 0.0001)x10^{-3}$	0.0143 ± 0.0002	$(5.21 \pm 0.0001)x10^{-3}$	0.0121 ± 0.0002
$(4.41 \pm 0.0001)x10^{-3}$	0.0140 ± 0.0002	$(5.18 \pm 0.0001)x10^{-3}$	0.0125 ± 0.0002
$(4.36 \pm 0.0001)x10^{-3}$	0.0140 ± 0.0002	$(5.33 \pm 0.0001)x10^{-3}$	0.0116 ± 0.0002

Table 2: Table of slope and y-intercept

Now to calculate the x-intercept it would be $\frac{-b}{m}$. First the error for each trial is calculated using the equation in the error manual of 360B (Treatment of Errors):

$$e_a\% = \sqrt[2]{(e_b\%)^2 + (e_c\%)^2} \tag{2}$$

After calculating the percentage error for each trial then when the average of the three trials is calculated, the error of each trial determined using:

$$e = \sqrt[2]{(e_1)^2 + (e_2)^2 + (e_3)^2} \tag{3}$$

Doing so for both bulbs the result are -3.3 ± 0.09V for bulb 1 and -2.3 ± 0.05V for bulb 2. From the three trials of bulb 1 the last points taken before the cut-off were 14.6 ± 0.05, 14.9 ± 0.05, and 14.1 ± 0.05 likewise for bulb 2 the values were 14.8 ± 0.05, 15.0 ± 0.05, and 14.7 ± 0.05. If then the average values for the break point was calculated

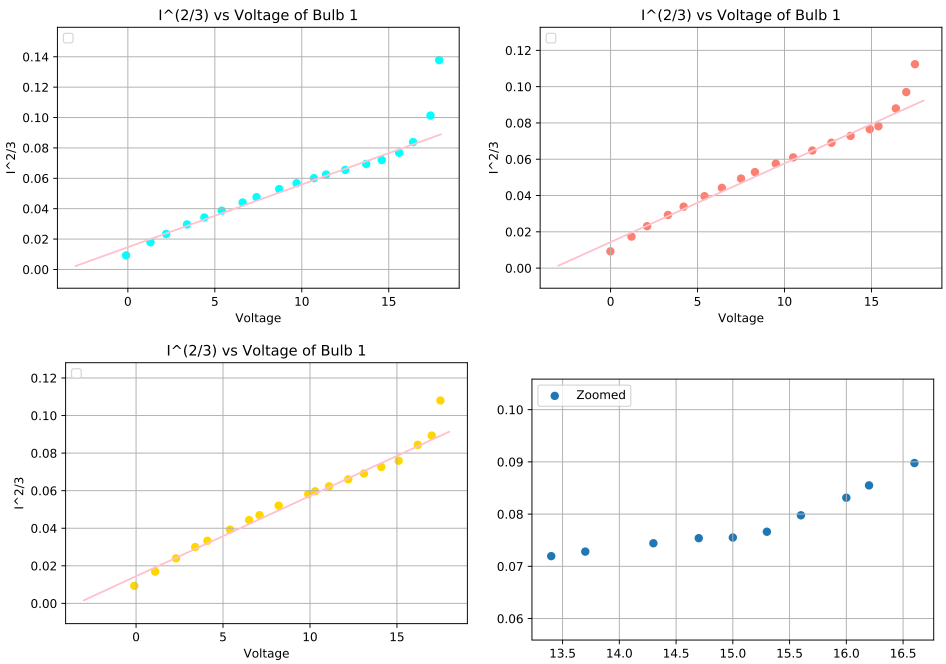

Figure 3: Three trials of Bulb 1 with their linear fits and close-up.

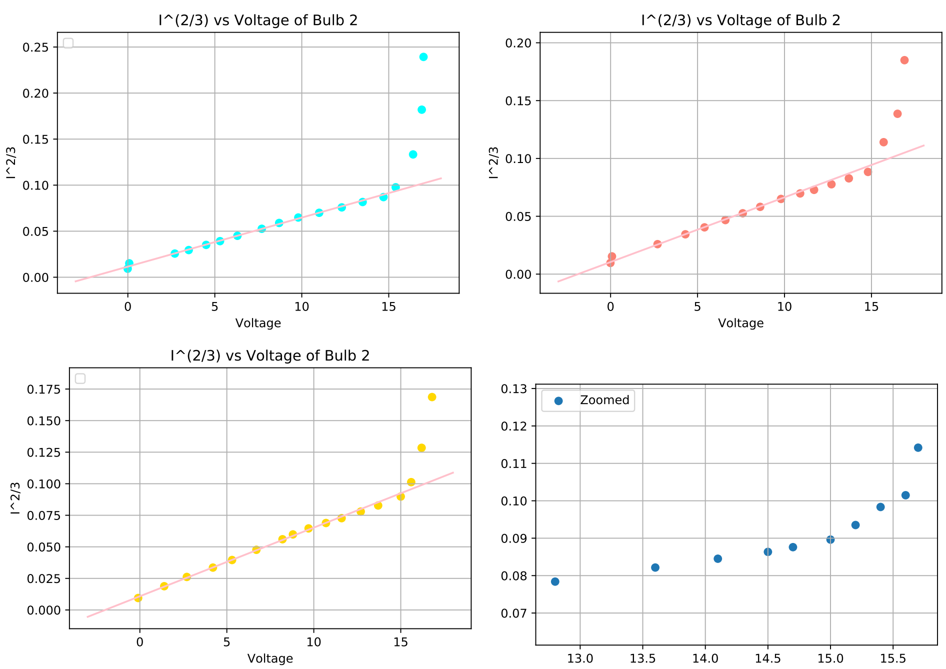

Figure 4: Three trials of Bulb 2 with their linear fits and close-up.

and using the error calculation for additions. Then the average of bulb 1 values is $14.5 \pm$

0.08 and bulb 2 14.8 $\pm$ 0.08 . From this the ionization potential can be calculating by taking the break-off voltage and subtracting with the x-intercept value. This gives the ionization potential for bulb 1: $17.8 \pm 0.1V$ and for bulb 2: $17.1 \pm 0.09V$.

The result were quite off with the accepted value of 15.69 (Van Atta et al. 1940) with bulb one having a percent error of 13% and bulb 2 having error of 9%. The large percent error with the accepted value might be mainly due to the large average break-off point for both bulbs. If the break-off point is incorrect or off this can also effect the x-intercept since the x-intercept is derived from the linearization of the points. If for example the break point was chosen at two high of a voltage this would result in a steeper line of best fit and resulting in smaller x-intercept. Therefore the key to having a number close to the accepted value is based on the break point.

Conclusion

The expected value for the excitation was 15.7596eV. The qualitative for bulb one was 15.7eV which is around the expected value given the certainty of the digits. The second blub had a potential of 15.4eV which is below the expected potential. If the voltage was higher, it would most likely be due to seeing the colour change late, however since it is lower then the expected value, there should not be any colour there. There could be reflection from outside sources, but the chances of the refection being the exact colour of excited argon is unlikely. Perhaps the voltage that was recorded was lower then it actually was, although since this data was used in the quantitative analysis, which didn't bring up this speculation, this is likely not the case either.

For the quantitative analysis, the values where higher then expected, with potentials of $17.8 \pm 0.1V$ and $17.1 \pm 0.09V$, respectfully. The value of these could be due to a large break-off point, if the chosen voltages where too high, then the slope would have been too steep. Although, the expected value lies outside of the calculated value, the percent errors were not extremely high, being 13% and 9%, respectfully.

References

ChemGlobe. 2015c. Argon [ChemGlobe]. Online. ChemGlobal; [Jan 19, 2019]. Available from: https://chemglobe.org/ptoe/_/18.php

Gardiner, Jeff. n.d. Ionization Potentials. Waterloo (On): University of Waterloo.

Gardiner, Jeff. n.d. Treatment of Errors. Waterloo (On): University of Waterloo.

L. C. Van Atta, J. E. Meade,E. S. Lamar. 1940. Measurement of an Ionization Potential.American Journal of Physics 8, 322 p.

Helmenstine, Anne. n.d.Ionization Energy Definition and Trend [ThoughtCo]. Online. ThoughtCo; [Jan 24, 2019; Jan 19, 2019]. Available from: https://www.thoughtco.com/ionization-energy-and-trend-604538

Purdue University. n.d.Gas Discharge Tubes [Purdue University]. Online, Purdue Uniservisty; [Jan 19, 2019]. Available from: http://chemed.chem.purdue.edu/demos/main_pages/6.5.html

Singhal, Rahul. June 2013. Synthesis of Carbon Nanowires by Shi Irradiation of Fullerene c7 Thin Film Figure 5 [ResearchGate]. Advance Materials Letters; [Jan 19, 2019]. Available from: https://www.researchgate.net/figure/The-current-vs-voltage-I-V-characteristics-at-the-ion-tracks-at-different-fluences-of_fig2 _281317528