IPT Problem 12: GRAPHITE LAMP

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Factors to consider: Making the most efficient lamp

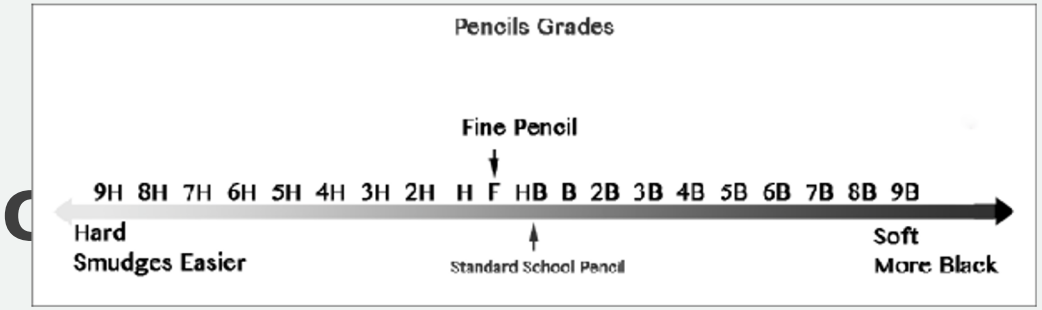
We are trying to maximize the efficiency of the light source. Therefore we need to try to maximize the duration (then we do not have to change the graphite rod as often) and minimize the amount of energy that gets converted into heat.

Objectives:

-Find the length, hardness and thickness that makes the the rod last longer

-Understand how luminosity is affected by these same parameters

Hardness relation to conduc



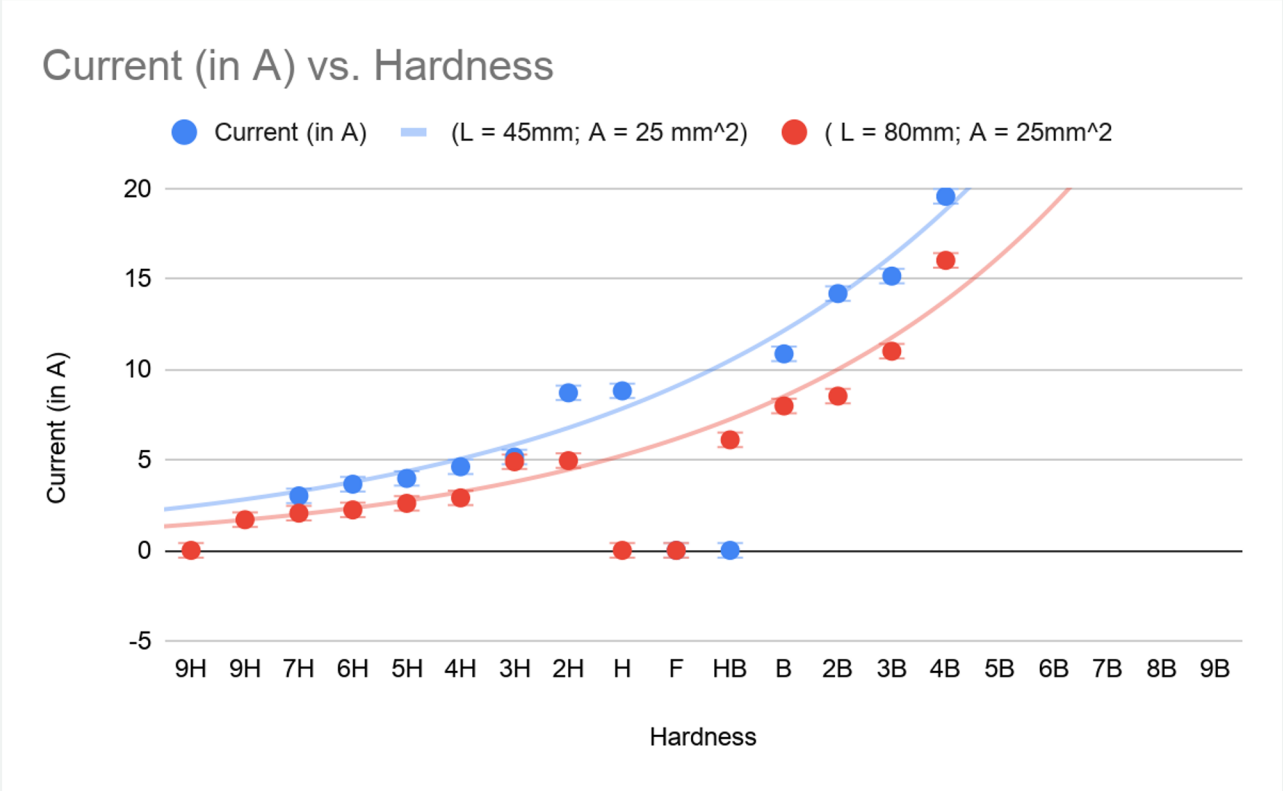
- On the HB scale, hardness is measured in terms H and B.
- H represents hardness of the lead
- B represents blackness, i.e. the concentration of Graphite
- Increasing the H scale decreases the conductivity of the pencil because of the decreasing amount graphite used
- Increasing the B scale increases the conductivity of the pencil because of the increasing amount of graphite. (As it becomes softer the amount of graphite increases)

The Experimental Set- Up

- The data for the power emitted for various models would primarily be measured using the current.
- The Voltage across the circuit would be a constant at 13.5V
- The length of the rod, it’s area would be our controls
- The hardness along with a carbon content would be the main variables for this experimental set-up.
- Furthermore, the conductivities of the graphite lamps would be calculated to describe a trend between the hardness and the electrical conductivities

Current -vs- Hardness

- As we see in the data collected, the current had an exponential relation with the softness, i.e. the graphite content in the pencil.
- Since there was a linear shift in the with the increases in length, suggesting an inverse relation between the two



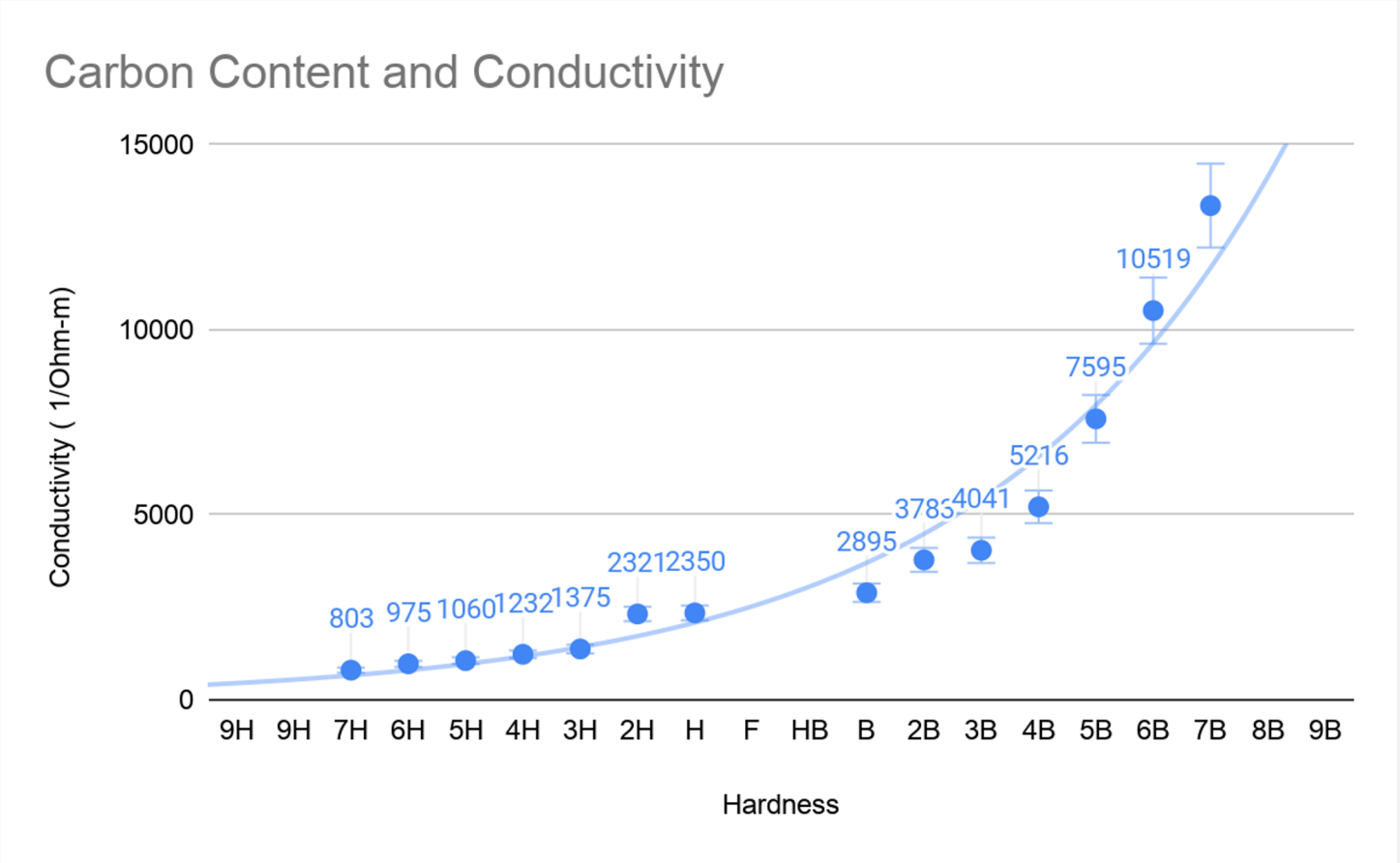
Conductivities -vs- Hardness for Graphite Leads

• Using the Ohm's Law and the definition of conductivity, we can find out the conductivity, of our material, independent of its physical (external properties).

$$V = IR$$
$$R = L/(\boldsymbol{\sigma} \cdot A)$$
$$\boldsymbol{\sigma} = I \cdot L/(V \cdot A)$$

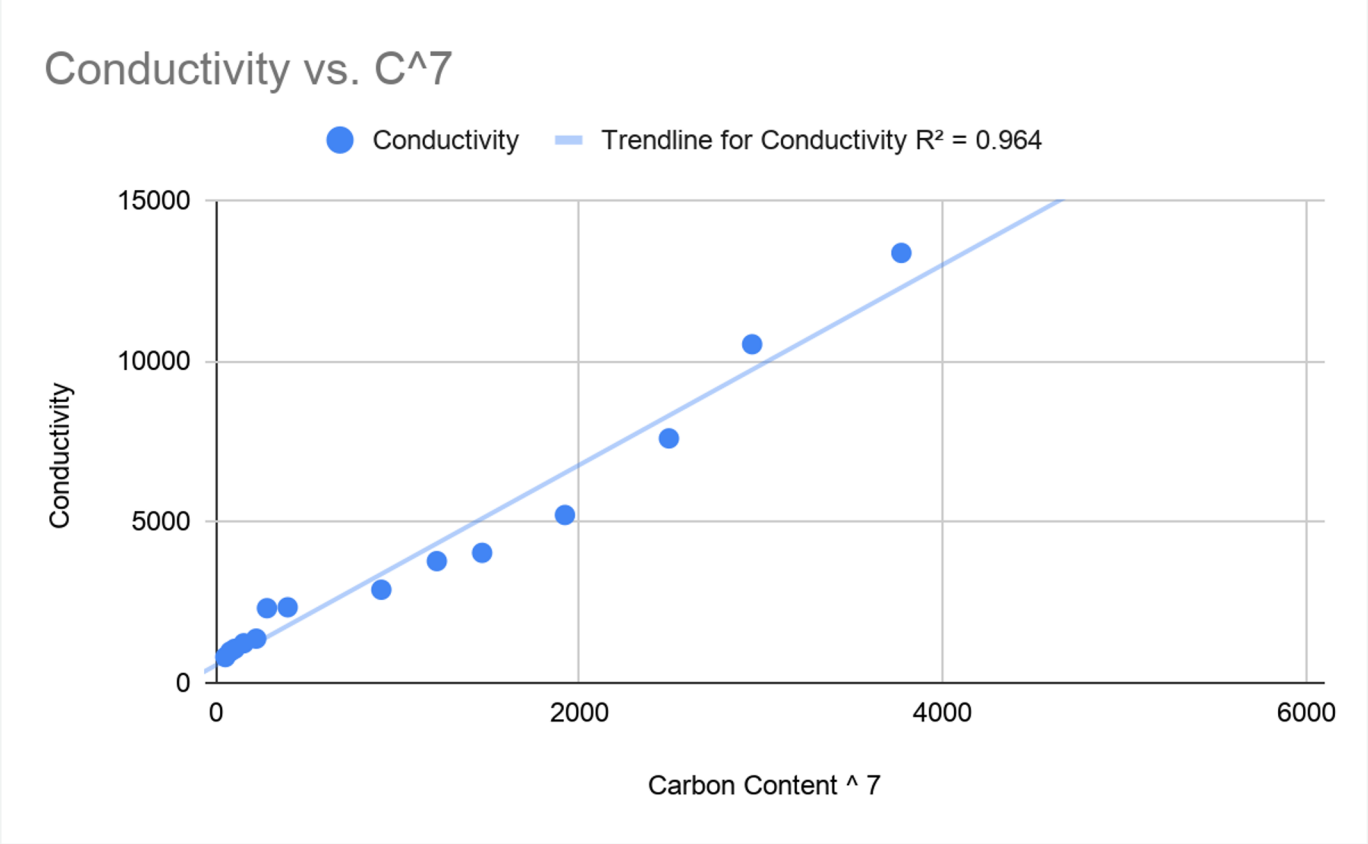
- The results from the experiment showed an exponential curve for the conductivity –vs- the HB scale going from 7H (hardest) to 7B (softest).
- Using the linear relation between blackness (or less hard) and graphite content, we can say that the resistance is an exponential function of the graphite in the pencil
- Thus, the brightest lead would be the 7B one.

Data


Carbon Content and Conductivity
15000
10000
5000
0
Conductivity (1/Ohm-m)
803
975
1060
1232
1375
2321
2350
2895
3783
4041
5216
7595
10519
9H
9H
7H
6H
5H
4H
3H
2H
H
F
HB
B
2B
3B
4B
5B
6B
7B
8B
9B
Hardness

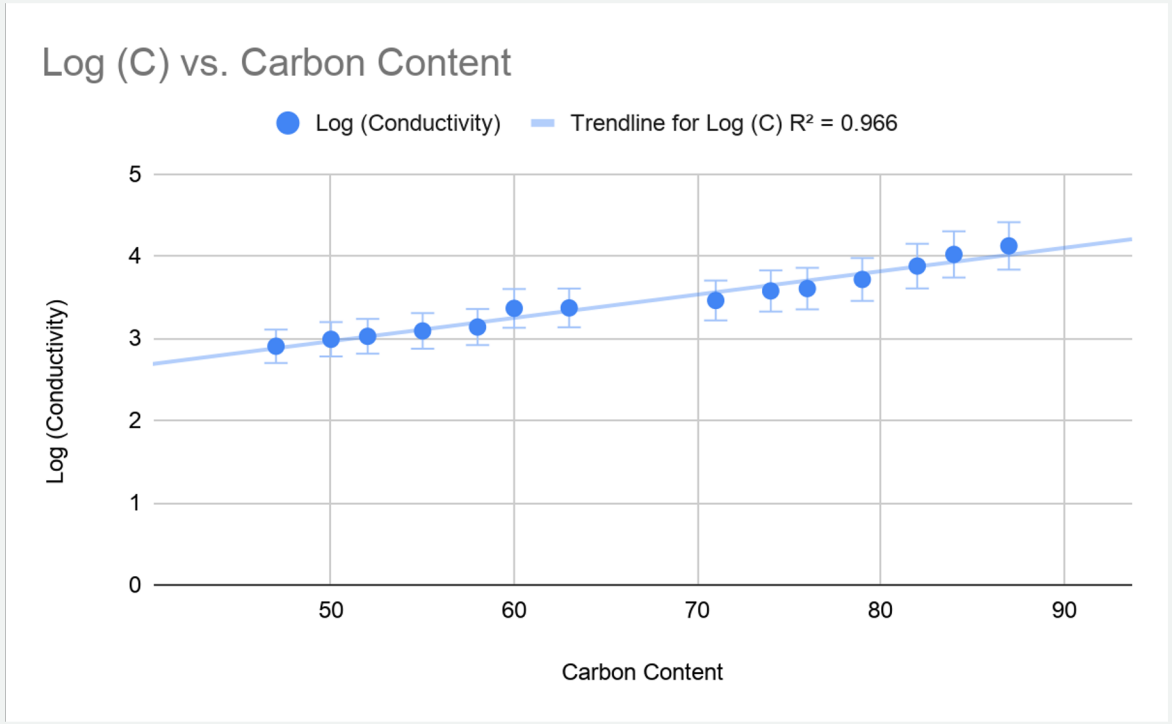
Linearizing Data

- After various rounds of data analysis yield a linear curve between the seventh power of carbon content in the lead
- The confidence level, aka the R^2 value was 96% which represents accuracy in the model to be very high



The Exponential Model

- The exponential model also provides very accurate description upon linearizing the data with R^2 value of 0.966
- However due to the weak relation between the carbon content and the log of the conductivity and the absence of exponential models in physical system, this model is



Size: Thickness and Length

- A main drawback of using a higher thickness is the amount of energy needed to make the rod incandescent. In order to achieve glowing temperature more mass means more energy as $\Delta Q = m*c*\Delta T$. This sometimes means that depending on the power of our source we might not be able to take it to incandescence. Therefore for our purpose, we will stick to smaller diameters.
- In addition, a higher diameter means a higher power output as $P \sim 1/R \rightarrow P \sim A$ and A is the cross section therefore depending on the diameter. A higher power will also mean a higher luminosity.

Size: Thickness and Length continued

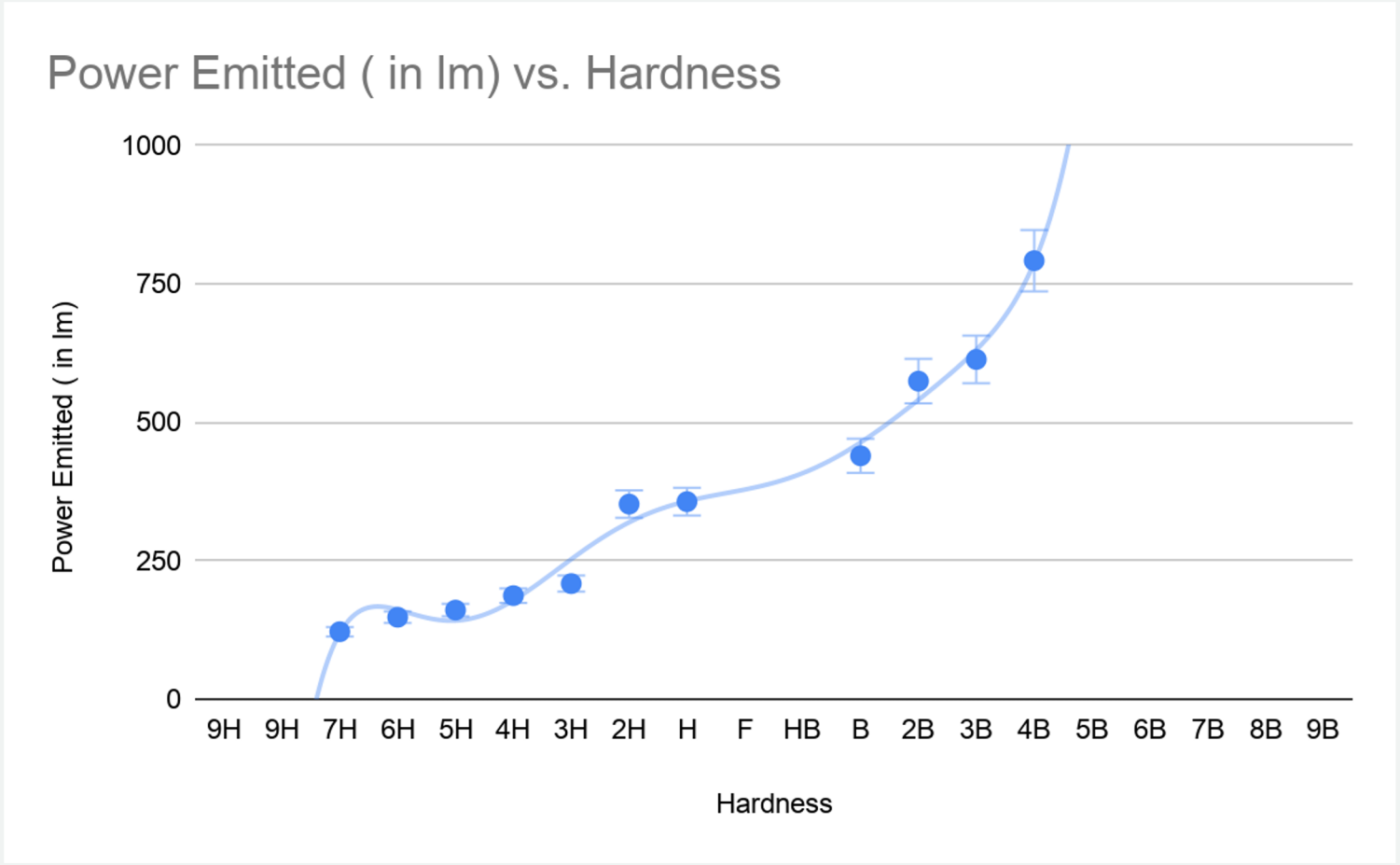
- Our experimentation also shows that using a thickness over 0.5mm in diameter has some drawbacks. Especially with the quantity of smoke produced as takes much more time for the rod to lit up.(If the rod is enclosed in some transparent container, it will reduce the amount of light that reaches outside and therefore reducing the efficiency drastically).

- Our experiments show that the length of graphite increases the lifetime of the incandescence. As a drawback increasing the length will decrease the power output and therefore the luminosity of the bulb. As $R = L/(A*\sigma)$ then $P \sim 1/R \rightarrow P \sim 1/L$

Efficiency Measure: Use of power for luminosity

- Due to lack of means to calculate the luminosity experimentally with a high confidence, the main measure for luminous power was the total power through the graphite leads. Thus, it's luminous efficacy was taken as the constant of proportionality
- The luminous efficacy of a light source is its generated luminous flux divided either by its radiant flux or by its electrical power consumption.
- Assuming a fairly stable optical spectrum for pencil leads made of graphite of very comparable sizes, we can assume that the luminous efficacy is constant throughout the experiment
- Using the Standard luminous efficacy for carbon lamps ~ 3lm/ W, we can find a trend for the luminous intensity- vs- the hardness

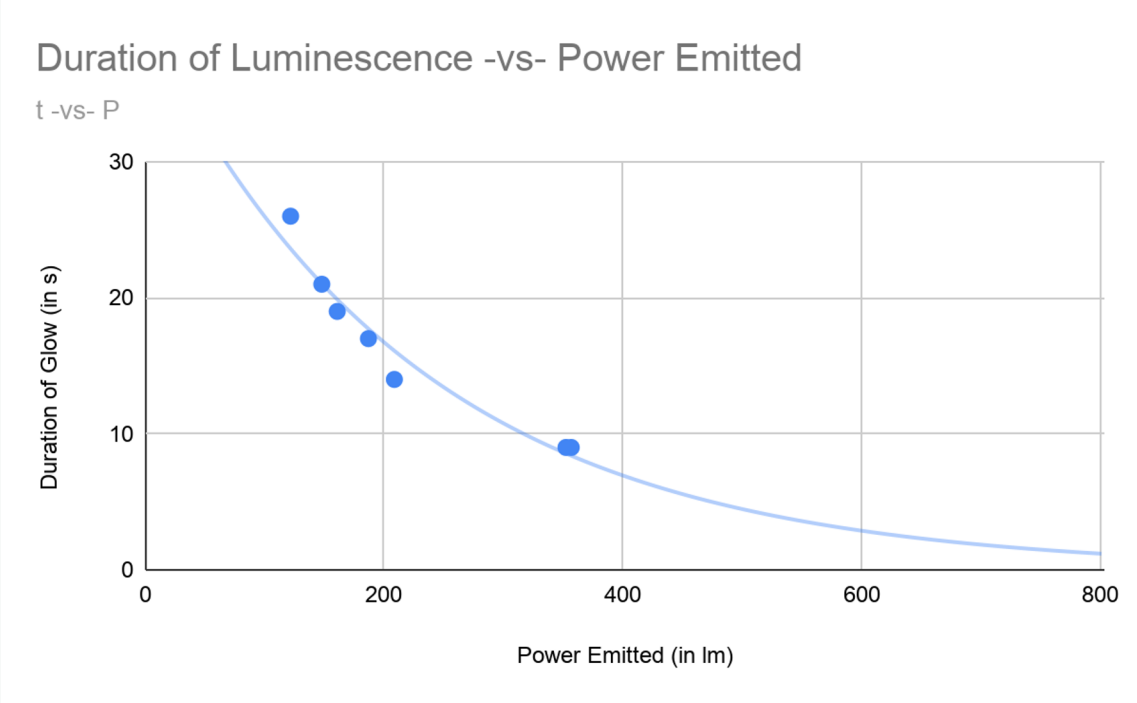
Power Emitted by the Graphite Arc Lamp

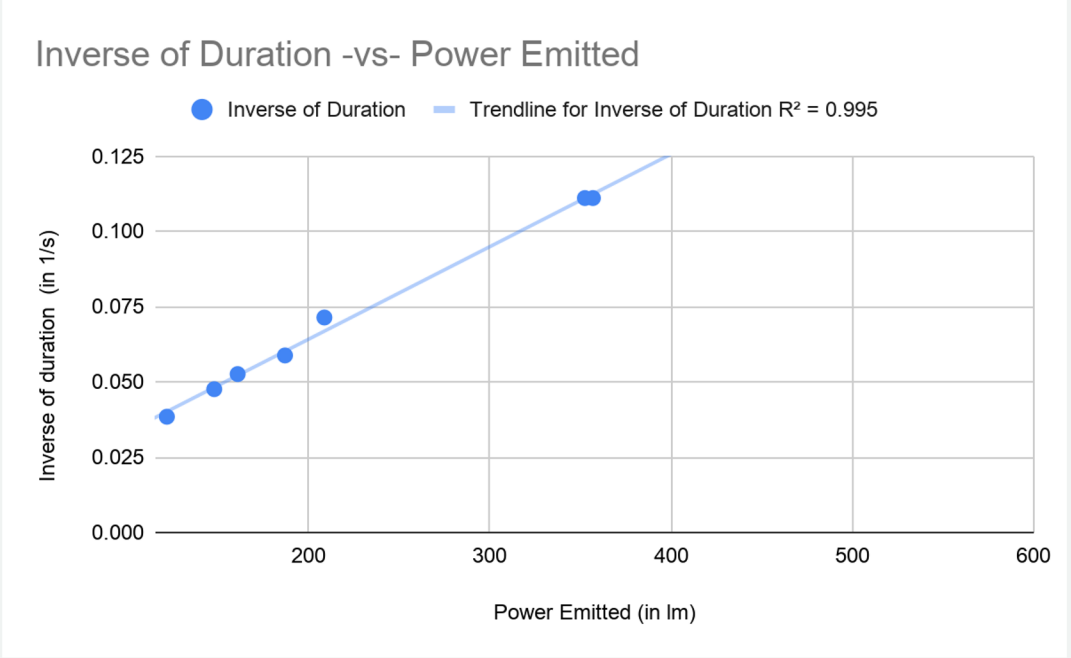


Duration of Glow

- The duration of the glow depended on the power that was used. A higher a power means a higher heat therefore the rod melts faster. Therefore t~1/P
- Due to this we need to limit the power and therefore the luminosity. This can be done by increasing the length.
- If we want to increase the luminosity without altering the power, we could use a reflection shield. It is easier to increase the luminosity this way as it's inconvenient to be changing the rod.
- The duration can also be drastically increased if the rod is enclosed in a vacuum or in an enclosure where the oxygen has been taken away. (The oxygen reacts fast with the graphite oxidizing it).

Duration -vs- Power Emitted Correlation





Conclusions

- Our optimal thickness will be 0.5 mm as a thicker one might have trouble ignite properly causing too much smoke and needing a higher voltage. Despite the increased brightness with area, the total heat capacity also increases, that too anisotropically, biased against the area of cross-section so we minimize that.
- The rod will have the lowest hardness possible (9B) as this makes it brighter
- To increase the duration, we will use the highest length possible for our recipient as this will make it last longer at the cost of decreasing the brightness of the lamp linearly
- This slight decrease would be easily compensated by the seventh power relation of power and carbon content and additional external factors like

Citations

- https://www.rp-photonics.com/optical_spectrum.html
- Gürgünoğlu, D. (2015). Electrical conductivities of different grade lead pencil graphite (Doctoral dissertation, TED Ankara Koleji).\
- Akampulira, B. (2018). Design and construction of a graphite operated bulb.