What is the relationship between the intensity of a light bulb and the distance from the light source

Physics Internal Assessment

Word count 1572

1.Introduction

With the invention of the light bulb, light appears in every corner of our lives, and every time we look into the light, we can feel some blinding, we have more or less felt the presence of electromagnetic waves. I have some photophobia in my eyes and have been shaken by the bright light, so I wanted to study more about the intensity and observe the relationship between the intensity of light and the distance between us and the light source, in order to determine suitable distance without being irritated by the light to our eyes.

Firstly, to give a more accurate definition of light intensity, not just the degree of light irritation to the eyes, we can define it as the amount of power that is transported per unit area, where the area is calculated on a plane which is perpendicular to the energy's direction of propagation. It has units of watts per square metre. With waves like acoustic waves or electromagnetic waves like light or radio waves, intensity is most usually employed to describe the average power transfer across one period of the wave. It is well known that optical intensities and powers are measurements that are averaged across at least one oscillation cycle. They are not thought to be oscillating on the same time scale as an optical oscillation, in other words.

The intensity of light is largely related to the distance between the receiving point and the light source. The equation for light intensity is as follow:

$$\text{Intensity} = \frac{\text{Power of light source}}{\text{Light illuminated area}}$$

Next, we continue with the explanation of distance in physics. Distance is the total movement of an object without any regard to direction. In my experiment, the distance is from the bulb. With these ideas, I set out to investigate the research question **"What is the relationship between the intensity of radiation and the distance from the light source"**. I predict that the farther the distance the lower the intensity of the light will be, this is because light photons spread out across a larger region as one gets farther from a light source.

Method

Materials

- Light sensor (figure 1)
- 5W/9W/12W Bulbs (figure 2)
- Ruler (figure 3)
- Light bulb socket (figure 4)
- Cardboard (figure 5)
- Goggles (figure 6)
- Data display (figure 7)

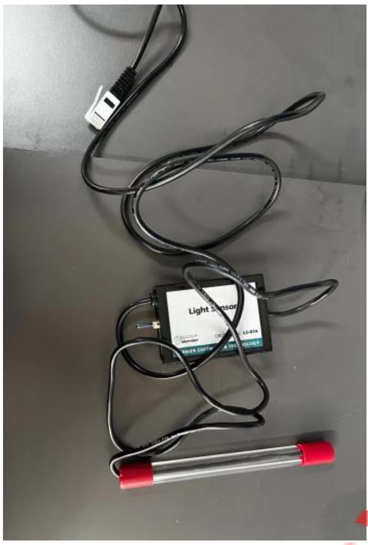


Figure 1 Light sensor

Figure 2 5W/9W/12W Bulbs.

Figure 3 Ruler

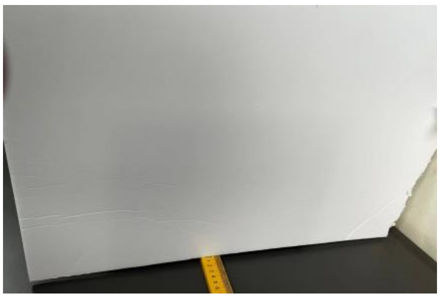


Figure 4 Light bulb socket Figure 5 Cardboard

Figure 6 Goggle

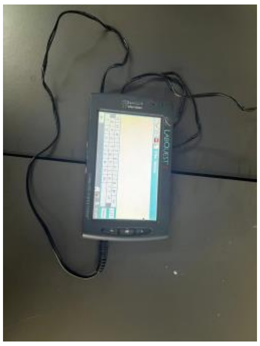


Figure 7 Data display

Variables

	Variable and units	Method of control
Independent	the distance from the bulb to the light sensor	Validated by using ruler to determine the location
Dependent	light intensity of the bulbs	Using light sensor to measure it.
Controlled	External environment	The location of the experiment was set at my school lab and the light rays of the external environment in the experiment were ensured to be the same

Procedure

1. Wear goggles before starting the experiment to prevent eye injury
2. Inserting the bulb into the light bulb socket
3. Hold the white cardboard vertically and hold the light sensor flat in front of the white cardboard
4.Place the zero mark of the ruler at the intersection of the vertical lines of the light sensor.
5. Turn on the light bulb and place it at the 40 cm mark of the ruler
6. Record the data from the data display and change the position of the bulb. Place it at the

60 cm, 80 cm, 100 cm and 120 cm marks and match the corresponding data.
7. Turn off and repeat the experiment with a different wattage bulbs and repeat procedures 2-6
8.Record the corresponding data from 40cm, 60 cm, 80 cm, 100 cm and 120 cm.

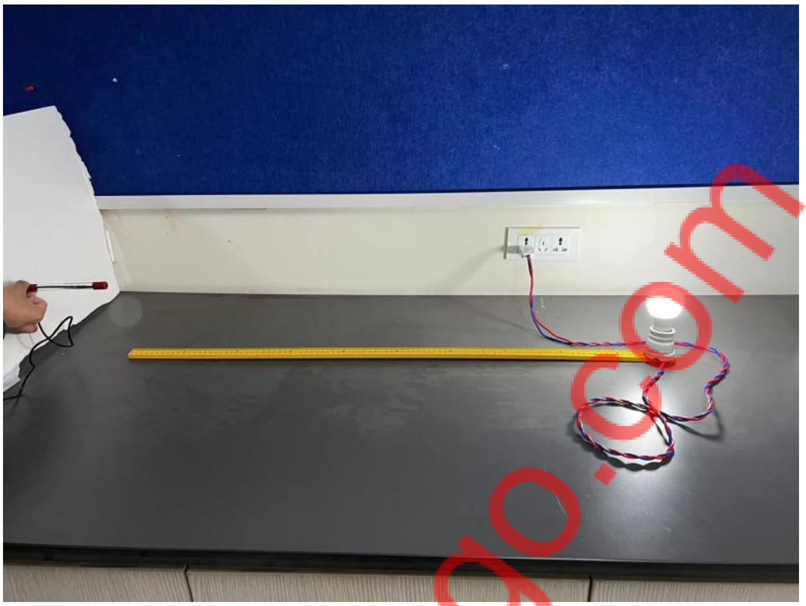


Figure 8 Experimental procedure

Safety consideration

1.When using light bulbs, looking directly into bright lights can cause injury to our eyes
2.When replacing a bulb, this can lead to burns as the bulb may get hot. We need to leave it for a while to prevent the bulb from burning our fingers.

Ethical concern

There are no ethical concerns with this experiment.

Result and Analysis

Raw Data

Table 1 Illuminance of light of 5W bulb			
Distance between the bulb and the light sensor (±0.05 cm)	Trial number	Illuminance of light light(lux) (±0.05 lux)	Illuminance of light bulb light(lux) (±0.05 lux)
40	1	283.6	286.0
	2	284.5	
	3	290.2	
	4	285.3	
	5	286.4	
60	1	165.1	162.1
	2	164.4	
	3	162.5	
	4	165.7	
	5	163.2	
80	1	117.2	116.5
	2	115.4	
	3	116.2	
	4	117.4	
	5	116.5	
100	1	90.30	91.12
	2	89.20	
	3	94.50	
	4	93.20	
	5	88.40	
120	1	76.80	75.34
	2	69.40	
	3	74.80	
	4	78.40	
	5	77.30	

Table 2 Illuminance of light of 9W bulb			
Distance between the bulb and the light sensor (±0.05 cm)	Trial number	Illuminance of light (lux) (±0.05 lux)	Illuminance of light (lux) (±0.05 lux)

40	1	506.2	506.0
	2	504.2	
	3	508.3	
	4	509.2	
	5	502.4	
60	1	270.7	274.5
	2	273.2	
	3	274.5	
	4	275.3	
	5	274.2	
80	1	176.6	178.4
	2	174.4	
	3	175.2	
	4	176.4	
	5	174.3	
100	1	140.4	140.8
	2	141.4	
	3	140.6	
	4	143.2	
	5	138.5	
120	1	114.0	114.3
	2	112.3	
	3	113.4	
	4	115.6	
	5	116.2	

Table 3 Illuminance of light of 12W bulb			
Distance between the bulb and the light sensor (±0.05 cm)	Trial number	Illuminance of light (±0.05 lux)	Illuminance of light (lux) (±0.05 lux)
40	1	648.2	647.9
	2	649.2	
	3	647.5	
	4	643.4	
	5	651.2	
60	1	323.5	323.5
	2	325.4	
	3	322.4	
	4	322.6	
	5	323.8	
80	1	216.2	216.9
	2	213.2	

	3	218.5	
	4	217.4	
	5	219.2	
100	1	166.7	166.5
	2	163.3	
	3	164.7	
	4	167.8	
	5	170.2	
120	1	144.3	143.4
	2	143.5	
	3	142.6	
	4	143.7	
	5	142.8	

3.2 Calculation

Lux and (W/m^2) cannot be directly converted; instead, it relies on the light's wavelength or frequency. So we use as an example the conversion factor of sunlight with a similar frequency to that of a light bulb which refer to $0.0079 \mathrm{W/m^2}$ per lux

Sample calculation for conversion of Illuminance of light(lux)to light intensity(W/m^2)

$$1lux = 0.0079W/m^2$$

$$286.0lux = (286.0 \pm 0.05) \times 0.0079 = 2.26W/m^2 \ \pm 0.000395W/m^2$$

Sample Error calculation

$$\text{Uncertainty for Intensity:} \frac{0.05}{286.0} \times 2.26 = 0.000395 = 3.95 \times 10^{-4}$$

Table 4 Intensity of light of 5W bulb		
Distance between the bulb and the light sensor(cm) (±0.05 cm)	Intensity of light ($\boldsymbol{W/m^2}$)	Uncertainty of intensity of light($\boldsymbol{W/m^2}$)
40	2.26	3.95×10^{-4}
60	1.28	3.95×10^{-4}
80	0.92	3.95×10^{-4}
100	0.72	3.95×10^{-4}
120	0.60	3.95×10^{-4}

Calculation of power of bulb

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{A}} \text{ so that } \mathrm{P} = \mathrm{IA}$$

Because the light bulb illuminates the area of a sphere so that $\mathrm{A} = 4\pi x^2$(x is the distance between the light sensor and the bulb)

$$\mathrm{P1} = \mathrm{IA} = 4\mathrm{I}\pi x^2 = 4 \times 2.26 \times \pi \times 0.4^2 = 4.54\mathrm{W}$$

$$\mathrm{P_2} = \mathrm{IA} = 4\mathrm{I}\pi x^2 = 4 \times 1.28 \times \pi \times 0.6^2 = 5.79\mathrm{W}$$

$$P_3 = IA = 4I\pi x^2 = 4 \times 0.92 \times \pi \times 0.8^2 = 7.40W$$
$$P_4 = IA = 4I\pi x^2 = 4 \times 0.72 \times \pi \times 1.0^2 = 9.04W$$
$$P_5 = IA = 4I\pi x^2 = 4 \times 0.60 \times \pi \times 1.2^2 = 10.9W$$

$$\text{Average power} = \frac{4.54+5.79+7.40+9.04+10.9}{5} = 7.53W$$

$$\text{The percentage error for P is } \frac{7.53 \pm (3.95 \times 10^{-4}) - 5}{5} = 50.6\% \pm (7.9 \times 10^{-3})\%$$

This is a large error due to the lack of precision in our unit conversion results

Table 5 Intensity of light of 9W bulb		
Distance between the bulb and the light sensor(cm) (±0.05 cm)	Intensity of light (W/m^2)	Uncertainty of intensity of light(W/m^2)
40	4.00	3.95×10^{-4}
60	2.17	3.95×10^{-4}
80	1.41	3.95×10^{-4}
100	1.11	3.95×10^{-4}
120	0.90	3.95×10^{-4}

Table 6 Intensity of light of 12W bulb		
Distance between the bulb and the light sensor(cm) (±0.05 cm)	Intensity of light (W/m^2)	Uncertainty of intensity of light(W/m^2)
40	5.12	3.95×10^{-4}
60	2.56	3.95×10^{-4}
80	1.71	3.95×10^{-4}
100	1.32	3.95×10^{-4}
120	1.13	3.95×10^{-4}

Sample calculation of square root inverse of intensity

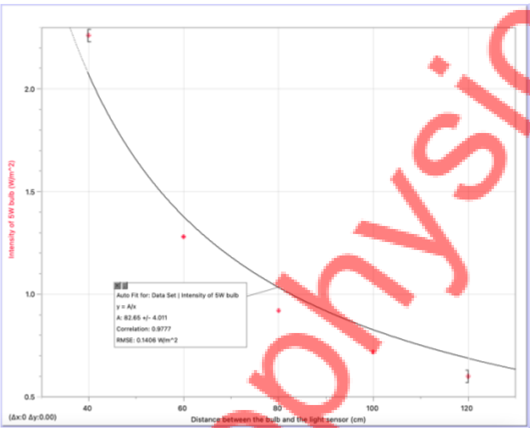
$$\frac{1}{\text{Intensity}^2} = \frac{1}{2.26^2} = 0.038$$

Table 7 Processed data for square root inverse of intensity of 5W bulb	
Distance between the bulb and the light sensor (cm)(±0.05 cm)	square root inverse Intensity of light (W/m^2)
40	0.196
60	0.610
80	1.180
100	1.930
120	2.778

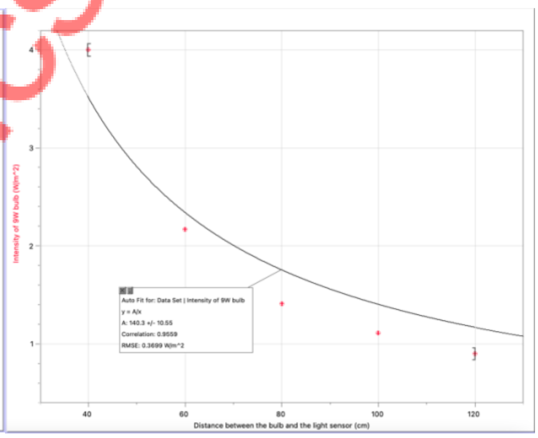
Table 8 Processed data for square root inverse of intensity 9W bulb	
Distance between the bulb and the light sensor (cm)(±0.05 cm)	square root inverse Intensity of light $(\mathrm{W/m^2})$
40	0.063
60	0.212
80	0.503
100	0.811
120	1.230

Table 7 Processed data for square root inverse of intensity 12W bulb	
Distance between the bulb and the light sensor (cm)(±0.05 cm)	square root inverse Intensity of light $(\mathrm{W/m^2})$
40	0.038
60	0.153
80	0.342
100	0.574
120	0.783

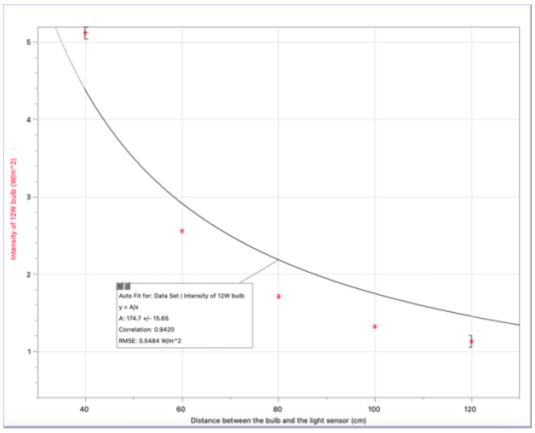
3.3 Graph



Graph 1 relationship between distance and light intensity of 5W bulb

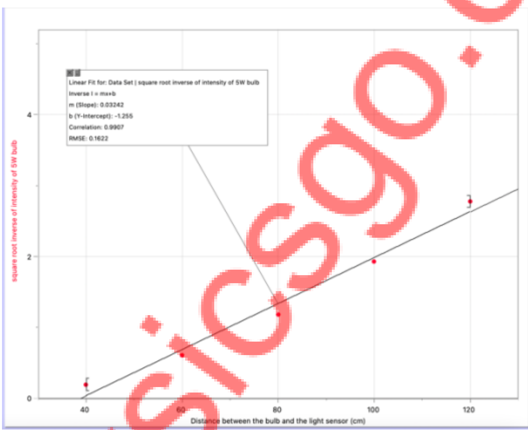


Graph 2 relationship between distance and light intensity of 9W bulb

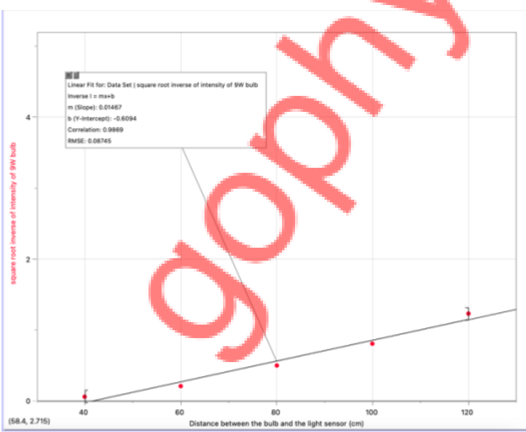


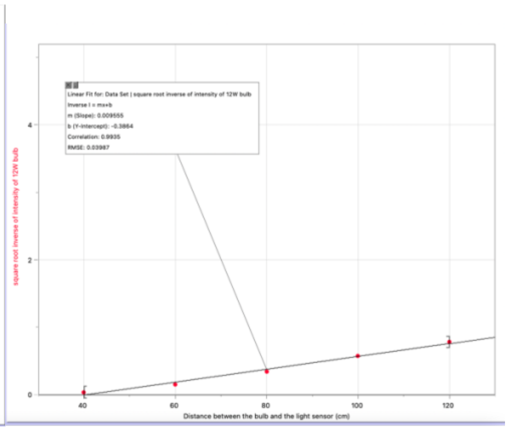
Graph 3 relationship between distance and light intensity of 12W bulb

From these three graphs, we can see that the inverse line of the best fit does not go through most of the points, which should be due to errors in the unit transformation process. However their r values are 0.9777, 0.9559 and 0.9420 respectively show a strong inverse relationship.



Graph 4 Relationship between distance and inverse square root of intensity of 5W bulb





Graph 5 Relationship between distance and inverse square root of intensity of 9W bulb

Graph 6 Relationship between distance and inverse square root of intensity of 12W bulb

We can see from these three plots that there is a strong positive relationship between distance and inverse square root of intensity. This is also due to the r values of 0.9907, 0.9869 and 0.9935.

4.Conclusion

Based on the data that has been analyzed, it is possible to draw the conclusion that the square root inverse of light intensity and distance between the source and the sensor are directly proportional, whereas the relationship between light intensity and distance is an inverse square relationship.

This can be shown by the best fit linear line between distance and inverse square root of intensity because the best fit linear line passes through most of the points, Even if there are points that haven't been crossed but they are still very close.

These can be explained by the r values close to 1 in each graph, which demonstrate strong negative as well as positive correlations.

However, the best fit line in some graphs does not go through some points resulting in not match expectations due to random error, which will be discussed in the evaluation.

5.Errors and limitations

The main systematic error in this experiment is from the original room brightness in the laboratory, which causes each set of brightness data we collect to be larger than the actual value and gives a positive offset to the line we draw. This will result in our results being less accurate.

There are many random errors, for example, a lack of precision in the placement of the bulb can lead to errors. The light sensor is hand-held and is not stable enough during the measurement process, which can lead to fluctuations in values. Most importantly, we treat the light from the bulb as the light from the sun in the unit conversion process and use the same conversion method as for sunlight, which can also lead to random error because the wave frequency of the bulb cannot be the same as the sun. These can also lead to less accurate experimental results.

In working with the data, when my data showed great correlation which when the R-value tended to be close to 1, I assumed that the distribution of the data conformed to an inverse proportional function, which was actually not comprehensive enough, and I should have tried a wider variety of functional forms, such as a linear function, to make sure that there was no other functional form that was more appropriate than the one that I had obtained.

6.Suggested methods for improvement

Firstly, in order to reduce the influence of ambient light on the experiment, we can conduct the experiment in a dark environment so that the experimental data will be more accurate. In addition, the light sensor can be fixed to ensure that it will not move during the experiment.

In the process of unit conversion, we should get a more accurate value, such as converting the illuminance to the light intensity of the bulb.

In extrapolating the equations, we should also try a wider variety of functional forms to ensure that what we get from the experiment is accurate.

7.Reference

1.Domat. “Conversion LUX to W/M2.” Domat-Int.com, 2017, www.domat-int.com/en/conversion-lux-to-w-m2.

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3.Voudoukis, Nikolaos, and Sarantos Oikonomidis. "Inverse square law for light and radiation: A unifying educational approach." *European Journal of Engineering and Technology Research* 2.11 (2017): 23-27.