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Investigating Propagation of Light Waves

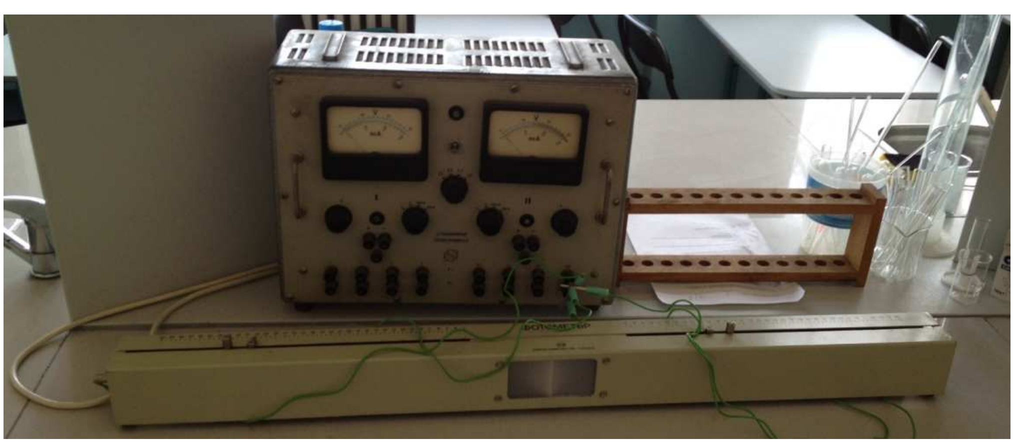
Lab Report № 13

Aim of the Laboratory Experiment: Understanding of propagation of light waves phenomena by using a photometer device.

Hypothesis: The luminous intensity of a lamp will increase as the voltage increases. However, when the distance between two lamps decreases, the voltage will also decrease, and as a result of this I predict that the light intensity will also decrease.

General Background: Light consists of electromagnetic waves with wavelength in vacuum from 400 to 700 nm. From a point source light propagates in every direction. The light intensity of a source I is measured by the international unit called candela (cd). The illumination E of a unit surface (1 m^2) is measured by unit called lux (lx). E is connected with the light intensity of the source and its distance r by the law of Lambert. The law of Lambert states: $E = (I / r^2) \cos a$, where I is the light source intensity, r is the distance to the source, E is the illumination of a surface with area of 1 m^2, and a is the angle between the distance to the source and the normal (imaginary line perpendicular to the surface).

A photometer is a device which consists of two surfaces which are illuminated by two different light sources. A photometer is illustrated in this picture:



Both surfaces are at the same angle a in respect to their light source. If the illumination on both surfaces is the same and the distance from the source is the same we can derive from the Law of Lambert that: $I_2 = I_1 (r_2^2 / r_1^2)$.

In order to perform an experiment with a photometer, both light sources are switched on and the distance of the second one is changed. When the source is placed at a location where the illumination of the two surfaces is equal, the distances r_1 and r_2 and the light intensity of one of the sources I_1 can be used to find the intensity of the second source I_2.

Variables

Considering the fact that we have 3 tasks, the quantities that we measure change their nature. For the 1st and for the 2nd task:

Independent variable – distance r_1

Dependent variable – distance r_2

Controlled variables – voltage V, light intensity I

For the 3rd task:

Independent variable – voltage V

Dependent variable – distance r_2

Controlled variables – distance r_1, light intensity I

Method

1. With the help of the photometer we determine the distances r_1 and r_2 between the two lamps and the light source.
2. With experiments we determine the light intensity of an unknown light source.
3. We determine the dependence of the lamp light intensity on the applied voltage.

   Task 1 consists of three parts. The first part is to experimentally verify the accuracy of the photometer. Two lamps of light intensity 35 cd are used and are connected to a source of 12 V. After that one lamp is set at 15 cm from its respective lamella. The second lamp is moved until both surfaces are equally illuminated. The distance r_2 is measured. The experimental error is determined by finding an average value, subtracting each measurement from it and taking the highest residual. The same process is repeated for two other distances – 20 and 25 cm.

Task 2 consists of experimentally determining the light intensity of an unknown light source. One lamp with intensity 35 cd is taken, and another one with an unknown intensity is given by the teacher. Both lamps are connected in parallel to a source of 12 V. One source is established at a distance r_1 = 15 cm. The second lamp is moved until both lamellas are equally illuminated. The distance r_2 is measured. Identically to step 1, the maximum residual is determined and accepted as the experimental error. The same step is repeated for two different distances – 20 and 25 cm. The light intensity I_2 of the unknown lamp is calculated three times using the formula $I_2 = I_1 (r_2^2 / r_1^2)$. The average value of I_2 is calculated. The maximum residual is accepted to be the experimental error. The percent error is determined by dividing the experimental error and the average value for I_2 and multiplying the result by 100.

Task 3 consists of determining the dependence of the lamp light intensity on the applied voltage. The first one is connected in parallel to a source of 12 V. The second one is connected to a smaller voltage. The distance r_1 is set to 25 cm and the second lamp is moved until both lamellas are equally illuminated.

No	r_1, cm	First measurement r_2, cm ± 0.25	Second measurement r_2, cm ± 0.25	Third measurement r_2, cm ± 0.25	Average r_2, cm	Experimental error Δr_2, cm

Then the distance r_2 is measured. The measurement is repeated 3 times and the average value is determined. The same steps are repeated for two other voltages V_2. The light intensity I_2 is calculated for every voltage applied by using the formula $I_2 = I_1 (r_2^2 / r_1^2)$. The graph of I_2 against V_2 is plotted with the voltage on the x axis and the light intensity on the vertical axis.

Data Collection and Processing

		cm	cm	cm		
1	15	14.8	14.7	14.8	14.8	± 0.1
Residuals	r_2	0	0.1	0		
2	20	22	19	21	20.7	± 1.7
Residuals	r_2	1.3	1.7	0.3		
3	25	25.5	24.0	26.5	25.3	± 1.3
Residuals	r_2	0.2	1.3	1.2		

The error for the distance = one quarter of the cm or 0.25 cm

Table 1: Experimentally checking the photometer

The average (mean) value of the distance r_2 can be calculated when the total result from the three measurements is divided by 3.

Table 2: Determining the light intensity of an unknown light source

No	r_1, cm	First measurement r_2, cm ± 0.25 cm	Second measurement r_2, cm ± 0.25 cm	Third measurement r_2, cm ± 0.25 cm	Average r_2, cm	Experimental error Δr_2, cm
1	15	13.5	13.7	14.0	13.7	± 0.3
Residuals r_2		0.2	0	0.3		
2	20	17.2	19.6	18.2	18.3	± 1.3
Residuals r_2		1.1	1.3	0.1		
3	25	19.6	20.7	19.8	20.0	± 0.7
Residuals r_2		0.4	0.7	0.2		

The light intensity of the second lamp for the first measurement of the 2nd task is:

$I_2 = I_1 (r_2^2 / r_1^2)$, where r_2 is the average distance.

$I_2 = 25 \times (13.7^2 / 15^2) = 20.9$ cd

The light intensity of the second lamp for the second measurement is:

$I_2 = 25 \times (18.3^2 / 20^2) = 20.9$ cd

The light intensity of the second lamp for the third measurement is:

$I_2 = 25 \times (20^2 / 25^2) = 16$ cd

The average value for the light intensity $I_{2\,av.} = (20.9 + 20.9 + 16) / 3 = 19.3$ cd

The residuals for the light intensity are: 20.9 – 19.3 = 1.6 and 19.3 – 16 = 3.3

Evidently the maximum residual is 3.3, so the experimental error $\Delta I_2 = \pm 3.3$

The relative error $p = \Delta I_2 / I_{2\,av} = 3.3 / 19.3 = 0.8$

The percent error = p x 100% = 80%

Table 3: Determining the dependence of the lamp light intensity on the voltage

No	V_2, V	First measurement r_2, cm ± 0.25 cm	Second measurement r_2, cm ± 0.25 cm	Third measurement r_2, cm ± 0.25 cm	Average r_2, cm	Experimental error Δr_2, cm
1	9	21.4	20.6	22	21.3	± 0.7
Residuals r_2		0.1	0.7	0.7		
2	8	18.9	17.4	18.5	18.3	± 0.9
Residuals r_2		0.6	0.9	0.2		
3	7	17.3	16.1	17.0	16.8	± 0.7
Residuals r_2		0.5	0.7	0.2		

Let's do not forget that r_1 as a controlled variable is 25 cm.

The light intensity of the second lamp for every voltage applied in the first measurement is:

$I_2 = 25 \times (21.3^2 / 25^2) = 18.1$ cd

For the second measurement:

$I_2 = 25 \times (18.3^2 / 25^2) = 13.4$ cd

For the third measurement:

$I_2 = 25 \times (16.3^2 / 25^2) = 10.6$ cd

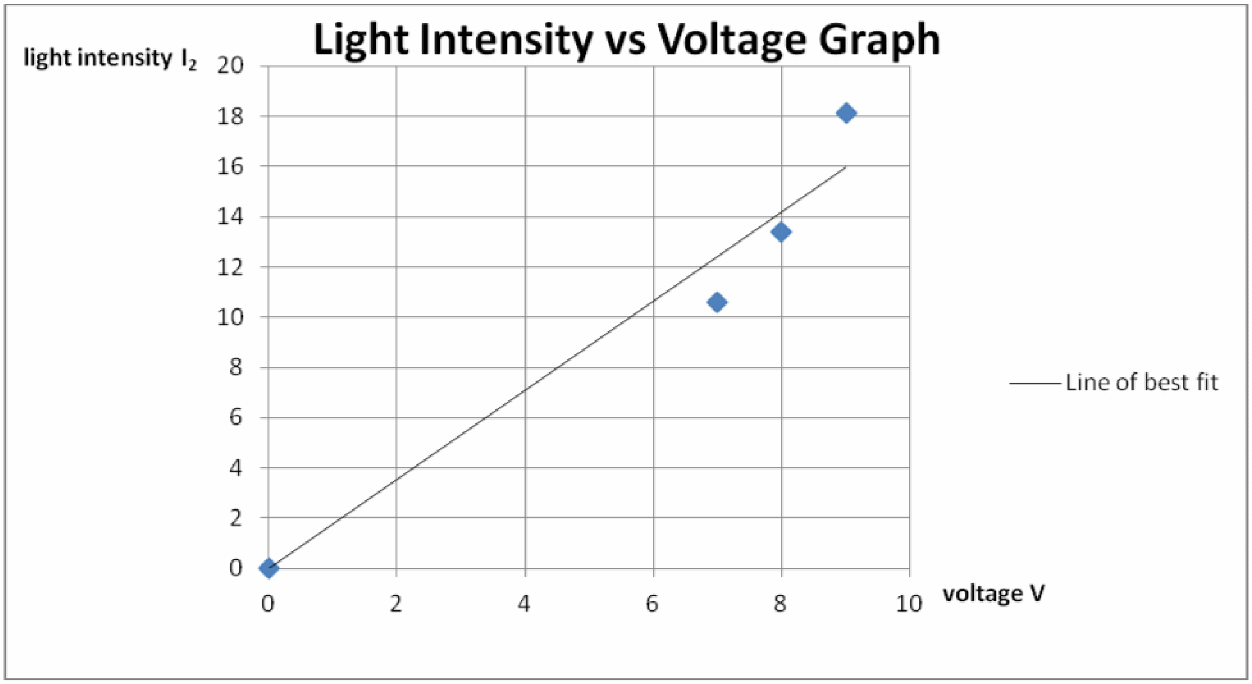
$I_{2\,av} = (18.1 + 13.4 + 10.6) / 3 = 14$ cd

The maximum residual $\Delta I_2 = 18.1 - 14 = 4.1$

The relative error for I_2 is: $p = \Delta I_2 / I_{2\,av} = 4.1 / 14 = 0.29$

The percent error = p x 100% = 29%

We draw light intensity vs voltage graph and we put the values for the light intensity and for the voltage from the 3rd task.



Gradient = 18.1 – 13.4 / 9 – 7 = 4.7 / 2 = 2.35

The graph is linear and shows the proportional (equal) increasing of the light intensity and the voltage.

Conclusion

Table 3 shows that when the voltage increases, the distance also increases, which practically means that when the voltage decreases, the distance decreases as well. When the voltage and the distance decrease, the light intensity also decreases, so when the light intensity increases, the voltage increases. This is illustrated in my graph, where the light intensity and the voltage are directly proportional to each other, but they are also directly proportional to the distance, and a distance vs voltage graph or/and light intensity vs distance graph would be similar and would have the same straight line. Table 3 and the graph prove my hypothesis.

Evaluation

It was difficult for the team to set the light intensity I_1 and I_2 to be exactly the same for the two sources because we did not have more precise device than our eyes, which resulted in a small inaccuracy. The sunlight entering through the windows of the laboratory was creating troubles for the team to see only the luminous light. It is evident on my picture that the photometer used is old and it used to confuse us when we were setting the light intensity I_1 and I_2 to be equal.

An old and a poor calibrated instrument increases the systematic errors, thus increasing the experimental error.

Improvements

The experiment can be improved when it is being held in a darker room, with limited or no presence of sunlight, because in this way human eyes will be more sensitive to the differences in the light intensity and would determine the equal light intensity of the sources more accurately and precisely. The photometer can be replaced with a newer and better one, a digital photometer if possible that would measure the equal light intensity electronically like this photometer: