European Journal of Applied Sciences – Vol. 13, No. 02
Publication Date: April 25, 2025
DOI:10.14738/aivp.1302.18651.
Mishra, P. K., Chauhan, A. S., Rustagi, H. V., Singh, I., Arun, P., Singh, N., & Kumar, K. (2025). An Undergraduate Experiment to Verify Cylindrical Wavefront Emission from Light Emitting Diodes. European Journal of Applied Sciences, Vol - 13(02). 479-485.

An Undergraduate Experiment to Verify Cylindrical Wavefront Emission from Light Emitting Diodes

P.K. Mishra
Department of Electronics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

A.S. Chauhan
Department of Electronics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

H.V. Rustagi
Department of Electronics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

I. Singh
Department of Electronics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

P. Arun
Department of Electronics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

Nimmi Singh
Department of Physics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

K. Kumar
Department of Physics,
Sri Guru Tegh Bahadur Khalsa College,
University of Delhi, Delhi 110 007, India

ABSTRACT

In this work, a simple experiment has been described to study and verify the occurrence of cylindrical wavefront, which are left untouched in the undergraduate levels. The experiment setup comprises of LEDs as the source of light and light dependent resistor (LDR) as the detector. The variation between the light intensity (detected by LDR) as a function of its distance from the LED has been studied. The

light intensity at the detector is found to decay as we move away from the LED source. The data points are then fitted to mathematical equations and it is observed that the light decay is not only governed by distance but also by the atmospheric conditions. The equation points to the occurrence of cylindrical wavefront in the emitted light. The same experiment is repeated with three different colored LEDs (red, green and blue) and a similar trend is obtained in all the cases. The work introduces students to concepts rarely mentioned in the text books.

Keywords: Wavefront, Light Emitting Diode, Intensity.

INTRODUCTION

At undergraduate level, in subjects like Photonics or Optics, students are introduced to Fraunhoffer's Diffraction [1] and in passing are informed about Fresnel's Diffraction [2]. They are educated about the geometrical features of the two, by associating Fraunhoffer's Diffraction with plane wavefront and Fresnel's Diffraction with the spherical wavefront. The fact that spherical wavefront, after propagating large distance, become plane wavefront is another geometrical method adopted to explain the difference between the two diffraction phenomena without dwelling on Fresnel's approximation obtained by Kirchoff's Integral method [3]. The students are, then, left poorer with no experiments to extinguish their curiosity about the phenomena and are rarely informed about the possibility of cylindrical wavefront. Even the popular textbooks are guilty of these omissions [4].

Wavefront formation, though, appears as an obvious extension of Huygens principle, students do not find it to be particularly compelling. This is true, given that it is practically challenging for an undergraduate student to visualize wavefront creation and its propagation. The typical textbooks don't help students understand the importance of aperture on both the source and detector sides; they only discuss wavefront with the assumption that the distance between the source and screen is great. For instance, it was discovered that all students believe that light travels through a rectangular slit in a plane wavefront. They fail to appreciate that the slit actually generates cylindrical wavefront that appears to be a plane wavefront if the screen is kept at a large distance from it. Pedagogically, it becomes crucial that physics instructors use an experimental strategy to clarify how source geometry and aperture size affect the kind of wavefront produced. Along with understanding the influence of aperture, students will also need to comprehend how the wavefront changes as the distance between the source and detector increases.

This short communication shows the ease with which an experiment can be introduced in school/colleges to educate students about the different wavefront. The experimental setup presented in this paper is straightforward and requires little training to install in any undergraduate laboratory. LEDs and a light-dependent resistor (LDR) make up the circuit.

The light emitting diodes (LEDs), which are easily available in the Physics laboratory are source of light that propagates in cylindrical wavefront This is attributed to the linear structure of LEDs. Broadly, LEDs comprise of an anode and a cathode to connect the pn junction, the p-layer in the junction is at the top, from where light emission takes place (Fig. 1) [5].

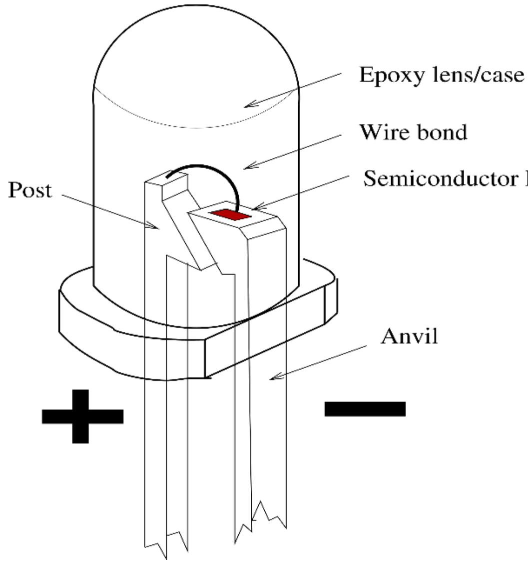

Figure 1: An artwork representation of LED.

The geometry of electrodes and the cylindrical transparent casing of the LED renders cylindrical wavefront. Huygens was the first to suggest that light propagates in the form of wavefront [1]. The shape of these wavefront depends upon the geometry of source and the distance of source from the detector. Of the power (P) is emitted by the source, then the amount of power detected by the sensor depends on its aperture area (A) and the surface area of the wavefront falling on it.

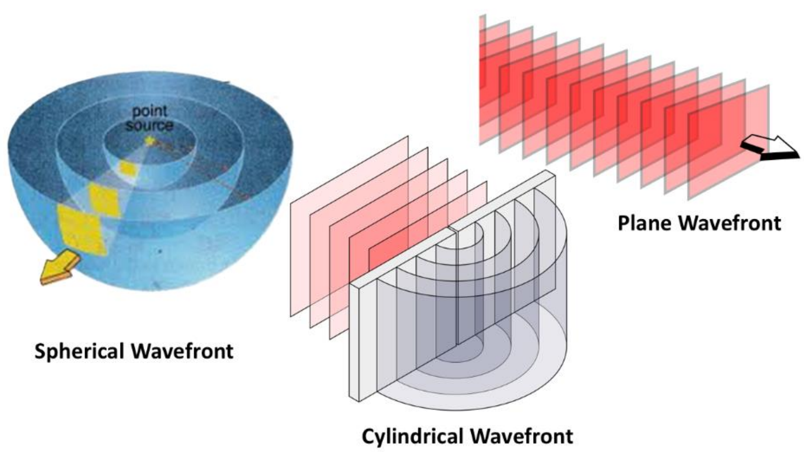

Figure 2: The figure shows propagation of spherical wavefront, cylindrical wavefront, and plane wavefront

The detected power is given by

$$\text{Power measured} = \frac{PA}{S_a} \tag{1}$$

where, S_a is total surface area of the wavefront. For the three important wavefront, power measured turns out to be

- $\frac{PA}{4\pi r^2}$for spherical wavefront where `r' is the distance between source and photo-sensor.
- $\frac{PA}{2\pi rL}$for cylindrical wavefront where `r' is the distance between source and photo-sensor and `L' is length of the cylinder.
- $\frac{PA}{a}$for plane wavefront where `a' is area of the rectangular wavefront.

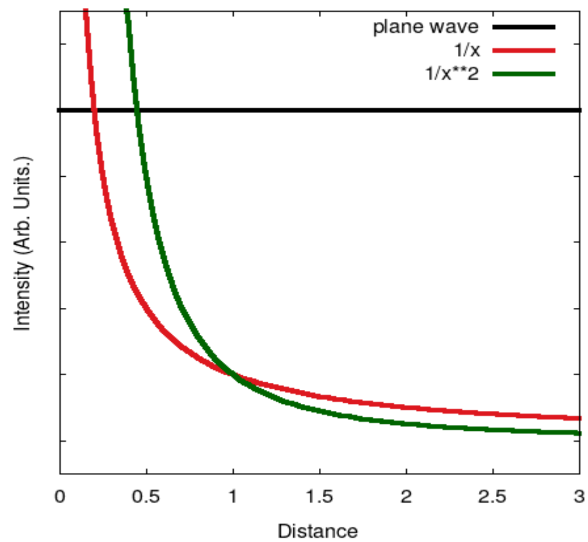

Figure 3: Theoretical variation in intensity of various wavefront with distance.

Fig 2 shows these three wavefront while Fig 3 gives the variation in the power detected by the sensor as a function of its distance from the source for all the three cases. The spherical wavefront is three-dimensional that grow outward over time. The cylindrical wavefront propagate outward in a cylindrical fashion from a line or axis, unlike spherical waves that radiate in every direction. while, plane waves are described by waves whose wavefront are planes, and the wave's amplitude is constant along the direction of propagation of wave. The observation of energy attenuation with propagation is an off-spin of the experiment we designed. Although the attenuation should be insignificant at short distances, it was detectable and noticeable for r<60 cm due to Delhi's high air pollution levels. Therefore, the proposed experiment might be expanded to investigate the number of suspended particles in the atmosphere. It can be observed that intensity falls rapidly as $1/r^2$ for spherical wavefront, for cylindrical wavefront the fall in intensity is determined by 1/r and for plane wavefront it remains constant because in this case the wavefront does not expand as we move away from the source.

EXPERIMENTAL SETUP

To understand the phenomenon, we have used LED as light source and measured its intensity as a function of distance using a light detecting resistor (LDR). The LDR's simple operation makes it easy to integrate into electronic circuits. Figure 4 shows use of LDR as photo-sensor, where light intensity is converted to current in a simple Ohmic circuit. The current (I_B) in the LDR circuit is given by:

$$I_B=\frac{V_{BB}}{R_{LDR}} \qquad (2)$$

Where, V_{BB} is the applied voltage and R_{LDR} is the resistance of the LDR.

The LDR changes its resistance as the intensity of light falling on it varies. The incident light results in creation of charge carriers. These carriers result in lowering of the resistance of the material used in LDR. Thus, a voltage to current converter circuit can be used as a linear detector in response for the incident light intensity. The relationship between light intensity and resistance in an LDR is approximated as [6-7]

$$R_{LDR}=\frac{k}{I^{\gamma}} \qquad (3)$$

where, I is the light intensity, \`k' and \`**β**' (usually between 0.5 and 1) are constants specific to the material. Using eqn(3) in eqn(2), we have

$$I_B=V_{BB}I^{\gamma} \qquad (4)$$

For cadmium sulfide (CdS) based LDR from SUNROM Technologies, ⍰~1 [8] Hence, current I_B in the circuit varies linearly with light intensity. In other words, our circuit is optimum since it is a linear detector. To perform the experiment, the source (LED) and detector (LDR) are loaded on an optical bench with gradation to measure the distance. The optical bench ensures minimum lateral displacement when the experiment is performed.

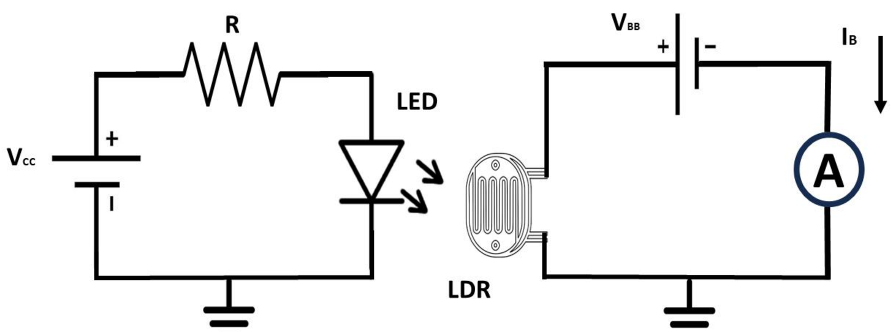

Figure 4: The circuit diagram of experimental setup to represent LED light falling on LDR.

RESULTS AND DISCUSSION

The measurements were done for three different colored LEDs and the variation with distance in all the three cases is plotted in Fig (5). It is observed that none of the plots fit directly with spherical and cylindrical wavefront variations. The nearest fit to the data was found to follow '1/r' trend. The variation in intensity with distance followed '$1/r^n$' trend with $1<n<2$. In fact, the best fit between measured current 'I' and distance 'r' is observed with the following.

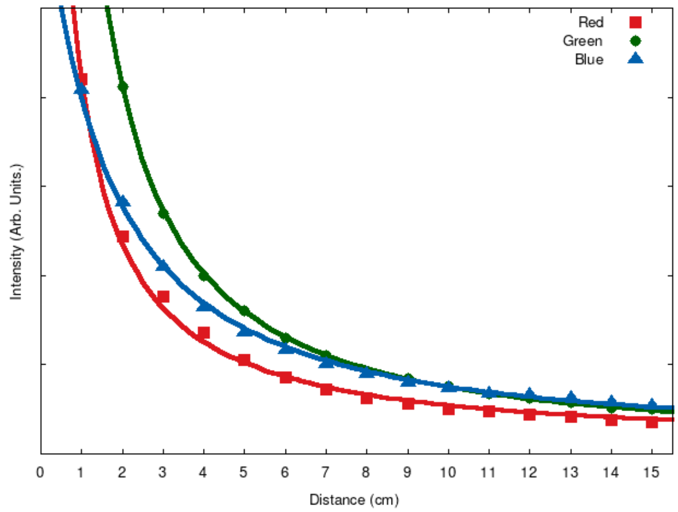

Figure 5: The variation in intensity of red, green and blue LEDs with distance as determined by our experimental technique.

$$I=I_o\left(\frac{e^{-\beta(r+b)}}{r+b}\right)+c \qquad (5)$$

where ‘I_o’ represents value of current when the LED is in contact with LDR i.e. r=0, ‘c’ represents the contribution due to background light, the exponential term represents the atmospheric attenuation in intensity with `⍰’ being the attenuation factor and ‘b’ is the distance between light emitting semiconductor layer and LDR caused due to the epoxy outer casing walls of the devices.

Thus, as we move away from a LED light source, the fall in light intensity is inversely proportional to the distance as ‘1/r’. This decay in light intensity is independent of the color of LED i.e. wavelength of light. The decay is also accompanied by the attenuation due to atmospheric conditions that affects the light propagation exponentially.

Table 1: The fitting parameters of eqn (5) for different LEDs shown in fig (3).

S.No.	LED	I_o (mA)	β (cm^{-1})	B (cm)	C (mA)
1	Red	2.65	0.035	0.25	0.09
2	Green	4.6	0.05	0.1	0.098
3	Blue	5.4	0.06	1.5	0.14

The calculated values of fitting parameters I_o, ⍰, b and c for all the three LEDs are shown in Table 1. The finite value of `c’ existed due to the background light present in the room. The significant contribution from exponential term in our data is due to air pollution in Delhi. The value of β is found to be nearly constant for all the three cases. Thus, atmospheric attenuation of light is independent of wavelength of light. The initial value of detector current `I_o’ for all the three cases is different. This is attributed to the difference in light intensity radiated by different LEDs for the fixed current maintained in the circuit. The value of ‘b’ is also found to be different for all the three LEDs, which again depends upon manufacturers.

CONCLUSIONS

This work highlights the lack of experimental exposure in undergraduate optics education regarding different wavefront, particularly the cylindrical wavefront. While students are introduced to Fraunhoffer and Fresnel diffraction, they are rarely given hands-on experience or discussions about cylindrical wavefront. The study demonstrates an easy experiment using LEDs to illustrate cylindrical wavefront propagation. LEDs, due to their structure and electrode geometry, emits light in cylindrical wavefront. To study the variation in intensity with distance, an experimental setup was designed using an LED as a light source and a light-dependent resistor (LDR) as a detector. Measurements from red, green, and blue LEDs showed that intensity follows an inverse-distance relation ($1/r^n$, where $1<n<2$) rather than purely spherical ($1/r^2$) or cylindrical decay ($1/r$). The measurements also accounts for atmospheric attenuation, and LED casing design, showing that attenuation is independent of wavelength. The findings suggest that incorporating such simple experiments in undergraduate curricula can enhance understanding of wavefront propagation, bridging the gap between theoretical knowledge and practical observation.

ACKNOWLEDGMENTS

This research was supported by Electronics Lab, Department of Electronics, Sri Guru Tegh Bahadur Khalsa College, University of Delhi, Delhi.

References

1. Born M. and Wolf E., Principles of Optics: Electromagnetic Theory of Propagation, Interference, and Diffraction of Light, (Cambridge University Press, London, 1999).
2. Young M., Optics and Lasers: An Engineering Physics Approach, (Springer Berlin / Heidelberg, Berlin, Heidelberg, 2013).
3. Kirchhoff G., Zur Theorie der Lichtstrahlen, Zenodo 1883 (254), p663-695.
4. Ghatak A., Optics, (Tata McGraw Hill, New Delhi, 1986).
5. Arun P., Electronics, (Narosa, New Delhi, 2nd Ed., 2011).
6. Kasap S.O., Optoelectronics and Photonics: Principles and Practices, (Pearson Education, Inc., New Jersey, 2nd Ed., 2013).
7. Marinho F., Paulucci L., Carvalho C.M., Apolinário F., Measuring light with light dependent resistors: an easy approach for optics experiments, European Journal of Physics, 2019, (40) 035801.
8. https://www.sunrom.com/download/3190-LDR.pdf.