Intensity of Colors in a Spectrum

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That white light is made up of different colours (wavelengths) is a well known fact, even at school level. When this white light is incident on a prism, these different wavelength radiations travel in different directions (speeds) within the glass medium whose refractive index is higher than the refractive index of air. These different light radiations, after exiting from the other surface of prism, move on paths which are diverging, as shown in Figure 1.

Figure 1. Input light splitting up in to different colours/wavelengths.

Thus it is a great pleasure for school students to determine the intensity of each of the different wavelengths. Determining these intensities can open up several different possibilities of experimentation and application of these measurements. The instrument used to measure these intensities is called a spectrometer.

However, for students to manufacture a spectrometer is far more interesting (and inexpensive) than relying on a commercially manufactured spectrometer. This article will deal with two aspects. The first one describes fabrication of the equipment/spectrometer and the other is use of the spectrometer to make interesting measurements.

Apparatus:

1. Source Unit: A short optical bench with a white LED (Light Emitting Diode), a source slit C_s in front of the LED, a converging lens mounted on separate stands.
2. Analyzer Unit: Another optical bench consisting of a prism, cylindrical lens and a photo-diode with a collimation slit C_d on the diode on separate stands and a lateral adjustment screw at the base of the stand holding the photodiode.

Construction of the spectrometer.

[Many commercial spectrometers are available in the market, generally costing a lot of money. However, these do not allow a student to appreciate optical principles. The spectrometer described here is designed to be fabricated by the student/teacher. The components need to be aligned optically. This is a most essential component of all optics experiments. In the absence of proper optical alignment of components, the whole experiment will be filled with errors. If the slit is vertical and prism is placed on a horizontal plane, the spectrum that is generated will be vertical. However, if the slit is not perpendicular to the plane on which prism is placed, the spectrum generated will not be linear, but will appear twisted.

When a spectrum is generated from a prism the emerging light (of different wavelengths) begins to diverge, which means the physical separation between the different coloured rays of light keeps widening in the horizontal direction Figure 2. However, the intensity for each wavelength in the vertical direction is a waste if cannot be used to measure how the intensity is distributed horizontally.

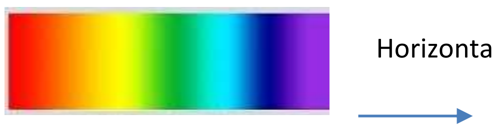

Figure 2. Optical spectrum.

Figure 3 Cylindrical lens

Hence a special cylindrical lens (Figure 3) is designed which bends the light in the vertical direction to add up all the intensity for each wavelength at a single point while, at the same time, not disturbing anything along the horizontal direction. This lens was fabricated at a private workshop in Mumbai.

It is also required that the white LED is placed as close to the slits as possible, and the slits as close to the prism as possible. In case light intensity is sufficient, the light source may be kept away from slit and a convex lens inserted so as to make the emergent light a parallel beam which is incident on the slits. Rest of the arrangement remains the same.

Figure 5 Cross view of the set up.

Figure 4 Top view of the set up.

Height of each stand can be adjusted and can be independently moved horizontally as can be seen in Figure 4,5 and 6.

Figure 6 Side view of the set up.

The prism base can be rotated about a vertical axis so that the light from the source can make different angles of incidence on the refracting surface of the prism.

The pitch of the screw at the base of the photodiode set up is 0.5 mm.

Procedure:

1) Arrange all the apparatus as shown in the photographs. **The photographs will be updated after the lockdown of COVID-19.**
2) Keep a converging lens in front of the white LED, in such a way that the emerging beam is slightly diverging (almost parallel). NOTE: This can be achieved by ensuring that the LED light focuses at approximately the distance at which photodiode will be placed. This should be a few centimeters from the prism. This lens can be avoided if the LED light intensity is sufficiently strong. User has to decide on the basis of the experimental results.
3) Keep slit C_s in the path of the emerging beam from the lens, so that a fine beam of light falls on the prism.
4) Adjust the optical bench, in such a way that the spectrum generated from prism falls horizontally on the cylindrical lens *(axis of the cylindrical lens should be horizontal). The resultant spectrum should be a horizontal line of different colors.*
5) Adjust the components on the long optical bench in such a way that the thin beam of the spectrum falls on the collimating slit C_d in front of the photo diode. Now the diode, behind the slit should be able to see a very narrow region of the spectrum. This spectrum will NOT be distorted only if all the components are on the optical axis and perpendicular to the optical axis.
6) Place a screen in between the LED and the slit C_s. Such that white light from LED does not fall directly on to the diode or the slit C_d.
7) Adjust the lateral screw in such a way that slit C_d is just outside the violet light of the spectrum.

8) Connect the leads of the photo-diode to the multimeter in the current mode. Note down the background reading when no visible light falls on the slit C_d.

Figure 7 Two different views of the photodiode arrangement.

9) Rotate the nut so that screw moves laterally such that slit is moves across the full spectrum.

10) Whenever slit is outside the range of visible spectrum you will see a background current value (on both sides of the spectrum).

11) After having familiarized with the movements of the slit, take it just outside the edge of the violet light and measure the distance (location x) using the Vernier screw arrangement.

12) Move the slit by rotating the screw **by one mark on the main scale** (0.5mm) such that it moves towards the red light.

13) Measure the current on the multimeter. Note the readings in the table.

14) Move the stand in steps of one full rotation of screw and note down the current (x) position in each case. **Do not reverse the movement otherwise you will get a backlash error.**

Current reading (background) outside the violet region = I_{bv} = ______________ A

Reading on the vernier (outside the violet region) = X_{bv} =_________________ cm

Current reading (background) outside the red region = I_{br} = ______________ A

Reading on the vernier (outside the red region) = X_{br}= _________________ cm

[X marks]

Sr. No	X /cm	Distance from X_{bv} d=(X- X_{bv}) /cm	I_x (measured) /A	I_{xc} (corrected) /A	Wavelength /(nm)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

[11 marks]

Calibrate the distance with wavelength. In simple terms relate distance x with wavelength λ .

m = (700-400)/(X_{br} - X_{bv})

To determine any value of λ use the equation λ = m * d + 400 nm

$I_{xc} = I_x - \{(I_{bv} + I_{br})/2\}$

Replace the LED by a filament bulb and repeat the experiment. In this case X_{br} is the point just outside red light region. Here the current will not drop to background since infrared radiation is still non-zero.

Current reading (background) outside the violet region = I_{bv} = ____________ A

Reading on the vernier (outside the violet region) = X_{bv} = ________________ cm

Current reading (background) outside the red region = I_{br} = _____________ A

Reading on the vernier (outside the red region) = X_{br} ________________ cm [X marks]

Sr. No	X (vernier reading) /cm	Distance from x_{bv} $d=(x- x_{bv})$ /cm	I_x (measured) A	I_{xc} (corrected) /A	Wavelength /(nm)

[X marks]

Plot I_{xc} vs λ for both the cases. Do not connect the points but draw a smooth curve. [X marks]

Q 1) Write your observations by comparing three spectra. [X mark]

[Teachers can frame different types of questions on the observations and skills of students based on their experience in their classrooms. A typical spectrum is plotted in the graph below. However, the spectrum may vary based on the type of LED used and sensitivity of the photodiode but general trend will be preserved where one can observe two humps in the spectrum, one in blue region of wavelength and other in the red region of the wavelength. A typical spectrum is plotted below.]