Chapter: Dispersion of Light

Types of light

- **Monochromatic light**
  (Light of single colour,
  Single frequincy and wavelength)
  e.g. Sodium light
- **Polycromatic light**
  (Light of many colours)
  e.g. Polychromatic light (White light)

Dispersion of light:

The splitting of white light into its constituent colors is known as dispersion of light. The band of seven colors obtained on the screen is called spectrum of white light. When the white light passes through a prism, it is splitted into seven colors which is known as dispersion of white light.

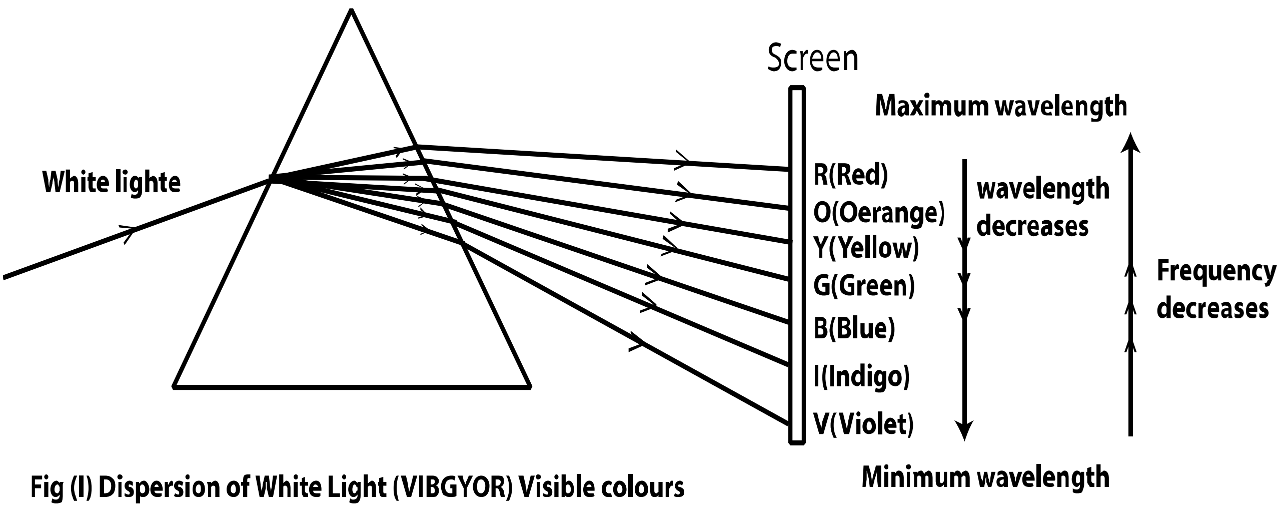

Fig (I) Dispersion of White Light (VIBGYOR) Visible colours

The color of light depends upon its wavelength.

Note: $\lambda \rightarrow$ small then $f \rightarrow$ more $\Rightarrow$

v of visible light is constant

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Note: Violet has maximum ReDDif (formula)

Here, R→ Refractive Index

D → Deviation

Di→ (Lateral) Displacement

f→ Frequency

Causes of Dispersion of Light(2069, 2071, 2076 ,2 Marks)

The Cauchy's formula for the refractive index (μ) of a material for light of wavelength (λ) is given by, $\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$, ...(1) where, a, b, c are constant

Since , $\lambda_{violet} < \lambda_{red}$ so from (1) , $\mu_{violet} > \mu_{red}$.

Also the deviation produced by a small angled prism is given by, $\delta = (\mu - 1)A$ . ...(2)

Where, A = angle of prism and μ = refractive index

Since, $\mu_{violet} > \mu_{red}$ so, $\delta_{violet} < \delta_{red}$. The other colour will deviate through angles between δ_{red} & δ_{violet} .

Thus, the white light consisting of different color will emerge from prism in different direction due to dispersion.

Relation between Refraction Index and Wavelength of Light (2069, 2074 , 2 marks)

From Cauchy's formula, $\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$ ......(1)

It is cleared that, refractive index varies inversely with the wavelength of the light. Hence, refractive index of light depends upon the wavelength of light.

Note: Different colors of light have different wavelength and hence different refractive index.

e.g. Red color → Longer wavelength and

Violet color → Shorter wavelength

Q. Define Dispersive power of a lens and write expression for it colors used Interms of the refractive indices of lens w.r.t different colours used.
(2073, 12056, 2053, 2 marks)

Dispersive power: The ratio of angular dispersion to mean deviation is a constant called dispersive power. It is denoted by ω.

i.e. Dispersive power (ω) = $\frac{\text{angular dispersion}}{\text{Mean deviation}}$

or, $\omega = \frac{\delta_{violet} - \delta_{red}}{\delta} = \frac{\mu_{violet} - \mu_{red}}{(\mu - 1)}$

Here, $\delta_V = (\mu_v - 1)A$ and $\delta_r = (\mu_r - 1)A$ and $\delta = (\mu - 1)A$

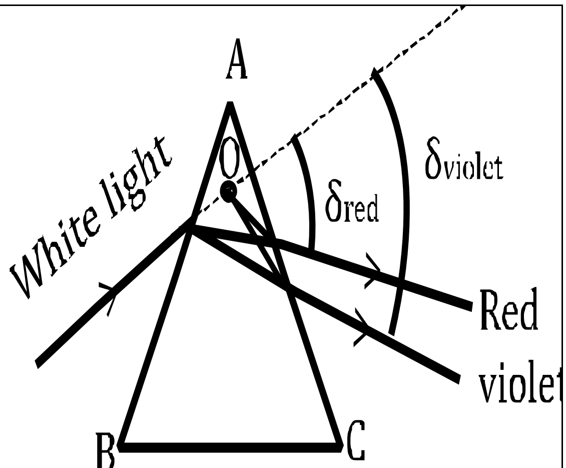
→ It's value depends upon nature of the prism.

→ The $\mu_{flint\ glass} > \mu_{crown\ glass}$ so $\omega_{flint\ glass} > \omega_{crown\ glass}$

→Greater is ω for material, larger is angle (spreading) between violet and red.

→ When white light passes through a prism, it suffers deviation and dispersion as well.

Angular Dispersion:

The difference in angle of deviation between any two colors of light is called angular dispersion. Here, Angular dispersion $= \measuredangle ROV$ $= \delta_v - \delta_r$ $= (\mu_v - 1)A - (\mu_r - 1)A = (\mu_v - \mu_r)A$ Clearly, Angular dispersion depends upon angle of prism (A) and the nature of the prism material.	 Fig (I) Deviation of light

Note: deviation $\delta = (\mu - 1)A$

Monochromatic aberration:

The defect of images produced by monochromatic light is called monochromatic aberration. It is due to optical system. There are five common monochromatic aberrations which are as follows:

a) Spherical Aberration b) Coma c) Astigmatism d) Distortion and e) Curvature

Spherical Aberration in a lens (2 marks)

→ The inability of lens to focus all the light rays (paraxial and marginal) at a single point after refraction through it is called Spherical aberration.

$\begin{bmatrix} \text{Paraxial rays} \rightarrow \text{rays incident on the lens near principal axis} \\ \text{marginal rays} \rightarrow \text{rays falling near the edge (periphery)} \end{bmatrix}$

→ Spherical Aberration occurs due to deviation at different angles by marginal and paraxial rays.

→ This defect can be removed by:

a) Using a stop
b) Using plans - convex lens
c) Using two lenses separated by a distance ($d = f_1 - f_2$)
d) Combining suitable convex and concave lenses.

→ This is not color defect.

Types of Spherical Aberration in a lens

a) Longitudinal Spherical Aberration ($F_m F_p$)
b) Lateral Spherical aberration (XY)

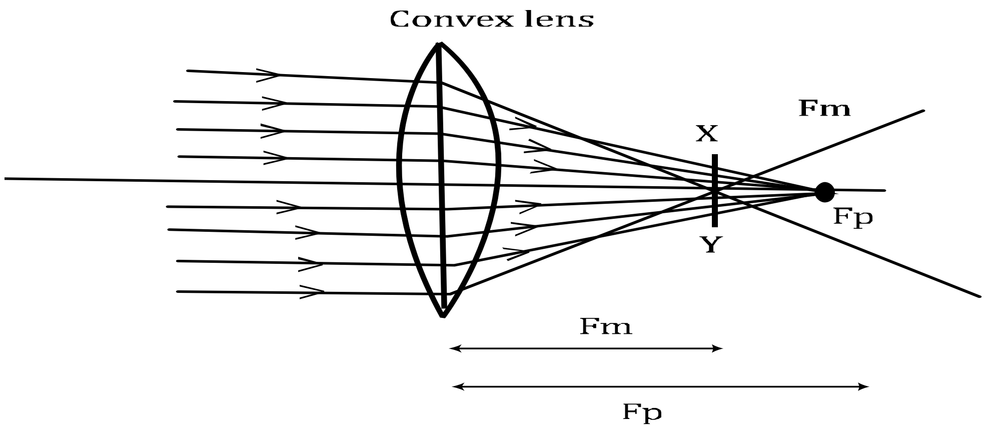


Fig (I) Spherical Aberration in a lens.

Since, paraxial rays and marginal rays focus at different points, the image of the bottom and top parts of an object

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will be formed at different distances from the lens and hence a curved image of the object is formed.

Method of Reading Spherical Aberration

(I) By using a stop:

The use of stop for reducing spherical aberration reduces brightness of the images.

Defect can be reduced when paraxial rays are cut off by covering the central portion of the lens. (fig a)

Defect can be reduced when marginal rays are cut-off by using a narrow circular aperture (Fig b)

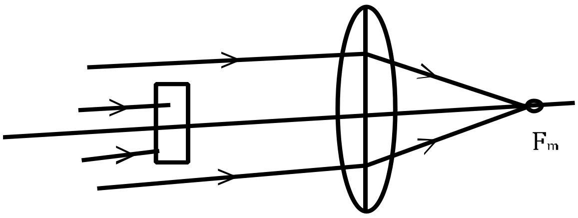


Fig (a)

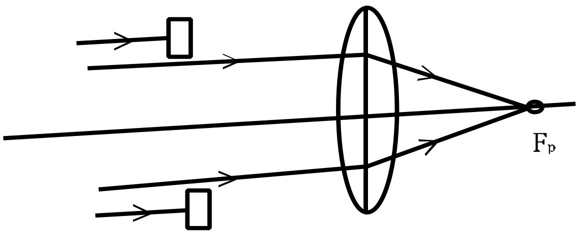


Fig (b)

Q. What is chromatic aberration in Lens? Deduce condition for achromatism in two thin lenses in contact. (2073, 2070, 2069,2058, 2055, 4 marks)

Chromatic Aberration in a lens:

→ The inability of a lens to focus all colors of light at a single point is called chromatic aberration or axial or longitudinal chromatic aberration.

→ Chromatic aberration occurs due to deviation at different angle by different colors of light.
→ This defect can be removed by Achromatic combination of Lens.
→ This is color defect in lens only and does not appear in mirror because reflection is not affected by wavelength.

Expression for axial chromatic aberration:(2070. 2069, 2066)

According to Lens Makers formula, the focal length of a lens for a mean color is given as,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

or, $\frac{1}{f} = (\mu - 1)k$ ....(1) Where, K= $\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

Here, $R_1$and R_2 are the radii of curvature of the two surfaces of the lens and μ is a refractive index for mean colour of the lens.

Similarly, for violet and red color, we can write

$\frac{1}{f_v} = (\mu_v - 1)k$ ....(2)

and $\frac{1}{f_r} = (\mu_r - 1)k$ ....(3)

Subtracting equation (3) from (2):

$$\text{or } \frac{1}{f_v} - \frac{1}{f_r} = (\mu_v - 1)k - (\mu_r - 1)k$$

or, $\frac{f_r - f_v}{f_v . f_r} = (\mu_v - \mu_r)k$

(use equation (1))

or, $\frac{f_r - f_v}{f_v . f_r} = (\mu_v - \mu_r)\frac{1}{f(\mu-1)}$

or, $\frac{f_r - f_v}{f_v . f_r} = \frac{(\mu_v - \mu_r)}{f(\mu-1)}$

or, $\frac{f_r - f_v}{f_v . f_r} = \frac{\omega}{f}$ ....(4)

{Where, Dispersive power $\omega = \frac{(\mu_v - \mu_r)}{(\mu-1)}$ }

Since, focal length of lens for mean light colour can be taken as geometric mean of focal length of violet and red light.

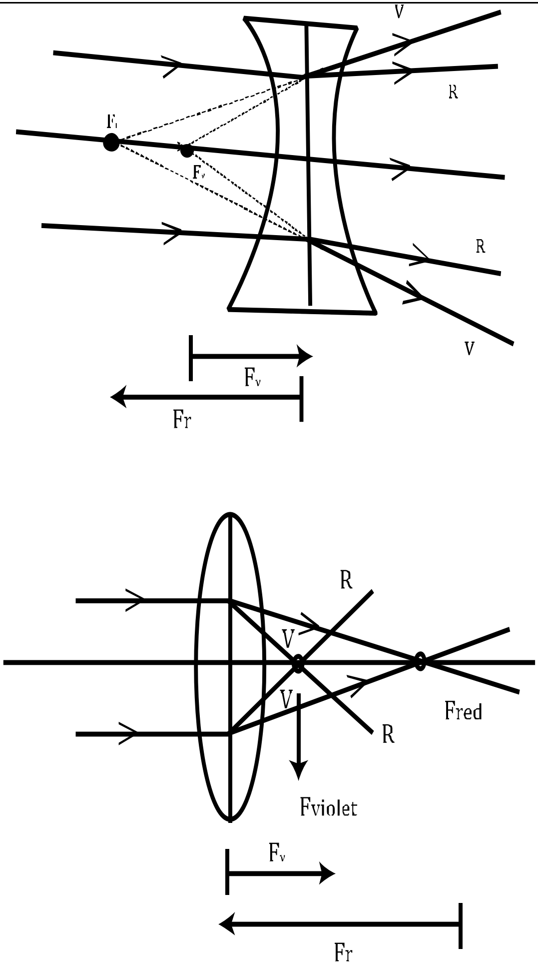
i.e. $f = \sqrt{f_v . f_r}$

or, $f^2 = f_v f_r$ ....(5)

use (5) in (4) ;

$$\frac{f_r - f_v}{f^2} = \frac{\omega}{f}$$

$\rightarrow f_r - f_v = \omega f$



Fig(a) Chromatic aberration in convex lens

i.e. Chromatic Aberration = Dispersive power × Mean focal length

This is required expression for axial chromatic aberration when object is at infinity.

Note: Smaller the focal length → Smaller the chromatic aberration in the lens.

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$$\begin{pmatrix} \text{for convex} \rightarrow \text{f} = +\text{ve} \\ \text{for concave} \rightarrow \text{f} = -\text{ve} \\ \text{Dispersive power } (\omega) \text{is always positive} \end{pmatrix}$$

Condition for Achromatism:(2073, 2070, 20689, 2058, 2053)

→ The combination of lenses used to eliminate the chromatic aberration is called Achromatic combination of lenses or Achromatic lens or Achromat and the phenomenon is called Achromatism.

Let two thin lenses of different materials of dispersive powers ω and ω' be combined fig (I). Again, let μ_v, μ and μ_r be the refractive indices for violet, mean color light and red of lens L_1 and f_V , f and f_r are their corresponding focal lengths for them. Also let μ'_v, μ' and μ'_r be refractive indices for violet, mean color light and red of lens $L_2$and f'_v , f' and f'_r are their corresponding focal lengths for them.

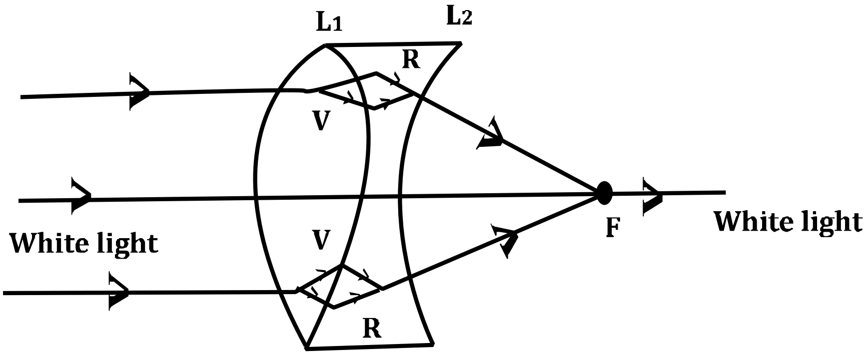

Fig (I) Achromatic Combination of lenses

For lens L_1: According to lens Maker's formula, the focal length for mean light is given as;

$\frac{1}{f}(\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$.............(a)

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Where R_1 and R_2 are radii of curvature of two surface of the lens L_1.

the focal length for violet light of lens L_1

$\frac{1}{f_v} = (\mu_v - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$..........................(b)

and the focal length for red light of lens L_1

$\frac{1}{f_v} = (\mu_r - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$ ....(c)

Similarly, for the lens L_2, we have

$\frac{1}{f\prime} = (\mu' - 1)\left(\frac{1}{R\prime_1} + \frac{1}{R\prime_2}\right)$..........................(d) (Where R_1' and R_2' are the radii of curvature of lens L_2)

$$\frac{1}{{f_v}'} = ({\mu'}_v - 1)\left(\frac{1}{{R'}_1} + \frac{1}{{R'}_2}\right) \ldots\ldots\ldots\ldots (e)$$

$$\frac{1}{{f_r}'} = ({\mu'}_r - 1)\left(\frac{1}{{R'}_1} + \frac{1}{{R'}_2}\right) \ldots\ldots\ldots\ldots (f)$$

Now, if F_v be focal length for the lens combination for violet colour, then we have,

$$\frac{1}{F_v} = \frac{1}{f_v} + \frac{1}{f_v'} \ldots\ldots (g)$$

Similarly for red colour,

$$\frac{1}{F_r} = \frac{1}{f_r} + \frac{1}{f_r'} \ldots\ldots (h)$$

For achromatism, we must have

$$F_v = F_r$$

or, $\frac{1}{F_v} = \frac{1}{F_r}$ (use equation (g) and (h))

$$\text{or}, \frac{1}{f_v} + \frac{1}{f_v'} = \frac{1}{f_r} + \frac{1}{f_r'}$$

or, , $\frac{1}{f_v} - \frac{1}{f_r} \;\; = -\left(\frac{1}{f'_v} - \frac{1}{f'_r}\right)$

or, $(\mu_v - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - (\mu_r - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) =$

$-\left\{(\mu'_v - 1)\left(\frac{1}{R'_1} + \frac{1}{R'_2}\right) - (\mu'_r - 1)\left(\frac{1}{R'_1} + \frac{1}{R'_2}\right)\right\}$

or, $(\mu_v - \mu_r)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = -(\mu'_v - \mu'_r)\left(\frac{1}{R'_1} + \frac{1}{R'_2}\right)$

...................(I)

Use Equation (a) and (d) in (I)

$$(\mu_v - \mu_r).\frac{1}{(\mu - 1)f} = -(\mu'_v - \mu'_r).\frac{1}{(\mu' - 1)f'}$$

or, $\left\{\frac{\mu_v - \mu_r}{(\mu - 1)}\right\}.\frac{1}{f} = -\left\{\frac{(\mu'_v - \mu'_r)}{(\mu' - 1)}\right\}.\frac{1}{f'}$

or, $\frac{\omega}{f} = -\frac{\omega'}{f'}$

where ω = $\frac{\mu_v - \mu_r}{(\mu - 1)}$ is the dispersive power of lens L_1

and $\omega' = \frac{(\mu'_v - \mu'_r)}{(\mu' - 1)}$ is the dispersive power of lens L_2

:. $\frac{\omega}{f} + \frac{\omega'}{f'} = 0$................(J)

This is the required condition for Achromatism for two thin lenses in contact.

Note: (1) Since ω and ω ' are always positive so the focal f and f' should be of opposite signs i.e. one is convex and other is concave lens.

Note: (2) If lenses L_1 and L_2 are of the same materials then ω = ω ' so from equation (I)

$\frac{1}{f} + \frac{1}{f'} = 0 \quad \rightarrow$ 1/F = 0

$\rightarrow F = \infty$ so Power (P) = 0 Dioptre

NOTE:3) $\frac{1}{F} = \frac{1}{f} + \frac{1}{f'}$, if $\omega = \omega'$

Pure and Impure spectra:

$\rightarrow$ The Spectrum in which there is no overlapping among the colors is called pure spectrum and the spectrum in which there is overlapping among the colors is called Impure Spectrum. e.g. Rainbow is an example impure spectrum.

$\rightarrow$ If the spectrum on the screen in which the splitted colors don't overlap to each other, all colors can be seen distinctly and this is called the pure spectrum.

If the splitted rays overlap to each other, all colors cannot be seen distinctly on the screen. Such spectrum is called the impure spectrum.

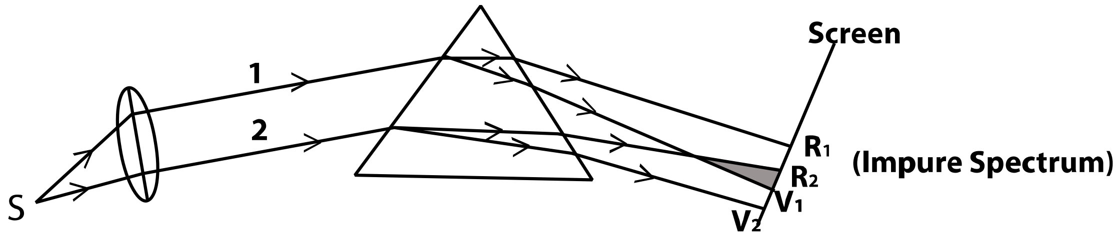

Fig (a) Impure Spectrum has different colours at small region.

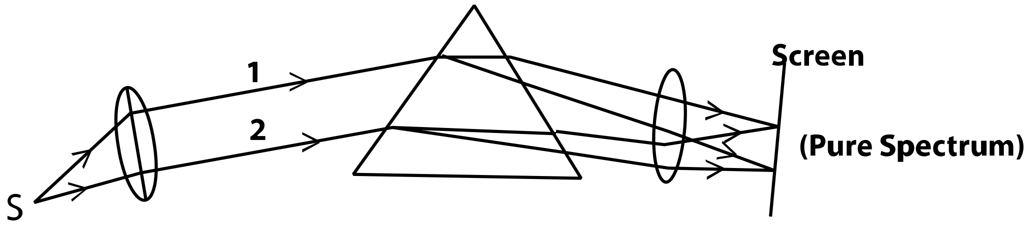

Fig (b) Pure Spectrum has single colour at small region.

Condition for production of pure spectrum

(I) The slit should be narrow.

(II) The prism should be placed in the position of minimum deviation for mean rays.
(III) An achromatic convex lens i.e. lens which produced no color effect should be placed between prism and screen.
(IV) The refracting edge of the prism should be parallel to the slit.

Scattering of light:

→ On being accelerated by the electric flied, the electric charge emits radiation in all direction and this process is called scattering.

Q. Why does the sun appears red during the sun rise and sunset?(2069, 2067 , 2marks)

→ According to Rayleigh law, the intensity of scattering of light is inversely proportional to the fourth power of the wavelength.

i.e. $I \propto \frac{1}{\lambda^4}$ where, I = Intensity of light and $\lambda = \text{wavelength of light}$

This is also called Rayleigh's law of scattering.

The red light has longest wavelength and hence get least scattered than other light ray. At sunrise and sunset, the sun is far and oblique from us. The red light get least scattered and reach to us but other light scattered more and hence, sun looks red during sun-rise and sun set.

Q. Why does the sky appear blue? (2066, 2075)

→ Sky is seen blue due to the scattering of light by air molecules. According to Rayleigh's law, the intensity of scattered light (I) is inversely proportional to the fourth power of the wavelength. i.e. $I \propto \frac{1}{\lambda^4}$

Since, wavelength of blue colour is approximately half the wavelength of red colour, the scattering of blue light is about 2^4 times i.e. 16 times more than that of red light. Due to this, blue colour predominates and the sky appears blue.

Spectrometer:

An optical instrument used to obtain a pure spectrum is called a spectrometer. It is used for only observing the spectrum is called a spectroscope. A spectrometer in which eyepiece is replaced by a photographic place is called a Spectrograph. It is used to produce pure spectrum and to determine refractive indices of solid and liquid in the form of prisms.

It has three parts: a) Collimator b) Telescope c) Prism table.

THE END