RAY OPTICS
6. DISPERSION

POINTS TO REMEMBER

1. **Dispersion :**
   a) The splitting of white light into constituent colours is called dispersion and the band of colours is called spectrum.
   b) Dispersion of light was discovered by Newton.
   c) As the wavelength is minimum for violet and hence R.I is maximum for violet.
   d) As the wavelength is maximum for red and hence R.I is minimum for red.
   e) A spectrum in which there is overlapping of colours is called impure spectrum.
   f) A spectrum in which there is no overlapping of colours is called pure spectrum.
   g) **Conditions to get a pure spectrum :**
      i) The incident beam should be passed through a narrow slit.
      ii) The incident beam is made parallel by using a convergent lens.
      iii) The prism should be in minimum deviation position.
      iv) The emergent beam is brought to focus on a screen by using a convergent lens.
2. **Angular dispersion :**
   a) The difference in deviation between any two colours (generally violet and red) is called angular dispersion.
   b) The angular dispersion $=d_V - d_R = (\mu_V - \mu_R)A$
      [since for small angled prism, $d_V = (\mu_V - 1)A$ and $d_R = (\mu_R - 1)A$]
3. **Dispersive power :**
   a) Dispersive power, $\omega = \frac{\text{angular dispersion}}{\text{mean deviation}}$

      $\omega = \frac{d_V - d_R}{d}$ where $d = (\mu - 1)A$ the mean deviation (i.e., for yellow colour)

      $\therefore \omega = \frac{\mu_V - \mu_R}{\mu - 1}$

      Dispersive power is independent of the angle of prism. It depends only on refractive index and nature of material.
   b) If μ_1 and μ_2 are the refractive indices of two colours and μ is the refractive index of the mean colour, then the dispersive power of the two colours is given by $\omega = \frac{\mu_2 - \mu_1}{\mu - 1}$. It is constant for those two colours and for the material of the prism. It is independent of the angle of the prism but angular dispersion depends on the angle of the prism.
4. **Deviation without dispersion :**
   a) Deviation with out dispersion means an achromatic combination of the prisms in which net or resultant dispersion is zero and deviation is produced.
   b) For the two prisms made of different materials and of different refracting angles the net dispersion is zero if

      $(d_V - d_R) + (d_V^1 - d_R^1) = 0 \Rightarrow \frac{A^1}{A} = -\frac{(\mu_V - \mu_R)}{(\mu_V^1 - \mu_R^1)}$ The negative sign indicates that the refracting angles of two prisms are in the opposite directions.
5. **Dispersion without deviation :**

A combination of two prisms in which the deviation produced for the mean ray (yellow colour) by the first prism is equal and opposite to that produced by the second prism. For the deviation to be zero $d+d^1=0 \Rightarrow (\mu-1)A+(\mu^1-1)A^1=0$

$$\Rightarrow \frac{A^1}{A}=-\frac{(\mu-1)}{(\mu^1-1)}$$

The negative sign indicates that refracting angles of the two prisms are in the opposite directions.

6. **Types of spectra :**

Spectra are two types

A) Emission spectra and B) Absorption spectra

A) Types of emission spectra :

Emission spectra is of three types.

a) continuous spectra, b) line spectra and c) band spectra

a) continuous spectra :

i) It is given by incandescent (red hooted) solids liquids).

ii) Continuous spectrum contains all wavelengths from violet tored.

iii)It is not the characteristic of atom or molecule but it is emitted by matter in bulk.

iv)Incandescent platinum wire (burning platinum wire), burning charcoal, filament of an electric bulb, kerosene lamp, candle flame, gases under great pressure produce continuous spectrum.

b) Line spectrum :

i) Hot gases or vapours in atomic state produce line spectrum.

ii) Line spectrum is also called ionic spectrum or atomic spectrum.

iii)Sodium vapour lamp emits light of wavelength 5890 Å and 5896 Å causing two lines called D_1, D_2 lines in the spectrum.

iv)Tube light, mercury vapour lamp, hydrogen discharge tube, helium discharge tube, neon discharge tube produce line spectrum.

c) Band spectrum :

i) Hot gases in molecular state gives band spectrum.

ii) It is also called molecular spectrum.

iii)Blue light of Bunsen burner, N_2 gas, cynogen gas, nitric acid, lead fluoride, calcium chloride, calcium bromide and other compound of calcium, carbon produce band spectrum.

B) Absorption spectra :

i) It is due to absorption of radiation by the matter.

ii) Absorption is based on Kirchoff's law which states that a substance which emits particular wavelength of radiation when excited, also possess the property of absorbing the same wavelength from the incident radiation when unexited.

7. **Solar spectrum :**

a) Solar spectrum is an absorption spectrum.

b) The dark lines present in a solar spectrum are called Fraunhoffer lines.

LONG ANSWER QUESTIONS

1. Describe the different kinds of spectra.

A. **Types of spectra :**Spectra are two types

A) Emission spectra and B) Absorption spectra

A) Emission spectra is of three types.

a) continuous spectra, b) line spectra and c) band spectra

a) continuous spectra :

v) It is given by incandescent (red hooted) solids liquids).

vi) Continuous spectrum contains all wavelengths from violet tored.

vii) It is not the characteristic of atom or molecule but it is emitted by matter in bulk.

viii) It depends on the temperature of the source.

ix) It is due to thermal excitation.

x) Incandescent platinum wire (burning platinum wire), burning charcoal, filament of an electric bulb, kerosene lamp, candle flame, gases under great pressure produce continuous spectrum.

b) Line spectrum :

I) Hot gases or vapours in atomic state produce line spectrum.

II) Line spectrum is also called ionic spectrum or atomic spectrum.

III) It consists of bright lines of different colours against dark back ground.

xi) The intensity of one line is different from the other.

xii) Line spectrum is a discontinuous one.

xiii) Line spectrum is due to electronic transition from higher orbits to lower orbits.

xiv) Line spectrum is the characteristic property of the atom producing light and it differs from one element to another.

xv) Sodium vapour lamp emits light of wavelength 5890 Å and 5896 Å causing two lines called D_1, D_2 lines in the spectrum.

xvi) Tube light, mercury vapour lamp, hydrogen discharge tube, helium discharge tube, neon discharge tube produce line spectrum.

c) Band spectrum :

iv) Hot gases in molecular state give band spectrum.

v) It is also called molecular spectrum.

vi) It consists of bright bands of different colour over dark back ground. Each band consists of closely packed lines.

vii) The spacing between two bands and the width of the band depends on the nature of the compound. calcium chloride, calcium

bromide and other compound of calcium, carbon produce band spectrum

viii) At very high temperature the band spectrum changes into line spectrum as the molecules split into atoms.

ix) This spectrum is due to transition of electrons combined with rotatory, translatory and vibratory effects of molecules.

x) Blue light of Bunsen burner, N_2 gas, cynogen gas, nitric acid, lead fluoride,

B) Absorption spectra :

iii) It is due to absorption of radiation by the matter.

iv) Absorption is based on Kirchoff's law which states that a substance which emits particular wavelength of radiation when excited, also possess the property of absorbing the same wavelength from the incident radiation when un-exited.

v) Absorption spectrum consists of dark lines over a bright back ground.

vi) Absorption spectrum is the characteristic property of the absorbing material. That is one can identify what are the elements present in the absorbing material.

vii) When the white light is passed through the gas in atomic state (say sodium vapour) line absorption spectrum is formed.

viii) When the white light is passed through the molecular gas (say iodine vapour) band absorption spectrum is formed.

SHORT ANSWER QUESTIONS

1. What is dispersion? Define a physical quantity which depends only on the material of prism for its dispersion. Obtain an expression for it.

A. **Dispersion:** The splitting up of a beam of white light in to its constituent colours (VIBGYOR) is called dispersion.

A physical quantity which depends only on the material of prism for its dispersion is the angle of prism

Angular dispersion = $\delta_V - \delta_R = A(\mu_V - 1) - A(\mu_R - 1) = A(\mu_V - \mu_R)$

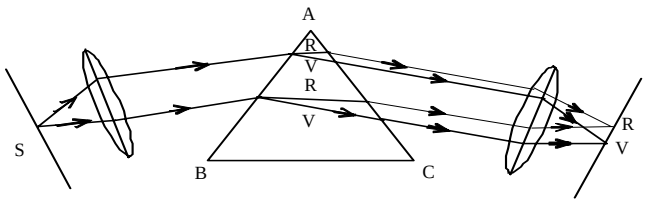
2. What are pure and impure spectra? State the conditions to produce a pure spectrum.

A. **Impure spectra :** The spectra in which the different colours overlap and the spectrum is not clear is called impure spectra.

Pure spectra: In a spectrum if all the different colours are brought to focus at different points without overlapping of colours, then such a spectrum is called pure spectrum.

Conditions for pure spectrum:

1. In a spectrum if all the different colours are brought to focus at different points without overlapping of colours,then such a spectrum is called **pure spectrum.**
2. The split's' must be narrow which is illuminated in to a source of white light.



2. The slit is placed at the focus of a convex lens'L_1' so that a parallel of white light rays are incident on the prism.
3. The prism must be in its minimum deviation position.
4. Different colours are brought to focus at different point on the screen by using a convex lens 'L_2'. The screen is placed at the focus of the convex lens L_2. Thus a pure spectrum is obtained on the screen

3. What are Fraunhodffer lines? Explain their origin.

A. The solar spectrum is found to be crossed by a large number of dark lines. It belongs to line absorption spectrum. These dark lines crossing the solar spectrum are called Fraunhoffer lines.

Origin : The visible disc of the sun is called photosphere and it emits white light of continuous spectrum.. The photosphere is surrounded by cooler atmosphere of gases called chromosphere. When white light passes through the relatively cooler atmosphere, the atoms present in it selectively absorb the radiations which they themselves would emit. In the place of the absorbed radiations dark lines are formed. These dark lines are called Fraunhodffer lines. Helium was discovered by the study of Fraunhoffer lines.

4. State the significance of emission and absorption spectra.

A. **Significance of Emission Spectra:**

1. Emission spectra are useful to identify elements from a mixture. The process is known as chemical analysis.
2. Emission spectra are used to study the abundance of an element in a given sample. The technique is useful in mineral exploration.
3. Rare earth materials and substances of very small concentration can be surely identified. Chemical analysis is not possible in such cases.
4. Line spectra are electronic in nature while bond spectra are vibrational in nature.

Significance of Absorption spectra:

1. Absorption spectra are used to identify a chemical compound
2. They are useful in studying the spectral characteristics
3. Absorption spectra are useful in identifying functional groups like OH, NH_2, CH etc.,
4. Absorption spectra help to understand molecular structure.

VERY SHORT ANSWER QUESTIONS:

1. What is angular dispersion? On what factors does it depend?

A. The difference in the deviation between any two colours is called angular dispersion.

Angular dispersion(θ) = $d_v - d_r$

[$d_v = (\mu_v - 1)A$ and $d_r = (\mu_r - 1)A$]

$\theta = (\mu_v - \mu_r)A$

Angular dispersion depends on the angle of the prism and difference between the refractive indices of two colours.

2. Distinguish between pure and impure spectrum.

A. **Pure spectrum**: In a spectrum if all the different colours are brought to focus at different points without overlapping of colours,then such a spectrum is called **pure spectrum.**

Impure spectrum: A spectrum in which different colours overlap is called an impure spectrum

3. What is a line spectrum? What does its study give?

A. **Line spectrum**: It is a spectrum of bright lines separated by dark spaces. It is due to the excitation of atoms of an element. It is obtained when electrons excited to higher energy states make transition to lower energy states.

The study of line spectrum gives the characteristic property of the atom producing light.

4. What is a band spectrum? What does its study give?

A. **Band Spectrum**: It is a spectrum in which different colours appear as bands separated by dark spaces. It is obtained due to the excitation of molecules of an element or a compound. Each band consists of large number of find lines. Each band is sharply defined at one edge called head of the band and along off gradually at the other edge.

The study of band spectrum explains the transition of electrons combined with rotatory translatory and vibratory effects of molecules.

5. What are Fraunhofer lines and what is their importance? (March 2011)

A. **Fraunhofer lines :** The dark lines observed in the solar spectrum are called Fraunhofer lines.

Importance: The are used to

1. Determine composition of sun's chromosphere.
2. Determine the wavelengths of spectral lines.

SOLVED PROBLEMS

1. The refractive indices of flint glass prism for C,D and F lines are 1.790, 1.795 and 1.805 respectively. Find the dispersive power of the flint glass prism.

A. $\mu_C = 1.790; \mu_D = 1.795 \, and \, \mu_F = 1.805$

$$\omega = \frac{\mu_F - \mu_C}{\mu_D - 1} = \frac{1.805 - 1.790}{13795 - 1} = 0.1887$$

2. Two small angled prism A and B deviate the blue rays by $6^0 \, and \, 8^0$ and the red rays by $4^0 \, and \, 6^0$ respectively. Which prism has a greater dispersive power?

A. Angular dispersion of $A = \delta_B - \delta_R = 6^0 - 4^0 = 2^0$

Mean deviation of $A = \left(\frac{\delta_B + \delta_R}{2} \right) = \left(\frac{6^0 + 4^0}{2} \right) = 5^0$

Dispersive power of $A = \frac{Angular \, dispersion}{Mean \, deviation} = \frac{2}{5} = 0.4$

b) Angular dispersion of $B = \delta_B - \delta_R = 8^0 - 6^0 = 2^0$

Mean deviation of $B = \left(\frac{\delta_B + \delta_R}{2} \right) = \left(\frac{8^0 + 6^0}{2} \right) = 7^0$

Dispersive power of $B = \frac{Angular \, dispersion}{Mean \, deviation} = \frac{2}{7} = 0.2857$

$\therefore$ Dispersive power of A is greater than that of B

3. Calculate a) the refracting angle of a flint glass prism which should be combined with a crown glass prism of refracting angle 6^0 so that the combination may have no deviation for D line and (b) the angular separation between the C and F lines, given that the refractive indices of the materials are as follows:

	C	D	F
Flint	1.790	1.795	1.805
Crown	1.527	1.530	1.535

A. Let A_1 *and* A_2 be the refracting angles of the flint and crown glass prisms respectively. μ_1 *and* μ_2 be the refractive indices for the D line of flint and crown glasses respectively.

a) If δ_1 *and* δ_2 be the angles of deviation due to the flint and crown glass prisms respectively. Then for no deviation of D line, $\delta_1 + \delta_2 = 0$

or $A_1(\mu_1 - 1) + A_2(\mu_2 - 1) = 0 \quad \Rightarrow \quad \frac{A_1}{A_2} = -\left(\frac{\mu_2 - 1}{\mu_1 - 1}\right)$

The negative sign indicates that A_1 *and* A_2 are oppositely directed.

$$\frac{A_1}{6^0} = \left(\frac{1.530 - 1}{1.795 - 1}\right) \Rightarrow \quad A_1 = -6^0 \times \frac{0.530}{1.795} = -4^0$$

b) Angular dispersion due to the flint glass prism, $A_1(\mu_F - \mu_C)_1 = -4^0(1.805 - 1.790) = -0.060$

Angular dispersion due to the crown glass prism, $A_2(\mu_F - \mu_C)_2 = 6^0(1.535 - 1.527) = 0.048$

Net angular dispersion = 0.048 – 0.060 = - 0.012

The negative sign indicates that the resultant dispersion is in the direction of the deviation produced by the flint prism.

4. Calculate a) the refracting angle of a flint glass prism which should be combined with a crown glass prism of refracting angle 4^0 so that the combination may have no angular dispersion between C and F lines and (b) the angular deviation for the D line. The refractive indices of the materials are as follows

	C	D	F
Flint	1.790	1.795	1.805
Crown	1.527	1.530	1.535

A. Let A_1 *and* A_2 be the refracting angles of the flint and crown glass prisms respectively.

a) For no angular dispersion between C and F lines due to the combination of the flint and crown glass prisms

$$A_1(\mu_F - \mu_C)_1 + A_2(\mu_F - \mu_C)_2 = 0 \Rightarrow \frac{A_1}{A_2} = -\left(\frac{(\mu_F - \mu_C)_2}{(\mu_F - \mu_C)_1}\right)$$

The negative sign indicates that the vertices of the two prisms are oppositely directed

$$\frac{A_1}{9^0} = -\left(\frac{1.805 - 1.790}{1.535 - 1.527}\right) = \frac{0.015}{0.008} \Rightarrow \quad A_1 = -4^0 \times \frac{0.015}{0.008} = -7.5^0$$

b) Deviation due to the flint glass prism D line

$= A_1(\mu_1 - 1) = 7.5^0(1.795 - 1) = -5.9625^0$

Deviation due to the crown glass prism D line

$= A_2(\mu_2 - 1) = +4^0(1.530 - 1) = +2.12^0$

Net deviation = 2.12-5.9625 = - 3.8425^0

The negative sign indicates that the net deviation is in the direction of the deviation produced by the flint prism.

UNSOLVED PROBLEMS :

1. The refractive indices of crown glass prism for C, D and F lines are 1,527, 1.530 and 1.535 respectively. Find the dispersive power of the crown glass prism.

A. $\mu_c = 1.527, \mu_D = 1.530, \mu_F = 1.535$

$$\omega = \frac{\mu_F - \mu_C}{\mu_D - 1} = \frac{1.535 - 1.527}{1.530 - 1} = 0.01509$$

2. A flint glass prism is of refracting angle 5^0. Its refractive index for C line is 1.790 and for F line is 1.805. Find the angular dispersion of C and F lines.

A. $\mu_c = 1.790, \mu_F = 1.805, A = 5^0$

From $\delta = A(\mu_F - \mu_C)$

$\Rightarrow \delta = 5(1.805 - 1.790) = 5(0.015) = 0.075^0$

3. Two small angled prisms A and B deviate the blue rays by 7^0 and 9^0 and the red rays by 5^0 *and* 7^0 respectively. Which prism has a greater dispersive power?

A. For prism A , $d_b = 7^0, d_r = 5^0$

$$\omega_A = \frac{d_b - d_r}{d}$$

Where $d = \frac{d_b + d_r}{2} = \frac{7+5}{2} = 6^0$

$$\Rightarrow \omega_A = \frac{7-5}{6} = 0.33$$

For prism B , $d_b = 9^0, d_r = 7^0$

$$d = \frac{d_b + d_r}{2} = \frac{9+7}{2} = 8^0$$

$$\omega_B = \frac{d_b - d_r}{d} = \frac{9-7}{8} = 0.25$$

$\therefore \omega_A > \omega_B$

Hence the prism A has greater dispersive power.

ASSESS YOURSELF

1. What is the ratio of the velocity of red colour light to the velocity of violet colours of light in vacuum?

A. 1 : 1 .

2. Is deviation always followed by dispersion?

A. Not nessessary.Total internal reflection do not produce dispersion.

3. Why is a narrow slit to be used as a source of light to form a pure spectrum?

A. To avoid the overlapping of colours , the slit must be narrow.

4. Which type of spectrum can be used to study atomic structure?

A. Line spectrum.

5. Which type of spectrum can be used to study molecular structure?

A. Band spectrum.

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