Chapter 6 Spectrum

SYLLABUS

Using a triangular prism to produce a visible spectrum from white light; Electromagnetic spectrum. Scattering of light.

Scope of syllabus : Deviation produced by a triangular prism; dependence on colour (wavelength) of light; dispersion and spectrum; electromagnetic spectrum; broad classification (names only arranged in order of increasing wavelength); properties common to all electromagnetic radiations; properties and uses of infrared and ultraviolet radiations. Simple application of scattering of light e.g. blue colour of the sky.

(A) DEVIATION, DISPERSION AND SPECTRUM

6.1 DEVIATION PRODUCED BY A TRIANGULAR PRISM

Fig. 6.1 shows the deviation produced by a triangular prism. When a light ray PQ of single colour enters a triangular prism ABC, it gets deviated, say, by an angle δ_1 towards the base BC at the first surface AB of the prism and travels straight as QR inside the prism. The angle of deviation δ_1 depends on the angle of incidence and the refractive index of glass with respect to air. On striking the second surface AC, the ray QR gets further deviated, say, by an angle δ_2 towards the base BC and travels straight as RS outside the prism. The angle of deviation δ_2 depends on the angle of incidence at the second surface (which depends on the angle of the prism *A*) and the refractive index of air with respect to glass. For the emergent ray RS, the total deviation δ with respect to the incident ray PQ (*i.e.*, the angle between the emergent ray RS and the direction PL of the incident ray PQ) is given as :

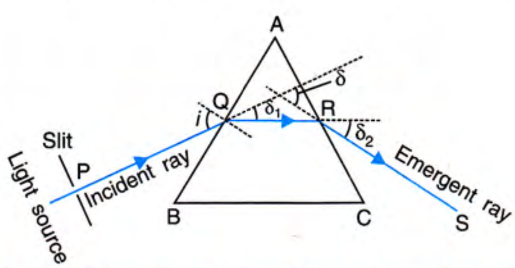

Fig. 6.1 Deviation produced by a triangular prism

$$\boxed{\delta = \delta_1 + \delta_2} \quad ...(6.1)$$

The total angle of deviation δ, thus, depends upon the following *three* factors :

(1) the angle of incidence (*i*) at the first surface,

(2) the angle of the prism (*A*), and

(3) the refractive index of the material of the prism (μ). But the refractive index depends on the colour (or wavelength λ) of the light used, so the angle of deviation depends also on the colour (or wavelength λ) of the incident light.

In chapter 4, we have discussed the dependence of angle of deviation δ on the angle of incidence *i*, angle of prism *A* and refractive index μ of the material of prism. Here we shall discuss in detail how the deviation δ produced by a prism depends on the colour (or wavelength λ) of the incident light.

Dependence of deviation on the colour (or wavelength) of light

The light of different colours have same speed in air but different speeds in a medium. If the light entering the prism is not of a single colour, *i.e.,* it is a mixture of several colours, then the emergent beam also has different colours arranged in a *definite order*. It is because the speed of light in a transparent medium decreases with the decrease in the wavelength of light. Therefore, *the refractive index of glass* (the material of prism) *increases with the decrease in the wavelength of light.* Therefore the deviation caused by a prism also increases with the decrease in the wavelength of light*. ***In visible light, violet colour (wavelength λ = 4000 Å) is deviated the most and red colour (wavelength λ = 8000 Å) is deviated the least*** because in glass, the speed of violet light is least and that of the red light is most.

6.2 COLOURS IN WHITE LIGHT WITH THEIR WAVELENGTH AND FREQUENCY RANGE

The white light emitted from a source consists of light of different wavelengths. The light of different wavelengths produce the sensation of different colours on the retina of our eye, so we perceive them as different colours. The prominent colours in white light are violet, indigo, blue, green, yellow, orange and red. Different colours differ in their wavelength. In fact, *wavelength is the characteristic of colour, irrespective of its origin i.e.*, the light of the same colour obtained from different sources will have the same wavelength. In other words, colour is the *subjective property* of light related to its wavelength.

* From the definition of refractive index

$$\mu_{glass} = \frac{\text{Speed of light in air}}{\text{Speed of light in glass}}$$

The speed of light for different colours is same in air, but it is different for different colours in glass (medium). In glass, the speed of violet light is *minimum* and the speed of red light is *maximum*. Therefore $\mu_{violet} > \mu_{red}$

But $\mu = \sin i / \sin r$ or $\sin r = \sin i / \mu$

Therefore, in glass, for a given value of i. the angle of refraction r is minimum for the light of violet colour and maximum for the light of red colour *i.e.*, $r_{red} > r_{violet}$.

Now angle of deviation $\delta = i - r$, so $\delta_{violet} > \delta_{red}$

The table below gives the range of wavelength and frequency for light of different colours present in the white light.

Wavelength and frequency of different colours in white light

Colour	Wavelength range (nearly)	Frequency range in 10^{14} Hz
Violet	4000 Å to 4460 Å	7·5 – 6·73
Indigo	4460 Å to 4640 Å	6·73 – 6·47
Blue	4640 Å to 5000 Å	6·47 – 6·01
Green	5000 Å to 5780 Å	6·01 – 5·19
Yellow	5780 Å to 5920 Å	5·19 – 5·07
Orange	5920 Å to 6200 Å	5·07 – 4·84
Red	6200 Å to 8000 Å	4·84 – 3·75

Note : **(1)** In the above table the letter Å denotes the unit Angstrom where 1 Å = 10^{-10} m (or 10^{-8} cm). Now a days the wavelength is expressed mostly in nanometre (nm) where

$$1 \text{ nm} = 10^{-9} \text{ m} = 10 \text{ Å}.$$

(2) In the spectrum of white light, the red colour has the longest wavelength 8000 Å (or 8×10^{-7}m or 800 nm) or lowest frequency $3{\cdot}75 \times 10^{14}$ Hz and the violet colour has the shortest wavelength 4000 Å (or 4×10^{-7}m or 400 nm) or highest frequency $7{\cdot}5 \times 10^{14}$ Hz. From the violet end to the red end of the spectrum, the wavelength increases while the frequency decreases.

6.3 DISPERSION OF WHITE LIGHT THROUGH A PRISM AND FORMATION OF A SPECTRUM

Sir Isaac Newton, while studying the image of a heavenly body formed due to refraction of white light by a lens, found that the image is coloured at its edges. He thought that the coloured image is due to some defect of the lens. He then repeated the experiment with a carefully polished lens, but the image was still coloured. Newton then concluded that the fault is not with the lens, but there is something in the nature of white light itself due to which the image is coloured at its edges. To investigate it further, he performed another experiment with a *prism*.

Newton's Experiment

Newton allowed the white light from sun to enter a dark room through a small aperture in a window and placed a glass prism in the path of light rays. The light emerging out of the prism was received on a white screen. On the screen, a coloured patch like a rainbow as shown in Fig. 6.2 was obtained which was termed as ***spectrum***.

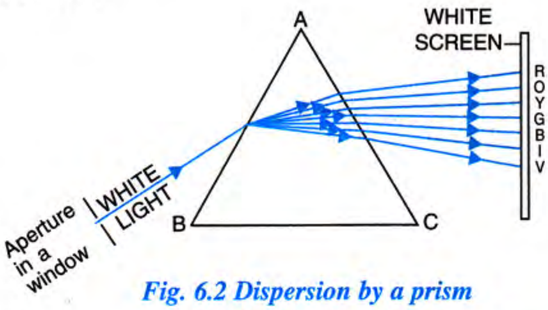

Fig. 6.2 Dispersion by a prism

Starting from the side of base of the prism, the order of colours in the spectrum on screen is :

Violet, Indigo, Blue, Green, Yellow, Orange, and *Red*. This order of colours in the spectrum can easily be remembered by the word ***VIBGYOR***.

Conclusion : From the above experiment, Newton concluded that *white light consists of seven prominent colours*. Each colour corresponds to a small range of wavelength. Thus, white light is a mixture of large number of wavelengths (*i.e.*, it is *polychromatic* in nature).

> ***Note :*** In the spectrum, each colour is mixed with the other colour *i.e., there is no sharp boundary line separating the colours*. In diagram, colours are shown widely separated just for clarity. The total spread of colours is much less than that shown in the diagram. Different colours have different width on the screen.

Dispersion

> The phenomenon of splitting of white light by a prism into its constituent colours is known as dispersion.

Spectrum

> The band of colours seen, on passing white light through a prism is called the spectrum.

Cause of dispersion of white light and formation of spectrum

The cause of dispersion of white light is the change in speed of light with wavelength. When white light enters the first surface of a prism, light of different colours due to their different speeds in glass, gets deviated through different angles towards the base of prism i.e. the dispersion (or splitting) of white light into its constituent colours takes place at the first surface of prism. The violet colour is deviated the most, while the red colour is deviated the least. Therefore light of different colours follow different paths in glass and then strikes the second surface of prism. On the second surface of prism, *only refraction takes place* (from glass to air) and different colours are deviated through different angles, *i.e.*, violet is deviated the most and red the least. As a result, the colours get further separated on refraction at the second surface. The light emerging out of the prism, thus, has different colours that spread out to form a spectrum on the screen.

> ***Note :*** (1) Dispersion of white light occurs at the first surface of prism.
>
> (2) Deviation of light occurs at both the surfaces of prism.
>
> (3) The prism does not produce colours, but it only splits the various colours present in the light incident on it.

EXAMPLES

1. Fig. 6.3 shows the light (blue + red + green) incident on a prism and on a parallel sided glass slab. Complete the diagrams by drawing the refracted and the emergent rays.

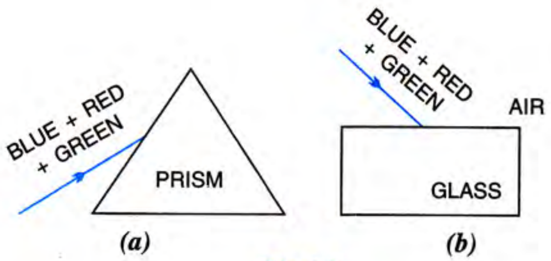

Fig.6.3

The completed ray diagrams are shown in Fig. 6.4.

In a prism, the refraction takes place at two inclined surfaces, so the prism causes dispersion and deviation of light into its constituent colours and a spectrum is seen.

In case of the parallel sided glass slab, the refraction takes place at two parallel surfaces. On the first surface, the colours are separated due to different deviation for the rays of different colours *i.e.*, dispersion takes place. On the second surface, the ray of each colour is refracted such that the emergent ray is parallel to the incident ray on the first surface. Since there is no further separation of colours due to refraction at the second surface (as it is in case of the prism), so the emergent coloured rays are parallel to each other and they are so close that it is difficult to see the separate colours and the emergent light appears to be almost white (= blue + red + green).

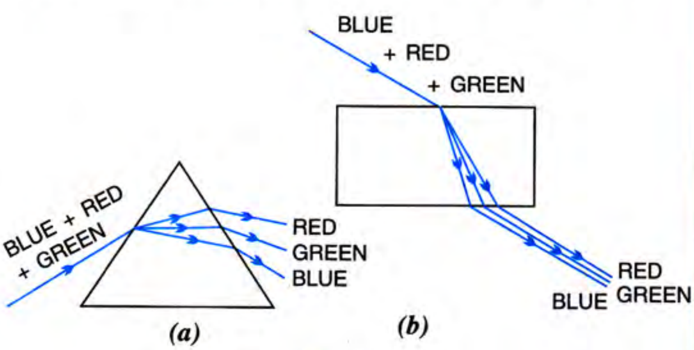

Fig. 6.4

2. A beam consisting of red, blue and yellow colours is incident normally on the face AB of an isosceles right angled prism ABC as shown in Fig. 6.5. Complete the diagram to show the refracted and the emergent rays. Given that the critical angle of glass-air interface for yellow colour is 45°.

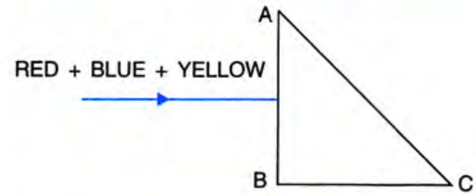

Fig. 6.5

The completed diagram is shown in Fig. 6.6. The beam is incident normally ($\angle i = 0°$) on the face AB, it passes without deviation ($\angle r = 0°$) for all colours and with no dispersion. Now the refracted beam inside the prism, strikes the face AC at an angle of incidence equal to 45°. Since the critical angle for yellow colour at the glass-air interface is 45°, so the yellow colour suffers refraction along the face AC of the prism ($\angle r = 90°$).

The critical angle for the light of red colour will be more than 45° (since $\sin C = \frac{1}{\mu}$ and $\mu_R < \mu_Y$), so the light of red colour is incident on the face AC at an angle less than the critical angle for red colour. The red colour is, therefore, refracted out of the prism obeying the laws of refraction, *i.e.*, it bends away from the normal at the face AC so the emergent ray bends towards the base of the prism.

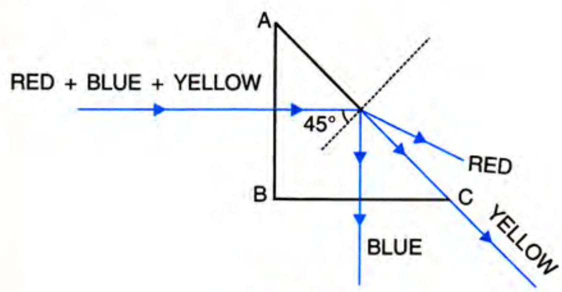

Fig. 6.6

Now the critical angle for the light of blue colour will be less than 45° since $\mu_B > \mu_Y$, so the light of blue colour is incident on the glass-air surface AC at an angle of incidence greater than the critical angle for blue colour. Therefore, the light of blue colour suffers total internal reflection and strikes normally on the base BC of the prism. It then emerges out of the prism without deviation. Thus blue colour emerges out of the prism at right angle to its incident direction.

3. A beam of white light is incident normally on the surface AB of an equilateral prism ABC and emerges out of it suffering a deviation of 60°.

(a) Draw a diagram to show the path of beam till it emerges out of the prism. Mark the angles wherever necessary.

(b) What assumption have you made while drawing the diagram ?

(c) Name the phenomenon exhibited by the light beam.

(a) The ray diagram is shown in Fig. 6.7.

The beam of white light incident normally on the face AB of the prism passes undeviated inside the prism and strikes the other face AC at an angle of incidence of 60°. At the face AC, it suffers total internal reflection. After total internal reflection at the face AC, the beam of light falls normally on the face BC, so it emerges out without deviation.

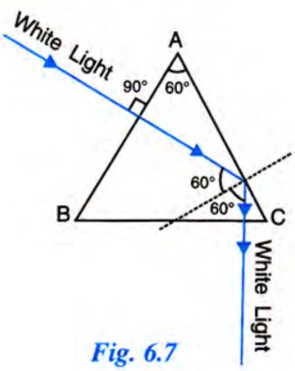

Fig. 6.7

(b) **Assumption :** The critical angle of glass-air interface is less than 60° for all colours of white light.

(c) **Phenomenon :** Total internal reflection.

4. The frequency of violet light is $7{\cdot}5 \times 10^{14}$ Hz. Find its wavelength in (i) nm, (ii) Å. Speed of light $c = 3 \times 10^8$ m s^{-1}.

Given : $f = 7{\cdot}5 \times 10^{14}$ Hz, $c = 3 \times 10^8$ m s^{-1}.

From relation $c = f\lambda$, wavelength $\lambda = \frac{c}{f}$

or $\lambda = \frac{3\times10^8}{7{\cdot}5\times10^{14}} = 4 \times 10^{-7}$ m.

(i) Since 1 nm = 10^{-9} m, $\therefore \lambda =$ **400 nm**

(ii) Since 1 Å = 10^{-10} m, $\therefore \lambda =$ **4000 Å**

5. The wavelength of red light is 800 nm. Find its frequency. Speed of light = 3×10^8 m s^{-1}.

Given : λ = 800 nm = 800×10^{-9} m = 8×10^{-7} m

$c = 3 \times 10^8$ m s^{-1}

Form relation $c = f\lambda$, frequency $f = \frac{c}{\lambda}$

or $f = \frac{3\times10^8}{8\times10^{-7}} =$ **$3{\cdot}75 \times 10^{14}$ Hz.**

EXERCISE–6(A)

1. Name *three* factors on which the deviation produced by a prism depends and state how does it depend on the factors stated by you.

2. How does the deviation produced by a triangular prism depend on the colours (or wavelengths) of light incident on it ?

3. How does the speed of light in glass change on increasing the wavelength of light ?

   Ans. Speed of light increases with increase in its wavelength.

4. Which colour of white light travels (a) fastest (b) slowest, in glass ? **Ans.** (a) red (b) blue

5. Name the subjective property of light related to its wavelength. **Ans.** colour

6. What is the range of wavelength of the spectrum of white light in (i) Å, (ii) nm ?

   Ans. (i) 4000 Å to 8000 Å (ii) 400 nm to 800 nm

7. Write the approximate wavelengths for (i) blue, and (ii) red light. **Ans.** (i) 4800 Å, (ii) 8000 Å

8. Write the seven prominent colours present in white light in the order of increasing wavelength

   Ans. violet, indign, blue, green, yellow, orange, and red.

9. Name the *seven* prominent colours of the white light spectrum in order of their increasing frequencies.

   Ans. red, orange, yellow, green, blue, indigo, and violet.

10. Name *four* colours of the spectrum of white light which have wavelength longer than blue light.

    Ans. green, yellow, orange, and red

11. Which colour of the white light is deviated by a glass prism (i) the most, and (ii) the least ?

12. The wavelengths for the light of red and blue colours are nearly $7{\cdot}8 \times 10^{-7}$ m and $4{\cdot}8 \times 10^{-7}$ m respectively.

Downloaded from https:// www.studiestoday.com

(a) Which colour has the greater speed in vacuum ?

(b) Which colour has the greater speed in glass ?

Ans. (a) In vacuum, both have the same speeds.
(b) In glass, red light has a greater speed.

13. Define the term dispersion of light.

14. Explain the cause of dispersion of white light through a prism.

15. Explain briefly, with the help of a neat labelled diagram, how does white light get dispersed by a prism.

On which surface of prism, there is both the dispersion and deviation of light, and on which surface of prism, there is only the deviation of light ?

16. What do you understand by the term spectrum ?

17. A ray of white light is passed through a glass prism and spectrum is obtained on a screen.

(a) Name the seven colours of the spectrum in order.

(b) Do the colours have the same width in the spectrum ?

(c) Which of the colour of the spectrum of white light deviates (i) the most, (ii) the least ?

18. The diagram shown below in Fig. 6.8 shows the path taken by a narrow beam of yellow monochromatic light passing through an equiangular glass prism. It the yellow light is replaced by a narrow beam of white light incident at the same angle, draw another diagram to show the passage of white light through the prism and label it to show the effect of prism on the white light.

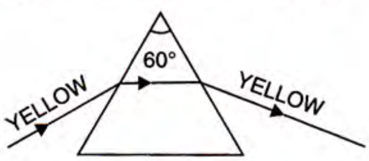

Fig. 6.8

19. Fig. 6.9 shows a thin beam of white light from a source S striking on one face of a prism.

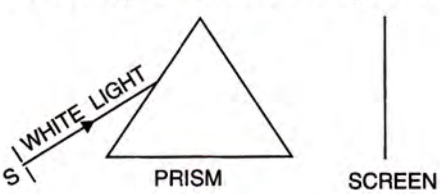

Fig. 6.9

(a) Complete the diagram to show the effect of prism on the beam and to show what is seen on the screen.

(b) If a slit is placed in between a prism and a screen to pass only the light of green colour, what will you then observe on the screen ?

(c) What conclusion do you draw from the observation in part (b) above ?

20. (a) A beam of monochromatic light undergoes minimum deviation through an equiangular prism, how does the beam pass through the prism, with respect to its base ?

(b) If white light is used in same way as in part (a) above, what change do you expect in the emergent beam ?

(c) What conclusion do you draw about the nature of white light in part (b) ?

Ans. (a) parallel to the base, (b) white light splits into its constituent colours *i.e.*, spectrum is formed (c) white light is polychromatic

MULTIPLE CHOICE TYPE

1. When a white light ray falls on a prism, the ray at its first surface suffers :

(a) no refraction

(b) only dispersion

(c) only deviation

(d) both deviation and dispersion.

Ans. (d) both deviation and dispersion.

2. In the spectrum of white light by a prism, the colour at the extreme end opposite to the base of prism is :

(a) violet (b) yellow

(c) red (d) blue.

Ans. (c) red

3. The wavelength range of white light is :

(a) 4000 nm to 8000 nm

(b) 40 nm to 80 nm

(c) 400 nm to 800 nm

(d) 4 nm to 8 nm.

Ans. (c) 400 nm to 800 nm

NUMERICALS

1. Calculate the frequency of yellow light of wavelength 550 nm. The speed of light is 3×10^8 m s^{-1}.

Ans. $5{\cdot}4 \times 10^{14}$ Hz

2. The frequency range of visible light is from $3{\cdot}75 \times 10^{14}$ Hz to $7{\cdot}5 \times 10^{14}$ Hz. Calculate its wavelength range. Take speed of light = 3×10^8 m s^{-1}.

Ans. 4000 Å to 8000 Å

(B) ELECTROMAGNETIC SPECTRUM AND ITS BROAD CLASSIFICATION

6.4 ELECTROMAGNETIC SPECTRUM

Classification : Till now we have limited ourselves to the spectrum which lies between the red and the violet regions. This spectrum is the *visible spectrum* and it is only a very small part of the entire electromagnetic spectrum. Experiments show that the spectrum of sun light is limited not only between the violet and red extremes, but it extends on either side beyond these extremes to which our eyes do not respond. *This part of spectrum beyond the red and the violet extremes is called the* ***invisible spectrum****.

The waves of wavelength longer than the red part of the visible spectrum in increasing order of wavelength are (i) *infrared radiations,* (ii) *microwaves,* and (iii) *radio waves*, while the waves of wavelength shorter than the violet part of the visible spectrum in decreasing order of wavelength are : (i) *ultraviolet rays,* (ii) *X-rays,* and (iii) *gamma rays*. These radiations together form the electromagnetic spectrum.

The complete electromagnetic spectrum *in the increasing order of their wavelengths* (or *decreasing order of their frequencies*) is given below :

(1) Gamma rays, (2) X-rays, (3) Ultraviolet rays, (4) Visible light, (5) Infrared radiations, (6) Microwaves, and (7) Radio waves.

These electromagnetic waves are of different wavelengths, but they have properties similar to the light waves. Each wave travels with same speed equal to 3×10^8 m s^{-1} in vacuum (or air).

The speed (c), frequency (f) and wavelength (λ) of the electromagnetic waves are related as :

$$\boxed{c = f\lambda} \quad \text{....(6.2)}$$

The complete electromagnetic spectrum is shown in Fig. 6.10 with the wavelength increasing towards the right side (or frequency increasing towards the left side).

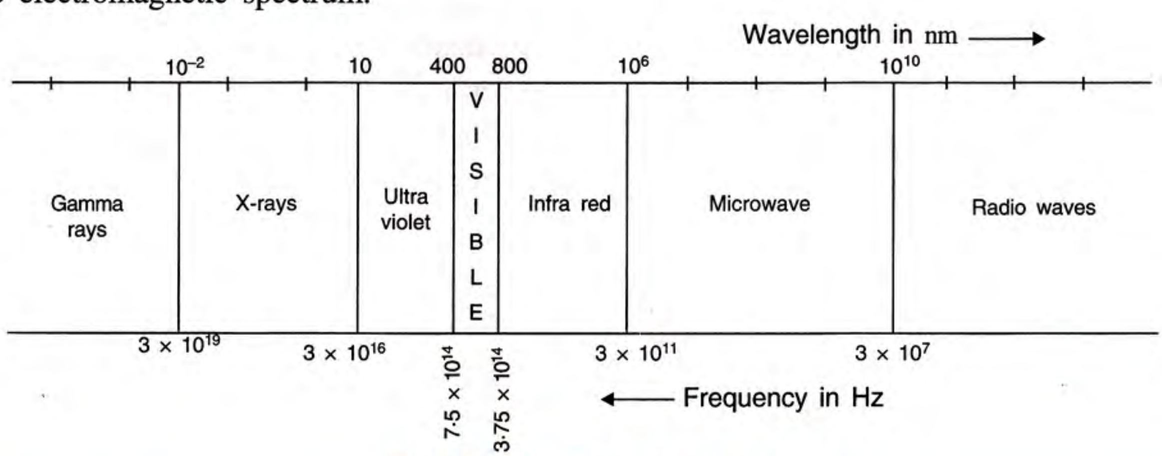

Fig. 6.10 Electromagnetic spectrum

Note : **(1)** In Fig. 6.10, although we have shown the boundary line in each part, but there is no sharp boundary of wavelength (or frequency) between the two successive kind of electromagnetic waves. In fact, they overlap to a good extent.

(2) The infrared spectrum is the part of spectrum just beyond the red end, while the ultraviolet spectrum is the part of spectrum just before the violet end.

* The portion of electromagnetic spectrum other than the visible part, do not excite our retina to produce the sensation of vision, but a part of it can damage the retina.

The table below shows different waves of the electromagnetic spectrum in order of their increasing wavelengths alongwith their discoverer, source and method of detection.

Electromagnetic spectrum

Name of the wave	Wavelength in nm	Discoverer	Source	Method of detection
Gamma rays	below 0·01	Becquerel & Curie	In cosmic rays, from radioactive substances.	By their large penetrating power
X-rays	0·01 – 1·0	Roentgen	Front a heavy metal target of high melting point when highly energetic electrons are stopped by it.	By the fluorescence produced on a zinc sulphide screen. The photographic film gets affected.
Ultraviolet	1·0 – 400	Ritter	Sunlight, arc-lamp, spark	By their chemical activity on dyes. Photographic plates get affected. It causes fluorescence.
Visible light	400 – 800	Newton	Sunlight, light from electric bulb, flame, white hot bodies.	Other objects can be seen in its presence.
Infrared waves	800 – 10^6	Hershell	Lamp with thoriated filament, heated silicon carbide rod, red hot bodies	Heating effect is more. The mercury rises rapidly when a thermometer with the blackened bulb is kept in these radiations.
Microwaves	10^6 – 10^{10}	Hertz	Electronic devices such as crystal oscillators	Oscillatory electrical circuit.
Radio waves	above 10^{10}	Marconi	TV and radio transmitters	Aerials of radio and TV receiver.

Approximate ranges of wavelength and frequency

(1) *Gamma rays*–wavelength shorter than 0·1 Å (or λ < 0·01 nm) or frequency above 10^{19} Hz.

(2) *X-rays*–wavelength range 0·1 Å to 100 Å (or $\lambda \approx$ 0·01 nm to 10 nm) or frequency from 3×10^{19} to 3×10^{16} Hz.

(3) *Ultraviolet rays*–wavelength range 100 Å to 4000 Å (or $\lambda \approx$ 10 nm to 400 nm) or frequency from 3×10^{16} to $7{\cdot}5 \times 10^{14}$ Hz.

(4) *Visible light*–wavelength range 4000 Å to 8000 Å (or $\lambda \approx$ 400 nm to 800 nm) or frequency from $7{\cdot}5 \times 10^{14}$ to $3{\cdot}75 \times 10^{14}$ Hz.

(5) *Infrared radiations*–wavelength range 8000 Å to 10^7 Å (or $\lambda \approx$ 800 nm to 1 mm) or frequency from $3{\cdot}75 \times 10^{14}$ to 3×10^{11} Hz.

(6) *Microwaves*–wavelength range 10^7 Å to 10^{11} Å (or $\lambda \approx$ 1 mm to 10 m) or frequency from 3×10^{11} to 3×10^7 Hz.

(7) *Radio waves*–wavelength above 10^{11} Å (or λ > 10 m) or frequency below 3×10^7 Hz.

Properties common to all the electromagnetic waves

(1) Electromagnetic waves do not require any material medium for their propagation.

(2) They all travel with the same speed in a medium e.g. in vacuum (or air) speed is 3×10^8 m s^{-1}.

(3) They exhibit the properties of reflection and refraction. In refraction, when an electromagnetic wave passes from one medium to the other, there is change in its direction of travel, speed and wavelength, but its frequency remains unchanged.

(4) These waves are not deflected by the electric and magnetic fields.

(5) These waves are transverse waves.

6.5 PROPERTIES AND USES OF DIFFERENT RADIATIONS OF ELECTROMAGNETIC SPECTRUM

(1) Gamma rays

These are the most energetic electromagnetic radiations of wavelength less than 0·1 Å (or 0·01 nm).

Sources : They are obtained in emissions from the radioactive substances due to energy change in the *nucleus* of their atoms. They are also present in cosmic radiations.

Properties : Like X-rays, they cause fluorescence when they strike the fluorescent materials such as zinc sulphide. They can easily penetrate through the thick metallic sheets (even 30 cm thick iron sheet). Gamma radiations easily pass through human body and cause immense biological damage.

Uses : They are used in medical science to kill cancer cells (*i.e.*, radio therapy) and in industry to check welding.

(2) X-rays

X-rays are given out from a heavy metal target of high melting point when highly energetic cathode rays are stopped by it. They have wavelength in the range of 0·1 Å to 100 Å (or 0·01 nm to 10 nm).

Properties : X-rays are chemically more active than the ultraviolet radiations. They strongly affect the photographic plate. Like gamma rays, they cause fluorescence in certain materials such as zinc sulphide, etc. They can penetrate through human flesh, but they are stopped by bones.

Uses : They are used for the detection of fracture in bones, teeth, *etc*. (*i.e.*, radiography), and for diagonistic purposes such as CAT scan in medical science. X-rays are also used for studying atomic arrangement in crystals as well as in complex molecules. X-rays are used by the detective agencies to detect the concealed precious metals.

(3) Ultraviolet radiations

The electromagnetic radiations of wavelength from 100 Å to 4000 Å (or 10 nm to 400 nm) are called the ultraviolet radiations. The ultraviolet part of the spectrum was first detected by *Prof. J. Ritter* in 1801.

Detection : (i) If silver-chloride solution is exposed to the electromagnetic waves starting from the red to the violet end and then beyond it, it is observed that from the red to the violet end, the solution remains almost unaffected. But just beyond the violet end, the solution first turns violet and finally it becomes dark brown (or black). It shows that *there exist certain radiations beyond the violet extreme of the visible part, which are chemically more active than the visible light*. These radiations are called the *ultraviolet radiations* (or *actinic rays*).

(ii) The ultraviolet radiations can be detected by their chemical activity on dyes and photographic plates.

(iii) The spectrum of ultraviolet radiations is obtained when they are passed through a quartz prism in place of a glass prism because glass absorbs these radiations.

Sources of ultraviolet radiations : *The electric arc* and *sparks* give ultraviolet radiations. A *mercury vapour lamp* emits radiations, a part of which has ultraviolet radiations along with the visible light. Sun is also a source of ultraviolet radiations, but a large fraction of it is absorbed by the ozone layer in the upper atmosphere* which protects us from its harmful effect.

Properties of ultraviolet radiations

(i) Ultraviolet radiations can pass through *quartz*, but they are absorbed by glass. Therefore to obtain the ultraviolet spectrum from its source, a quartz prism is used instead of a glass prism. For the same reason the ultraviolet bulbs have the envelope made of quartz instead of glass.

(ii) These radiations travel in a straight line with a speed of 3×10^8 m s^{-1} in air (or vacuum).

(iii) They are usually scattered by the dust particles present in the atmosphere.

(iv) They obey the laws of reflection and refraction.

(v) They strongly affect the photographic plate as they are chemically more active than the visible light.

(vi) They produce fluorescence on striking a zinc-sulphide screen.

* Due to large pollution, there is depletion of ozone layer which is dangerous for us because our exposure to ultraviolet radiations is harmful to us.

Harmful effect of ultraviolet radiations

The ultraviolet radiations cause health hazards like skin cancer if human body is exposed to them for a long period.

Uses of ultraviolet radiations

Ultraviolet radiations are used for the following purposes :

(a) For sterilising purposes.

(b) For detecting the purity of gems, eggs, ghee, etc.

(c) In producing vitamin D in food of plants and animals.

(4) Visible light

The electromagnetic radiations of wavelength from 4000 Å to 8000 Å are called visible radiations (or visible light) because in the presence of these radiations, other objects are seen by us. The visible part of spectrum was discovered by Newton while passing the sun light through a prism. The prominent colours of visible light are *violet, indigo, blue, green, yellow, orange* and *red*.

Sources : The sun, electric bulb, flame and white hot bodies are the main sources of visible light.

Uses : The visible light is used in photography, in photosynthesis and to see the objects around us.

(5) Infrared radiations

These are the electromagnetic waves of wavelength in the range of 8000 Å to 10^7 Å (or 800 nm to 1 mm). The infrared part of the spectrum was first detected by *William Hershell* in about 1800.

Detection : (i) If a thermometer having its bulb blackened, is moved from the violet end towards the red end of the spectrum of visible light, it is observed that there is a very slow rise in temperature. But when this thermometer is moved beyond the red extreme, a rapid rise in temperature is noticed. *It means that the part of spectrum beyond the red extreme of the visible light has certain radiations which produce a strong heating effect, but they are not visible.* These radiations are called the infrared (or heat) radiations.

(ii) A thermopile can also be used to detect the heat radiations. The galvanometer connected with the thermopile shows deflection when infrared radiations fall on the thermopile.

(iii) The spectrum of infrared radiations is obtained by using a *rock-salt prism because the rock-salt prism does not absorb the infrared radiations, whereas a glass prism absorbs them.*

Sources of infrared radiations : All red hot bodies such as a heated iron ball, flame, fire, etc. are the sources of infrared radiations. The sun is the natural source of infrared radiations.

Properties of infrared radiations

(i) They travel in *straight lines* like light, with a speed equal to 3×10^8 m s^{-1} in vacuum (or air).

(ii) They obey the laws of *reflection* and *refraction*.

If a source of heat (say, an infrared lamp) is placed at the focus of a parabolic mirror, a parallel infrared beam is obtained.

A *burning glass* (*i.e.*, a convex lens) focuses the infrared radiations of short wavelengths obtained from the sun on a paper due to which the paper chars (or burns).

(iii) They do not affect the ordinary photographic film. However, a specially treated photographic film is affected by them.

(iv) They are absorbed by glass, but they pass through the rock-salt.

(v) They are detected by their *heating property* using a blackened bulb thermometer or a thermopile.

(vi) They are scattered less by the atmosphere because of their long wavelength (since intensity of scattered radiation $\propto 1/\lambda^4$).

Hence they can penetrate deep in atmosphere even in fog.

Harmful effect of infrared radiations

A high dose of infrared radiations may cause skin burns.

Uses of infrared radiations

(a) The infrared radiations are used for therapeutic purposes by doctors.

(b) They are used in photography at night and also in mist and fog because they are not much scattered, so they can penetrate appreciably through it.

(c) Infrared lamps are used in dark rooms for developing photographs as they provide some visibility without affecting the photographic film.

(d) They are used as signals during war as they are not visible and they are not absorbed *much* in the medium.

(e) They are used in remote control of television and other gadgets.

(6) Micro waves

The microwaves have wavelength in the range of 10^7 Å to 10^{11} Å (or 1 mm to 10 m) or frequency in the range of 3×10^{11} Hz to 3×10^7 Hz.

Source : These waves are produced by the electronic devices such as the crystal oscillators.

Uses : They are used for satellite communication, for analysis of atomic and molecular structure, for cooking in microwave-ovens and in radar communication.

(7) Radio waves

These are the waves of longest wavelength amongst all the electromagnetic waves. They have wavelength above 10 m (or 10^{11}Å) or frequency below 3×10^7 Hz. They show all the properties of the electromagnetic waves.

Uses : These waves are used mainly in radar communication and also in radio and television transmission.

6.6 DISTINCTION BETWEEN THE ULTRAVIOLET, VISIBLE AND INFRARED RADIATIONS

Ultraviolet radiations	Visible radiations	Infrared radiations
1. They have wavelength in the range of 100 Å to 4000 Å.	1. They have wavelength in the range of 4000 Å to 8000 Å.	1. They have wavelength in the range of 8000 Å to 10^7 Å.
2. They are invisible.	2. They are visible.	2. They are invisible.
3. They produce no heating effect.	3. They produce slight heating effect.	3. They produce strong heating effect.
4. They affect the photographic plate.	4. They affect the photographic plate.	4. They do not affect the photographic plate.
5. They cause fluorescence on zinc sulphide screen.	5. They do not cause fluorescence.	5. They do not cause fluorescence.
6. They cause health hazards like skin cancer.	6. They do not affect the body.	6. They do not affect the body, but high dose may cause skin burns.
7. They can pass through quartz but they do not pass through glass.	7. The can pass through glass.	7. They can pass through rock-salt, but they do not pass through glass.

EXERCISE–6(B)

1. (a) Give a list of at least *five* radiations, in the order of their increasing wavelength, which make up the complete electromagnetic spectrum.

(b) Name the radiation mentioned by you in part (a) which has the highest penetrating power.

2. (a) Arrange the following radiations in the order of their increasing wavelength :
X-rays, infrared rays, radio waves, gamma rays, and micro waves.

(b) Name the radiation which is used for satellite communication.

Ans. (a) gamma rays, X-rays, infrared rays, micro waves, and radio waves. (b) micro waves

3. A wave has a wavelength 10^{-3} nm. (a) Name the wave. (b) State its *one* property different from light.
Ans. (a) gamma ray, (b) strong penetrating power

4. A wave has wavelength 50 Å. (a) Name the wave. (b) State its speed in vacuum. (c) State its *one* use.
Ans. (a) X-ray, (c) 3×10^8 m s^{-1}
(d) in detection of fracture in bones

5. (a) Name the high energetic invisible electromagnetic wave which helps in the study of structure of crystals.
(b) State *one* more use of the wave named in part (a).
Ans. (a) X-rays, (b) to detect fracture in bones

6. State the name and the range of wavelength of the invisible electromagnetic waves beyond the red end of visible spectrum.

7. Name *three* radiations and their wavelength range which are invisible and beyond the violet end of the visible spectrum.

8. Give the range of wavelength of the electromagnetic waves visible to us. **Ans.** 4000 Å to 8000 Å

9. Name the region just beyond (i) the red end, and (ii) the violet end, of the spectrum.
Ans. (i) infrared (ii) ultraviolet

10. What do you understand by the invisible spectrum ?

11. Name the radiation which can be detected by (a) a thermopile (b) a solution of silver chloride.
Ans. (a) infrared radiation (b) ultra violet radiation

12. State the approximate range of wavelength associated with (a) the ultraviolet rays, (b) the visible light, and (c) infrared rays.

13. Name the radiations of wavelength just (a) longer than 8×10^{-7} m, (b) shorter than 4×10^{-7} m.
Ans. (a) infrared (b) ultraviolet

14. Name *two* electromagnetic waves of wavelength smaller than that of violet light. State *one* use of each.

15. Give *one* use each of (a) microwaves, (b) ultraviolet radiations, (c) infrared radiations, and (d) gamma rays.

16. Name the waves (a) of lowest wavelength, (b) used for taking photographs in dark, (c) produced by the changes in the nucleus of an atom, (d) of wavelength nearly 0·1 nm.
Ans. (a) gamma rays (b) infrared rays,
(c) gamma rays (d) X-rays

17. Two waves A and B have wavelength 0·01 Å and 9000 Å respectively.
(a) Name the two waves.
(b) Compare the speeds of these waves when they travel in vacuum.
Ans. (a) A–gamma, B–infrared, (b) 1 : 1

18. Name *two* sources, each of infrared radiations and ultraviolet radiations.

19. What are infrared radiations ? How are they detected ? State *one* use of these radiations.

20. What are ultraviolet radiations ? How are they detected ? State *one* use of these radiations.

21. Name *three* properties of ultraviolet radiations which are similar to the visible light.

22. Give *two* properties of ultraviolet radiations which differ from the visible light.

23. Mention *three* properties of infrared radiations similar to the visible light.

24. Give *two* properties of infrared radiations which differ front the visible light.

25. Name the material of prism required for obtaining the spectrum of (a) ultraviolet light, (b) infrared radiations. **Ans.** (a) quartz (b) rock salt

26. State *one* harmful effect each of the (a) ultraviolet and (b) infrared radiations.

27. Give reason for the following :
(i) Infrared radiations are used for photography in fog.
(ii) Infrared radiations are used for signals during war.
(iii) The photographic darkrooms are provided with infrared lamps.
(iv) A rock salt prism is used instead of a glass prism to obtain the infrared spectrum.
(v) A quartz prism is required for obtaining the spectrum of the ultraviolet light.
(vi) Ultraviolet bulbs have a quartz envelope instead of glass.

MULTIPLE CHOICE TYPE

1. The most energetic electromagnetic radiations are :
(a) microwaves (b) ultraviolet waves
(c) X-rays (d) gamma rays.
Ans. (d) gamma rays

2. The source of ultraviolet light is :
   (a) electric bulb (b) red hot iron ball
   (c) sodium vapour lamp (d) carbon arc-lamp.
   Ans. (d) carbon arc-lamp

3. A radiation P is focused by a proper device on the bulb of a thermometer. Mercury in the thermometer shows a rapid increase. The radiation P is :
   (a) infrared radiation (b) visible light
   (c) ultraviolet radiation
   (d) X-rays. **Ans.** (a) infrared radiation

NUMERICALS

1. An electromagnetic wave has a frequency of 500 MHz and a wavelength of 60 cm.
   (a) Calculate the speed of the wave.
   (b) Name the medium through which it is travelling.
   Ans. (a) 3×10^8 m s^{-1}, (b) air

2. The wavelength of X-rays is 0·01 Å. Calculate its frequency. State the assumption made, if any.
   Ans. 3×10^{20} Hz
   Assumption : Speed of X rays = 3×10^8 m s^{-1}.

(C) SCATTERING OF LIGHT AND ITS APPLICATIONS

6.7 SCATTERING OF LIGHT

When light from sun enters the earth's atmosphere, it gets scattered (*i.e.*, the light spreads in all directions) by the dust particles and air molecules present in the atmosphere. The path of sun light entering a dark room through a fine hole is seen because of scattering of the sun light by the dust particles present in its path inside the room. The scattering of light was first studied by the scientist Rayleigh.

Scattering is the process of absorption and then re-emission of light energy.

The air molecules of *size smaller than the wavelength of incident light* absorb the energy of incident light and then re-emit it without change in its wavelength. The scattering of light is not same for all wavelengths of incident light. The intensity of scattered light is found to be inversely proportional to the fourth power of wavelength of light (*i.e.*, $I \propto 1/\lambda^4$). *The wavelength of violet light is least* (≈ 4000 Å) *and that of red light is most* (≈ 8000 Å), *therefore from the incident white light, violet light is scattered most and the red light is scattered least (violet light is scattered nearly* 16 *times more than the red light)*. As a result, the light from sun when reaches on earth surface, has less intensity of the light of violet end (such as blue, indigo and violet) and more intensity of light of the red end (such as orange and red). *However the air molecules of size bigger than the wavelength of incident light, scatter the light of all wavelengths of white light to the same extent.*

6.8 SOME APPLICATIONS OF SCATTERING

Some effects of scattering of sunlight by the earth's atmosphere are : (1) red colour of sun at sunrise and sunset, (2) white colour of sky at noon, (3) blue colour of sky, (4) black colour of sky in the absence of atmosphere, (5) white colour of clouds, and (6) use of red light for the danger signal.

(1) Red colour of sun at sunrise and sunset

At the time of sunrise and sunset, the light from sun has to travel the longest distance of atmosphere to reach the observer. Since the blue light of short wavelength is scattered more, much of it is lost, while the red light of long wavelength is scattered a little, so it is not much lost. Thus blue light is almost absent in sunlight reaching the observer and only the red (white – blue = red) light reaches us. As a result, the sun

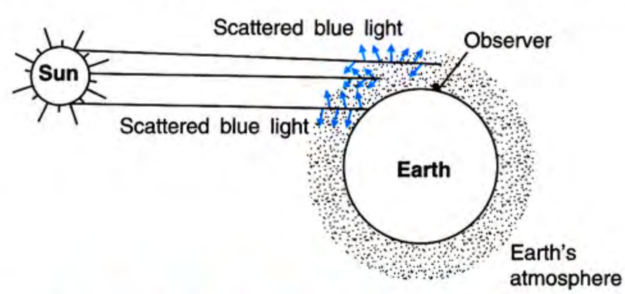

Fig. 6.11 Red colour of sun at sunrise and sunset

and the region near by it, is seen red. Fig. 6.11 shows the scattering of blue light.

(2) White colour of sky at noon

At noon, sun is directly above our head, so we get the light rays directly from sun after travelling the shortest distance, without much scattering of any particular colour. Hence the sky is seen white.

(3) Blue colour of sky

The light from sun has to travel a long distance of the earth's atmosphere before reaching us. As light travels through the atmosphere, it gets scattered in different directions by the air molecules present in its path. The blue (or violet) light due to its short wavelength is scattered more as compared to the red light of long wavelength. Thus the light reaching our eye directly from sun is rich in red colour, while the light reaching our eye *from all other directions* is the scattered blue light. Therefore *the sky in direction, other than the direction of sun, is seen blue*. Further after the sunset and before the sunrise, there is no sunlight reaching directly to us. Then the blue scattered light makes the entire sky to appear blue.

(4) Black colour of sky in absence of atmosphere

If there would have been no atmosphere, there would be no scattering of light and no scattered light would reach our eyes and thus the sky will appear black (instead of blue).

Since there is no atmosphere on moon therefore no scattered sunlight reaches the moon's surface. Hence to an observer on the surface of moon, no light reaches the eyes of the observer except the light reaching directly from the sun. Thus *the sky in direction other than that of the sun will appear black* to an observer on the moon's surface.

Similarly when an astronaut goes above the atmosphere of the earth in a rocket, he sees the sky black, but to him the earth appears blue due to the blue colour of sunlight scattered by the earth's atmosphere, reaching him. The stars and other heavenly bodies are seen as usual, but without twinkling.

(5) White colour of clouds

The clouds are nearer the earth surface and they contain dust particles and aggregates of water molecules of size *bigger than the wavelength* of visible light. Therefore, the dust particles and tiny ice particles present in clouds scatter all colours of incident white light from sun to the same extent and hence when the scattered light reaches our eyes, the clouds are seen white.

(6) Use of red light for the danger signal

In the visible light, the wavelength of red light is longest, therefore the light of red colour is scattered least by the air molecules of the atmosphere. Hence the light of red colour as compared to the light of other colours can penetrate to a longer distance without becoming weak. Thus red light can be seen from the farthest distance in comparison to the light of other colours having the same intensity. Hence red light is used for danger signal so that the signal may be visible from the far distance even in fog, etc. Similarly remote control of electrical gadgets (like T.V. etc) also make use of the infrared radiations.

EXERCISE–6(C)

1. What is meant by scattering of light ?
2. How does the intensity of scattered light depend on the wavelength of incident light ? State the condition when this dependence hold.
3. When sunlight enters the earth's atmosphere, state which colour of light is scattered (i) the most, and (ii) the least.

   Ans. (i) violet (ii) red.

4. A bean of blue, green and yellow light passes through the earth's atmosphere. Name the colour which is scattered (a) the least, (b) the most.

Ans. (a) yellow (b) blue

5. Which colour of white light is scattered the least ? Give reason.

Ans. red because wavelength of red light is longest and intensity of scattered light $I \propto 1/\lambda^4$.

6. The danger signal is red. Why ?

7. How would the sky appear when seen from the space (or moon) ? Give reason for your answer.

8. What characteristic property of light is responsible for the blue colour of sky ? **Ans.** scattering

9. The colour of sky, in direction other than of the sun, is blue. Explain.

10. Why does the sun appear red at sunrise and sunset ?

11. The sky at noon appears white. Give reason.

12. The clouds are seen white. Explain.

MULTIPLE CHOICE TYPE

1. In the white light of sun, maximum scattering by the air molecules present in the earth's atmosphere is for :

(a) red colour (b) yellow colour
(c) green colour (d) blue colour.

Ans. (d) blue colour.

2. To an astronaut in a space-ship, the earth appears :

(a) white (b) red
(c) blue (d) black **Ans.** (c) blue