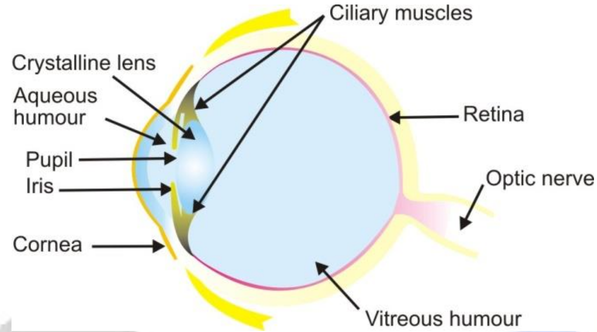
1. THE HUMAN EYE

The human eye is one of the most valuable and sensitive sense organs, which enable us to see the colourful world around us. It is just like a photographic camera. The lens system of the eye forms an image of the object on a light sensitive screen.



STRUCTURE OF THE EYE

The eye is a hollow, spherical organ about 2.3 cm in diameter. The main parts of the human eye are Cornea, Iris, Pupil, Ciliary Muscles, Convex Lens, Retina and Optic Nerve.

The front part of the eye, which is transparent and bulging outwards is called as CORNEA. Cornea serves as a window of the eye as the light coming from objects enters the eye through the cornea. Most of the refraction for the light rays entering the eye occurs at the outer surface of the cornea.

Behind the cornea, is a circular diaphragm called IRIS. There is a hole in the middle of the iris which is called PUPIL of the eye.

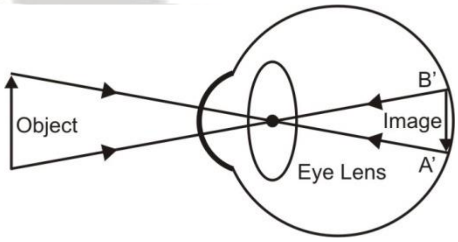
Behind the pupil, is a convex lens called EYE LENS. It is composed of transparent, fibrous jelly like material. It is held in position by CILIARY MUSCLES. The focal length of the eye lens and hence converging power is not fixed. It can be changed by changing its shape by action of ciliary muscles.

The eye lens forms an inverted real image of the object on the screen called RETINA. The retina is behind the eye lens and at the back part of the eye. The retina is a delicate membrane having enormous number of light sensitive cells – Rods and Cones.

The Rods respond to the intensity of light and the cones respond to colour of light. These cells get activated upon illumination and generate electric signals to brain.

WORKING OF THE HUMAN EYE

Light rays coming from the object to be seen enter the eye through pupil and fall on the eye lens. The eye lens being convex, forms a real and inverted image on the retina. The light sensitive cell of the retina gets activated upon illumination and generate electric signals. These signals are sent to the brain via the optic nerve. The brain interprets these signals and finally give rise to the sensation of vision.



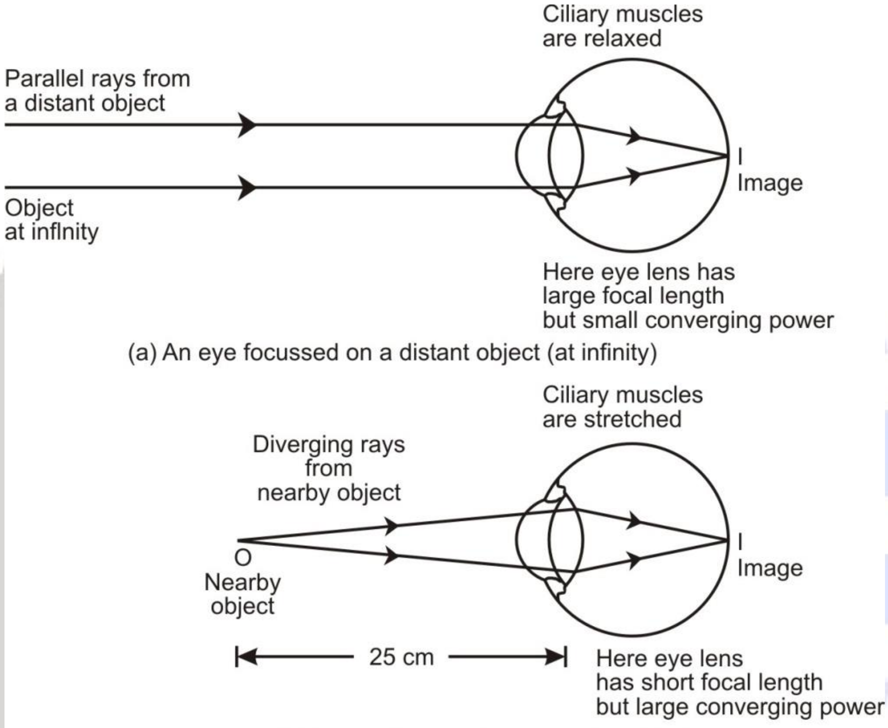
THE FUNCTION OF IRIS AND PUPIL

The iris adjusts the size of the pupil according to the intensity of light received by the eye. The pupil regulates and controls the amount of light entering the eye. When the intensity of outside light is high, the pupil contracts so that less light enters the eye. When the intensity of the outside light is low, the pupil expands so that more light enters the eye.

POWER OF ACCOMODATION OF HUMAN EYE

A normal eye can see the nearby as well as distant objects clearly. The eye lens is composed of a fibrous, jelly like material. Its curvature can be modified by the ciliary muscles. The change in the curvature of the eye lens can thus change its focal length, which in turn changes the converging power of the eye lens.

When the eye is looking at the distant object, the ciliary muscles are relaxed, the eye lens becomes thin. Thus its focal length increases and converging power decreases. Now the lens can converge the parallel rays of light coming from distant object to form the image on the retina. This enables us to see distant objects clearly.



(b) An eye focussed on a nearby object

When the same eye has to see nearby objects, the ciliary muscles contract. This increases the curvature of eye lens. The eye lens becomes thicker. So, focal length of the eye lens decreases. Due to short focal length, the converging power of the eye lens increases and now the eye lens can focus the diverging rays coming from the nearby objects on the retina.

The ability of an eye to focus the distant objects as well as nearby objects on the retina by adjusting its focal length is called accommodation. However the focal length of the eye lens cannot be decreased below a certain minimum limit. The maximum 'accommodation' of a normal eye is reached when the object is at the distance of 25 cm of the eye. Thus a normal human eye has a power of accommodation which enables objects as far as infinity and as close as 25 cm to be focused on the retina.

RANGE OF VISION OF A NORMAL HUMAN EYE

(i) The minimum distance, at which objects can be seen most distinctly without strain is called least distance of distinct vision. It is also called near point of the eye. The near point of normal human eye is at a distance of 25 cm from the eye.

(ii) The farthest point upto which the eye can see objects clearly is called the far point of the eye.

(iii) The range of vision of a normal human eye is from infinity to about 25 cms.

2. DEFECTS OF VISION AND THEIR CORRECTIONS

The ability to see is called vision. Sometimes the eye may gradually lose its power of accommodation. As a result, the eye of a person cannot focus the image of an object on the retina properly. In such cases, the vision of a person becomes blurred. As a result, he cannot see either the distant objects or nearby objects or both clearly and comfortably. The person is said to have defects of the eye. These defects of the eye are also known as the defects of vision or refractive defects of vision or the optical defects of the eye.

Following are the four common defects of vision:

(i) Myopia or short-sightedness
(ii) Hypermetropia or long-sightedness
(iii) Presbyopia
(iv) Astigmatism

(i) Myopia or short-sightedness: Myopia or short-sightedness is also known as near-sightedness. Myopia or near-sightedness is the defect of an eye due to which a person can see nearby objects clearly but he cannot see far away (distant) objects clearly and distinctly.

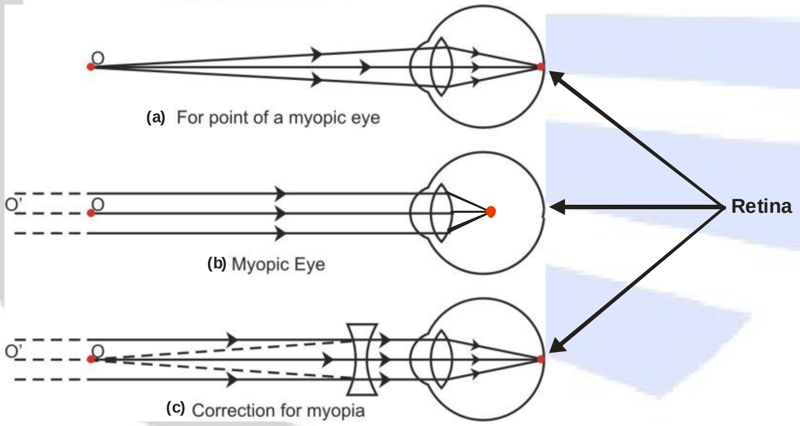
A person with this defect has the far point nearer than infinity.

In a myopic eye, the image of a distant object is formed in front of the retina and not at the retina as shown in the fig. (b)

Causes of Defect: The two possible causes of this defect are:-

(a) Excessive curvature of the eye lens or due to the high converging power of eye lens (short local length).
(b) Elongation of the eye ball.

Corrective Measures: This defect can be corrected by using spectacles with concave lens of suitable local length or power as shown in the figure (c).



(ii) Hypermetropia or Long-sightedness: Hypermetropia or long-sightedness is also known as far-sightedness, is the defect of an eye due to which a person can see far away (distant) objects clearly but cannot see nearby objects clearly and distinctly.

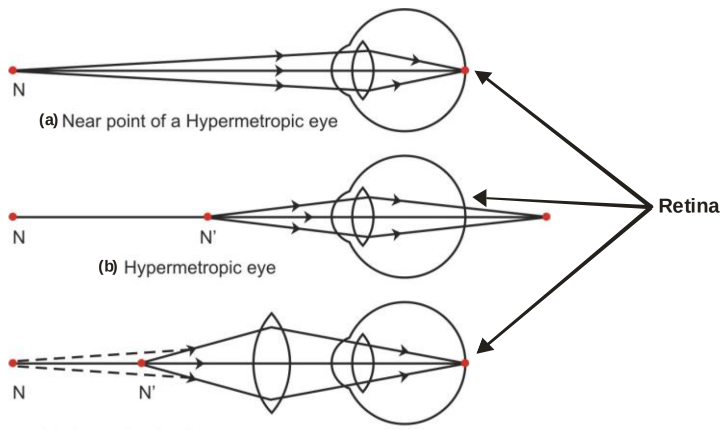
A person with this defect has the near point farther away from the normal point (25 cm).

In a hypermetropic eye the image of nearby object is formed behind the retina and not on the retina as shown in the figure (b).

Causes of Defect: The two possible causes of this defect are:-

(i) Low converging power of eye lens because of large local length.
(ii) Eye-ball being too short.

Corrective Measures: This defect can be corrected by using spectacles with convex lens of suitable focal length or power as shown in the figure (c).



(iii) Presbyopia or old sight: Presbyopia or old sight is the defect of the eye due to which an old person cannot see the nearby objects clearly. The near point of the old person having presbyopia gradually recedes and becomes much more than 25 cm.

Cause of Defect: Presbyopia arises due to the gradual weakening of the ciliary muscles and diminishing flexibility of the eye lens with age.

Presbyopia is the hypermetropia caused by the loss of power of accommodation of the eye due to old age.

Corrective Measures: Presbyopia defect is corrected in the same way as hypermetropia i.e. by using spectacles having convex lenses.

Some times, a person may suffer from both myopia and hypermetropia. Such persons often use spectacles having bifocal lenses in which upper part consists of a concave lens to correct myopia (used for distinct vision) and lower part consists of a convex lens to correct hypermetropia (used for reading).

(iv) Astigmatism: The inability of the eye in focusing objects in both horizontal and vertical lines clearly is called astigmatism.

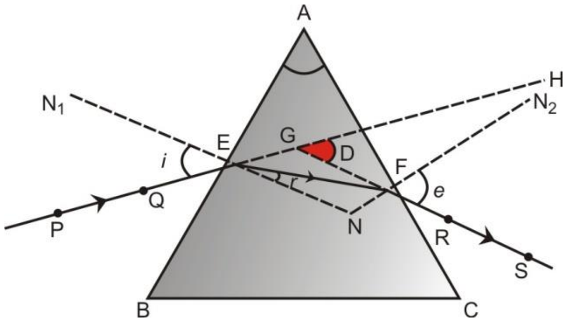
Cause of defect: This defect is caused due to varying curvature in the eye lens in horizontal and vertical lines.

Corrective Measure: This defect is corrected by using cylindrical lenses.

3. REFRACTION OF LIGHT THROUGH A GLASS PRISM

A glass prism is a five-sided solid with a triangular cross-section. It has two parallel, triangular faces and three rectangular faces that are inclined to each other at some suitable angle, which is called the angle of prism.

In the given fig. *ABC* is a glass prism of angle *A*. A ray of light *PE* is incident on the face *AB* of the prism an angle $\angle PEN_1 = i$ (the angle of incidence). N_1N is normal to the face *AB* at *E*.



The incident ray *PE* after refraction at *E* follows the path *EF* at an angle ∠*FEN* = *r* (the angle of refraction). Since this ray is going from air (rarer medium) to prism (denser medium), so it bends forwards normal N_1N.

The refracted ray *EF* suffers second refraction at *F* and follows the path *FS* at an angle $\angle N_2FS = e$, known as the angle of emergence. Since it is going from denser medium (glass prism) to rarer medium (air) so it bends away from normal N_2N.

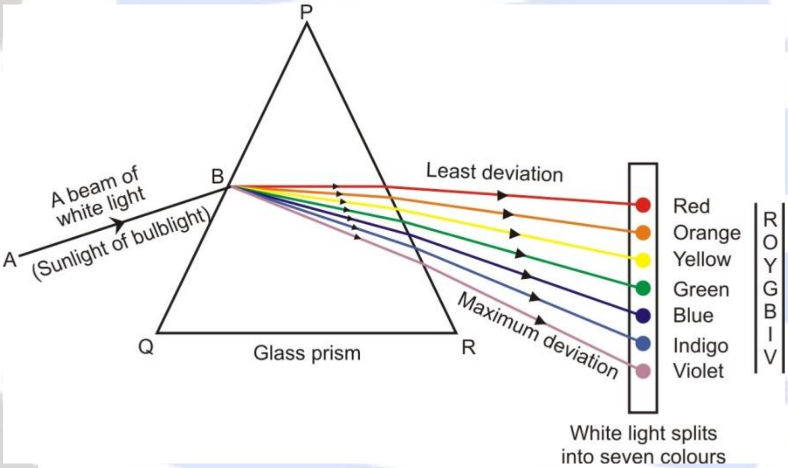
The incident ray *PE* undergoes two refractions, one at point *E*, while going from air to glass prism and other at point *F*, while going from glass prism to air. The path of the ray deviates through an angle ∠*HGS* = *D*, known as angle of deviation, on passing through the prism.

The deviation of a ray on passing through a prism depends on angle of prism 'A' and angle of incidence '*i*' of the ray on one face of the prism.

DISPERSION OF WHITE LIGHT BY A GLASS PRISM

The phenomenon of splitting up of white light into its constituent seven colours on passing through a prism is called dispersion of light.

In the year 1665, Newton discovered that if a beam of white light is passed through a triangular glass prism, the white light splits to form a band of seven colours on a white screen held on the other side of the prism.



This band of seven colours formed on the white screen, when a beam of light is passed through a glass prism, is called spectrum of white light.

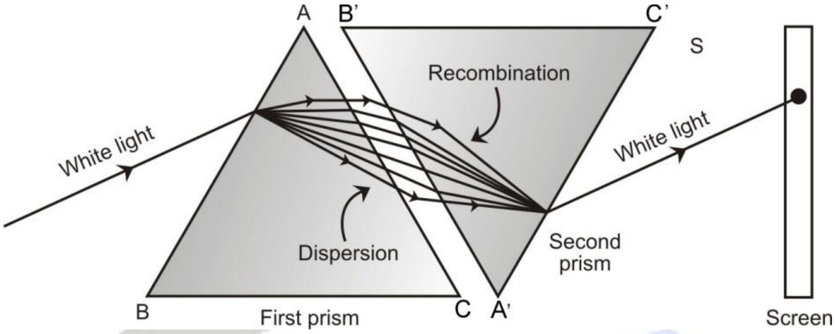
The colour sequence obtained on the screen is given by the famous acronym VIBGYOR where :

V stands for Violet
I stands for Indigo
B stands for Blue
G stands for Green
Y stands for Yellow
O stands for Orange
R stands for Red

Violet colour bends through maximum angle whereas the red colour bends the least on passing through the prism, that is why red colour is at the top and violet colour is at the bottom of the spectrum.

RECOMBINATION OF SPECTRUM COLOURS

When a beam of light is passed through a glass prism *ABC*, it splits up into seven colours. If this dispersed beam (spectrum) is passed through another identical glass prism say *A′ B′ C′* placed alongside the first prism *ABC* in the opposite direction and in the inverted position on its vertex *A′* then a patch of white light is obtained on the screen placed behind the second prism *A' B′ C′* as shown in the figure.



The recombination of seven colours, produced by the first prism is due to the fact that the refraction produced by second prism *A′B′C′* is equal and opposite to the refraction produced by the first prism *ABC*.

FORMATION OF A RAINBOW

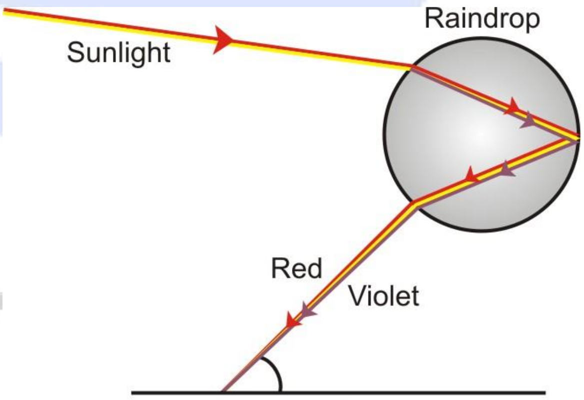
A rainbow is a natural spectrum appearing in the sky in the form of an arch of seven colours which is produced by the dispersion of sunlight by tiny water droplets, present in the atmosphere.

A rainbow is always formed in the opposite direction to that of the sun. The colours come from the dispersion of white light by raindrops suspended in air. The water droplets act like small prisms. Sunlight entering a drop gets refracted and is split into its component seven colours. These light rays of the component colours travel through the drop and fall on its other side.

These light rays get reflected and again fall on the surface of the drop and get refracted on the way out. The two refraction bend the light through a large angle, keeping them separate.

These light of different colours emerging from the rain drops forms a rainbow, such that the red colour is at the top and violet colour at the bottom.

Rainbow in the Sky



Rainbow formation

4. ATMOSPHERIC REFRACTION

The refraction of light caused by the earth's atmosphere is called atmospheric refraction. The physical conditions of the refracting medium (air) are not stationary. Some of the air layers are cold and act like a denser medium whereas other layers, of the atmosphere are comparatively warm and act like

a rarer medium. In the atmosphere the air layers have different optical densities. So when the light rays pass through the air layers of different optical densities, then refraction of light takes place.
For example: The air just above the fire becomes hotter than the air farther up. The hotter air is lighter (rarer medium) than the cooler air (denser medium) above it, and has a refractive index slightly less than that of cooler air. Since the physical conditions of the air are not stationary, therefore when we see the objects through hot and cold air layers then refraction of light takes place due to which the position of the objects fluctuates.
Some of the optical phenomena in nature which take place due to the atmospheric refraction of light are as follows:

TWINKLING OF STARS

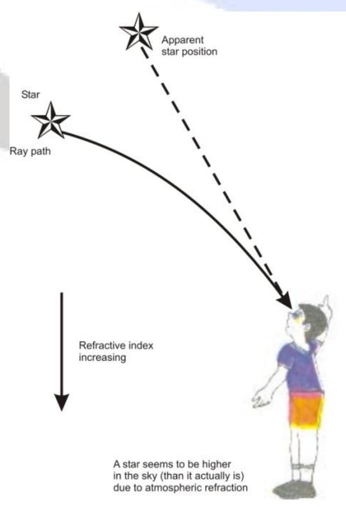
The twinkling of stars is due to the atmospheric refraction of star's light. Since stars are very far away heavenly bodies and therefore are considered single point sources of light.
When the light coming from a star enters the earth's atmosphere, it undergoes refraction due to the varying optical densities of air. The continuous changing conditions of the atmosphere, refracts the light coming from the stars by different amounts from one moment to another. When the atmosphere refracts more star light towards us, the stars appear to be bright and when the atmosphere refracts less star light towards us, the star appears to be dim. This phenomenon goes on thereby giving rise to twinkling of stars.

PLANETS DO NOT TWINKLE

The planets are much closer to the earth and are thus considered as the collection of infinite point sources of energy. Therefore the dimming effect produced by some of the point sources of light in one part of the planet is nullified by the brighter effect produced by the other point sources of light in the other part of the planet.
As a result, the total variation in the amount of light entering our eye from all the point sources of light will average out to be zero. Thereby nullifying the twinkling effect. Hence planets do not twinkle.

THE APPARENT POSITION OF THE STARS IS HIGHER THAN THEIR ACTUAL POSITION

The apparent position of the stars is higher than their actual position due to the atmospheric refraction. The upper layers of the atmosphere act like a rarer medium whereas the lower layers which are close to the earth act like a denser medium. As the star light enters from rarer to denser medium it bends more towards the normal. Since the atmosphere bends starlight towards the normal, the apparent position of the star is slightly different from its actual position, as a result, star appears slightly higher than its actual position, as shown in the figure.

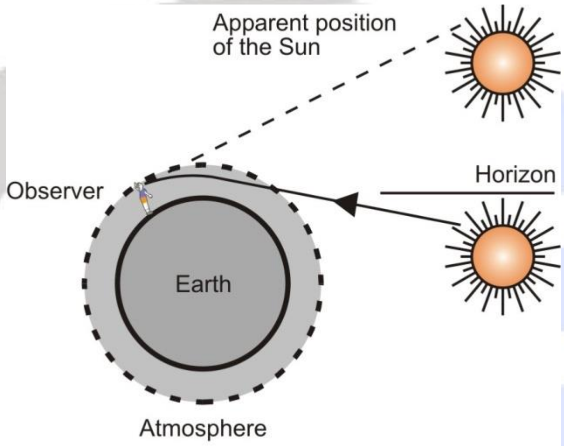


ADVANCE SUNRISE AND DELAYED SUNSET

The sun is visible to us about 2 minutes before the actual sunrise and 2 minutes after the actual sunset because of atmospheric refraction. The actual sunrise takes place when the sun is just above the horizon.

When the sun is slightly below the horizon, the sun's light coming from rarer medium (i.e. from less dense air) to denser medium (i.e. to more dense air) is refracted downwards as it passes through the atmosphere. Because of this atmospheric refraction, the sun appears to be raised above the horizon whereas it is actually slightly below the horizon (as shown in the figure).

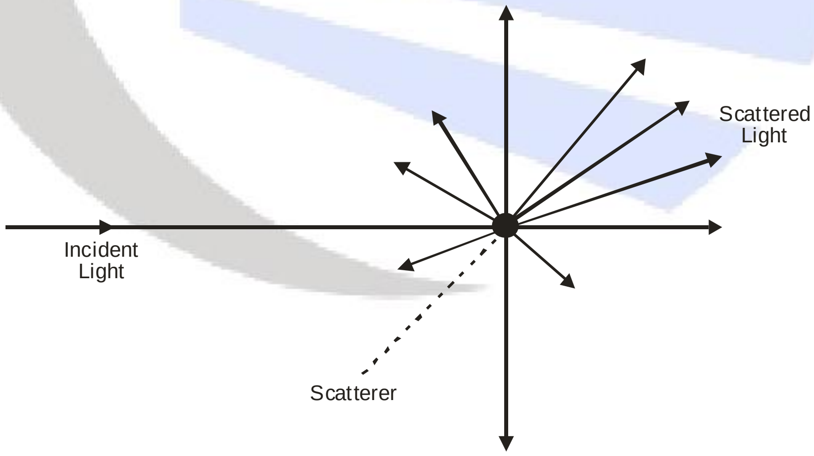
It is again due to the atmospheric refraction that we can see the sun for about two minutes even after the sun has set below the horizon. Because of this atmospheric phenomenon, the time from sunrise to sunset is lengthened by about 2 + 2 = 4 minutes.



Atmospheric refraction effects at sunrise and sunset

5. SCATTERING OF LIGHT

Scattering of light means to throw light in various random directions. The scattering involves bouncing off of light by atoms or molecules of the medium through which they are travelling.



The beautiful atmospheric phenomena like blue colour of the sky, the red colour of the sun at sunrise and at sunset can be explained on the basis of scattering of light by the atmosphere.

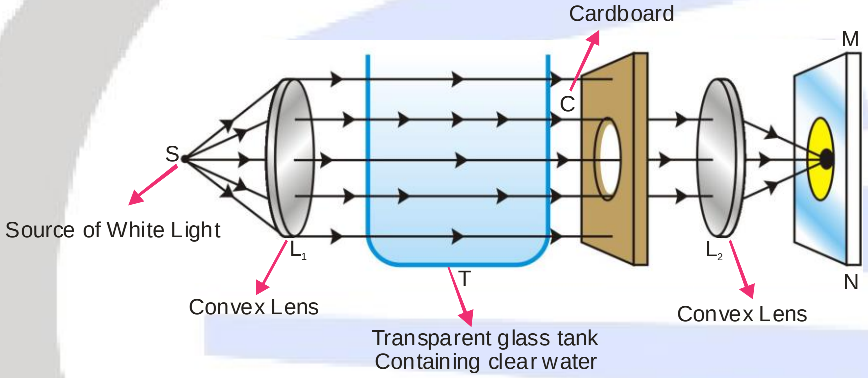
TYNDALL EFFECT

The scattering of light by the colloidal particles of the medium due to which the path of the light becomes visible is known as Tyndall effect.

This phenomenon is seen when a fine beam of sunlight enters a smoke-filled room through a small hole. Tyndall effect can also be observed when sunlight passes through a dense forest.
The colour of the scattered light depends upon the size of the particles scattering the light. Very fine particles scatter mainly blue light of smaller wave length while particles of bigger size scatter light of longer wavelength. If the size of the particles scattering the light is large enough, the scattered light may even appear white.

EXPERIMENT TO STUDY SCATTERING OF LIGHT

Let us do an experiment to understand the blue colour of sky and the reddish appearance of the sun at the sunrise or sunset due to scattering of light by the atmosphere.
A strong source *S* of white light is placed at the focus of a Convex Lens L_1. This lens L_1 provides a parallel beam of light. This parallel beam of light is passed through a transparent glass Tank *T* containing clear water. The beam of light after coming from the tank is made to pass through a circular hole '*C*' made in a Cardboard.
A sharp image of the circular hole is obtained on a screen *MN* by using a second Convex Lens L_2 as shown in the figure.



An arrangement for observing scattering of light in colloidal solution

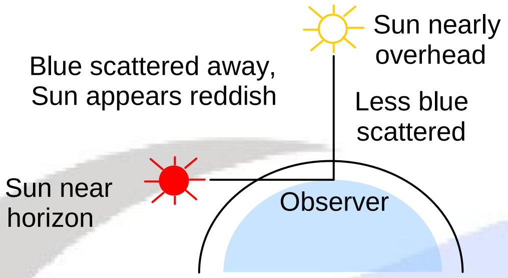
Now dissolve about 250g of sodium thiosulphate in about one litre of clear water taken in the tank. Add 1 to 2 ml of concentrated sulphuric acid to this water.
In a few minutes, fine microscopic sulphur particles are precipitated in water. As the sulphur particles begin to form, light gets scattered from the sulphur particles and we observe the blue colour from the three sides of the glass tank.
This is due to the scattering of light of short wave length by minute colloidal sulphur particles. When we observe the colour of the transmitted light from the fourth side of the tank facing the circular hole, we see first the orange red colour and then the bright crimson red colour on the screen.

BLUE COLOUR OF THE CLEAR SKY

The scattering of blue component of the white sunlight by the atoms and molecules present in the air of the atmosphere causes the blue colour of the sky.
The sunlight consists of seven coloured lights mixed together. When sunlight passes through the atmosphere, the shorter wave length of blue light is scattered all around the sky by the tiny particles (atoms and molecules) present in the atmosphere. Some of the scattered blue light enters in our eyes as a result the sky appears blue. Whereas the longer wave length light such as yellow, orange and red etc. do not get scattered much and hence they pass straight through.
If the earth had no atmosphere, there would not have been any scattering and the sky would have looked dark. The sky appears dark to the astronaut flying at very high attitudes because scattering is not prominent at such heights due to the lack of atmosphere.

COLOUR OF THE SUN AT SUNRISE AND SUNSET

At the time of sunrise and sunset, the sun is near the horizon. The sun rays have to travel much larger part of the atmosphere to reach on earth. As a result most of the light of smaller wave length i.e. blue coloured light gets scattered away. Where as the light of larger wave length i.e. red coloured light is scattered least. Out of all the colours of sunlight, the red coloured light is scattered the least and reaches the earth. Hence, the sun appears reddish at the sunrise and sunset.



When the sun is overhead, the sunlight has to travel much smaller portion of earth's atmosphere. As a result, a little of the blue and violet colours are scattered out, due to which the sun appear silver shiny (white).

DANGER SIGNALS ARE RED

Out of all the colours of visible light, red colour has the largest wavelength. Therefore red colour is least scattered. As a result, it can be seen from maximum distance. That is why danger signals are red.

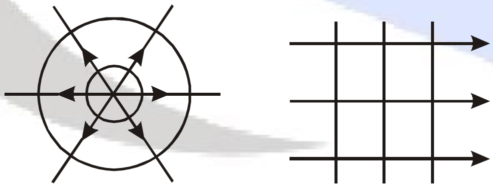
6. WAVE OPTICS

HUYGEN'S PRINCIPLE

Wavefronts and Rays

A wavefront is defined as a surface joining the points of same phase. The speed with which the wavefront moves outwards from the source is called the phase velocity or wave velocity. The energy of the wave moves in a direction perpendicular to the wavefront.

Figure shows light waves emitting out from a point source forming a spherical wavefront in three dimensional space. The energy travels outwards along straight lines emerging from the source, along radii of the spherical wavefront These lines are called the rays.



(a) (b)

Rays are perpendicular to wavefronts. The time taken by light to travel from one wavefront to another is the same along any line.

Every point on a wavefront vibrates in same phase and with same frequency. Every point on a wavefront acts like a secondary source and sends out a spherical wave, called a secondary wavelet. Wavefronts move in space with the velocity of wave in that medium.

SUPERPOSITION PRINCIPLE

The phenomena of interference is based on the principle of superposition. It states that the instantaneous optical disturbance at a point, where two or more light waves overlap, is the sum of the optical disturbances that would be produced by each of the waves separately.

COHERENT SOURCES

Two source are said to be coherent if they have the same frequency and the phase relationship remains constant and independent of time. In this case, the total intensity I is not just the sum of individual intensities I_1 and I_2 due to two sources but also includes an interference term whose magnitude depends on the phase difference at a given point.

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

where ϕ is the phase difference between the two sources and $2\sqrt{I_1 I_2}\cos\phi$ is called as interference term.

INCOHERENT SOURCES

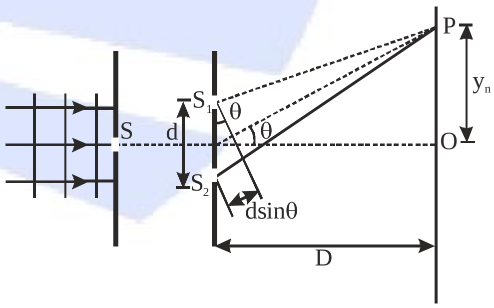
Two sources are said to be incoherent if they have different frequency and phase different is not constant with respect to time. In this case the $2\sqrt{I_1 I_2}\cos\phi$ averaged over a cycle is zero.

For such incoherent sources $I = I_1 + I_2$.

5. INTERFERENCE-YOUNG'S DOUBLE SLIT EXPERIMENT

It was carried out in 1802 by the English scientist Thomas Young to prove the wave nature of light. Two slits S_1 and S_2 are made in an opaque screen, parallel and very close to each other. These two are illuminated by another narrow slits S and light fall on both S_1 and S_2 which behave like coherent sources. Note that the coherent sources are derived from the same source. In this way, any phase change which occurs in S will occur in both S_1 and S_2. The phase difference $(\phi_1 - \phi_2)$ between S_1 and S_2 is unaffected and remains constant.

Light now spreads out from both S_1 and S_2 and falls on a screen. It is essential that the waves from the two sources overlap on the same part of the screen. If one slit is covered up, the other produces a wide smoothly illuminated patch on the screen. But when both slits are open, the patch is seen to be crossed by dark and bright bands called interference fringes. This redistribution of intensity, pattern is called interference pattern.



Schematic arrangement of YDSE

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

where is the phase difference and I is the resultant intensity.

Condition for bright fringes or maxima

$$\phi = 2n\pi$$

or path difference, $p = n\lambda$ where n = 0, 1, 2, …….

$$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$$

Condition for dark fringes or minima,

$\phi = (2n-1)\pi$

or path difference $p = \left(n - \frac{1}{2}\right)\lambda$, where n = 1, 2, 3, …….

$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

[The relation between phase difference (ϕ) and path difference (p) is given by $\phi = \frac{2\pi}{\lambda} p$]

How to find the Position of the nth Maxima or Minima on the Screen?

Let P be the position of the nth maxima on the screen. The two waves arriving at P follow the path S_1P and S_2P, thus the path difference between the two waves is

$$p = S_1P - S_2P = d\sin\theta$$

From experimental conditions, we know that D >> d, therefore, the angle is small,

Thus $\sin\theta \approx \tan\theta = \frac{y_n}{D}$

$\therefore \quad p = d\sin\theta = d\tan\theta = d\left(\frac{y_n}{D}\right) \quad \Rightarrow \quad y_n = pD/d$

For nth maxima

$$p = n\lambda$$

$\therefore \quad y_n = n\lambda\frac{D}{d}$ where n = 0, 1, 2, ……….

For nth minima $p = \left(n - \frac{1}{2}\right)\lambda$

$\therefore \quad y_n = \left(n - \frac{1}{2}\right)\frac{\lambda D}{d}$ where n = 1, 2, 3, ……..

Note that the nth minima comes before the nth maxima.

Fringe Width

It is defined as the distance between two successive maxima or minima.

$\therefore \quad \omega = y_{n+1} - y_n = (n+1)\frac{\lambda D}{d} - \frac{n\lambda D}{d}$ or $\omega = \frac{\lambda D}{d}$

[If λ changes to λ' then the fringe width $\omega' = \frac{\lambda' D}{d}$]

Optical Path

It is defined as distance travelled by light in vacuum taking the same time in which it travels a given path length in a medium. If light travels a path length d in a medium at speed v, the tame taken by it will be (d/c). So optical path length

$L = c \times \left[\frac{d}{v}\right] = \mu d$ (because $\mu = \frac{c}{v}$)

Since for all media optical path length is always greater then geometrical path length. When two light waves arrive at a point by travelling different distances in different media, the phase difference between the two is related by their optical path difference instead of simply path difference.

Fringe Shift

When a transparent film of thickness t and refractive index μ is introduced infront of one of the slits, the fringe pattern shifts in the direction where the film is placed.