8. LIGHT

NATURE OF LIGHT

Light is a form of energy. Strictly speaking, light means any radiation whose wavelengths excite a sensation of brightness, or illumination, in the retina of the eye. These wavelengths range from about 0.00004 centimetres to 0.000076 centimetres. Certain types of radiation–ultraviolet light and infrared light–are similar to visible light, though their wavelengths are somewhat shorter or longer than those of the visible range.

Not so many years ego, scientists were quite sure that light and other radiant energy consisted of electromagnetic waves rippling through space. They distinguished sharply between the wave character of radiation and the particle character of matter. Today the picture is not clear. In some respects, atleast, light and other radiations behave like streams of particles. What is even stranger, perhaps, electrons and other very small particles sometimes behave like waves.

The peculiar dual nature of radiation and of material particles is the subject matter of wave mechanics. It would take a great deal of space to explain this theory, even non-mathematically. It is perhaps enough to say here that neither radiation nor material particles ever exhibit both wave and particle characteristics at the same time. In the transit-that is, as it moves from place to place–light behaves like a system of waves. It has a fixed speed in empty space. Its wavelengths can be measured by a variety of methods. In many ways its behaviour is entirely consistent with the theory that it is an electromagnetic wave disturbance. But in its emission from electrons in an atom and in its absorption or other reaction with atoms in its path, light behaves more like a stream of very small particles of energy-photons.

The old argument over the nature of light seems to have ended in a draw. Instead of saying that light, or any other kind of radiation, consists of waves or particles, physicists recognize that it behaves like waves in certain respects and like particles in others. The speed of light is nearly 300,000 km per second.

Light is given out or emitted by very hot objects such as the Sun, or the filament of a bulb, or the hot gases in the flame. It may also be emitted from much cooler materials when electrons lose energy. This happens in a fluorescent tube, or a TV screen, or a laser. Any object which produces its own light is said to be self-luminous.

Most of the objects around you do not produce their own light and are said to be non-luminous. They are only visible because they reflect light from some other sources. Some surface are better at reflecting light than others; light which is not reflected is either absorbed, or in the case of the transparent material like glass, transmitted, i.e. it passes right through.

Rectilinear Propagation and Shadows

The formation of shadows with sharp edges demonstrates the rectilinear propagation of light, i.e. the fact that light travels in straight lines.

When an opaque obstacle is placed between a source of light and a screen, a shadow of the obstacle is formed on the screen. The kind of shadow depends on the size of the source of light. If it is a point source (light from a small hole), the shadow obtained is a region of total darkness, called **umbra.** If an extended source of light, e.g. a bulb, is used, the umbra is surrounded by a region of partial darkness, called **penumbra.**

Eclipse

Solar Eclipse : When moon comes between sun and earth then the shadow of moon falls on the earth and from the shadow region sun is not visible and this position is called solar eclipse and this eclipse may be full or partial. Full solar eclipse occurs on the day of full moon.

Lunar Eclipse : When earth comes between sun and moon then the shadow of earth falls on the moon then the shadow region of the moon is not visible and this position is called lunar eclipse and this eclipse may also be full or partial. Full lunar eclipse occurs on the day of new moon.

Reflection of light

When the light ray incidents on the smooth and light polished surface then it is reflected back almost in different direction, such incidence of light ray and its reflection is called reflection of light. The plane mirror is assumed to be the best reflector. The straight line perpendicular to the reflected surface is called normal. The angle between incident ray and normal is called angle of incident and between the normal and reflected ray is called angle of reflection.

Spherical mirror : In any spherical plane the constructed mirror is called spherical mirror, and in the one side of the mirror the layer of mercury or coating of lead oxide is painted and another side is used as reflecting side. The spherical mirror is of two types—

Concave mirror : The spherical mirror whose reflecting surface is inwardly leaned is called concave mirror. It is also called diverging mirror because it diverges the coming rays from infinity.

Convex mirror : The spherical mirror whose reflecting surface is outwardly leaned is called convex mirror. It is also called converging mirror because it converges the coming rays from infinity.

Magnification : The ratio of image distance to object distance or the ratio of the length of image to the length of the object is called the magnification of the mirror and it is represented by m.

The image formed by convex mirror : In convex mirror the image of an object is formed behind the mirror between pole and focus and image formed is smaller than object which is erected and virtual.

If the position of the object be increased from the pole then the virtual erected image becomes smaller and shifts towards focus.

The apparent upward bending of the immersed portion of a stick, when dipped in water, can also be explained on the basis of refraction. Another effect of refraction is the apparent shortening of a person's body when he is standing in water and we look at him from the side.

Atmospheric Refraction The density of the atmosphere surrounding the earth decreases with increasing altitude. Thus if light enters the atmosphere from outside, it encounters layers of air of increasing density and, therefore, bends gradually producing a curved path.

It is due to refraction, produced by the earth's atmosphere, that the sun is visible for several minutes after it has set below the horizon. Thus atmospheric refraction tends to lengthen the day.

When the sun (or moon) is near the horizon, it appears elliptical, i.e. with the vertical diameter less than the horizontal diameter. This happens because rays from the lower edge of the sun are bent more than those from the upper edge.

The twinkling of stars can also be partly attributed to atmospheric refraction. The light from a star reaches us after suffering refraction through various layers of air. These layers are not stationary because of convection currents in the air, and hence the light appears shimmering giving the impression of twinkling. Since planets are nearer to us, the light received from them is much greater. Therefore, minor variations in intensity caused by the above effect are not noticeable. Thus planets do not appear to twinkle.

Mirage One of the most interesting effects of atmospheric refraction occurs in the mirage, which is usually associated with hot deserts. The air in the desert is hot near the ground and cools rapidly with height. The hotter air is optically less dense.

Rays of light from the top of a tree (or the sky) suffer successive bending as they pass through the warmer layers of decreasing density. This results in the gradual increase of the angle of incidence. Eventually, a stage comes when the angle of incidence exceeds the critical angle and, therefore, total internal reflection takes place . After this the rays start bending upwards. An observer sees the tree upside down (as well as the actual tree) as if he were seeing the reflection on a surface of water. On hot summer days, motorists quite often see similar mirages on the roads.

As interesting use of the total internal reflection is in optical fibres, which are fine strands of high quality glass. When light is incident at one end of the fibre, it undergoes repeated total internal reflections and emerges at the other end. Thus an optical fibre pipes light from one point to another. Such optical fibres are used in decorative table lamps. Bundles of tiny optical fibres are used by doctors to see the inside of a patient's stomach. Light is piped down some of the fibres to illuminate the inside of the stomach and is reflected back along some other fibres. This procedure is called endoscopy.

These days optical fibres have largely replaced copper cables for telecommunication and networking. Optical fibres are being used because these are flexible and can be bundled as cables. It is especially advantageous for long-distance communications, because light propagates through the fibre with little attenuation compared to electrical cables. Also, each fibre can carry many independent channels, each using a different wavelength of light.

Although fibres can be made out of transparent plastic, glass, or a combination of the two, the fibres used in long-distance telecommunications applications are always glass, because of the lower optical attenuation.

Fibres have been used in remote sensing. These can be used as sensors to measure temperature, pressure etc. Extrinsic fibre optic sensors use an optical fibre cable. A major benefit of extrinsic sensors is their ability to reach places which are otherwise inaccessible. An example is the measurement of temperature inside aircraft jet engines by using a fibre to transmit radiation into a radiation pyrometer located outside the engine.

In some buildings, optical fibres are used to route sunlight from the roof to other parts of the building. Optical fibre illumination is also used for decorative applications, including signs and art.

Human Eye

The human eye too is a similar optical instrument. Its lens is a transparent structure made of proteins. The focused image falls on a screen behind the lens, called the retina. The retina sends electrical signals to the brain through the optic nerve so that we perceive objects.

The cornea is a transparent spherical structure that refracts light into the eye. The iris is a dark muscular assembly that controls the size of the pupil, the opening that regulates the amount of the light entering the eye. When the light is very bright, the pupil becomes very small, while in a dim light it opens up fully through the relaxing of the iris. The light through the cornea and pupil falls on the lens which focuses it on the retinal screen. The retina has an enormous number of light-sensitive cells. These get activated upon illumination and generate electrical signals that are sent to the brain through the optic nerves. The brain interprets these signals as the sense of light.

There are of course very important different between our eye and a camera. The image on the retina is not permanent but fades away after $1/20^{th}$ of the second and overlaps with the next image. This gives the impression of continuity. There is of course no film in the eye that records the images permanently as a photo film does. More importantly, the focal length of the eye lens is changed when its attached cilial muscles change their tension. When they are relaxed, the lens is thin and you can see distant objects clearly. When you are looking at nearby objects, the muscles compress the lens so as to decrease its focal length. This property of the eye lens of changing its focal length is called its power of accommodation.

However, the focal length of the eye lens cannot be decreased below a certain limit. Try to read this book by holding it close to your eyes. You may find that it strains your eyes. To read the book comfortably you have to hold it at about 25 cm from your eyes. This minimum distance at which one can see objects distinctly is called the distance of distinct vision.

DEFECTS OF VISION AND THEIR CORRECTION

Sometimes the eye loses its power of accommodation. When this happens one cannot see objects clearly, and vision becomes blurred.

Astigmatism This defect is due to the cornea not being spherical. As a result, the rays of light entering the eye in different planes are brought to a focus at varying distances from the retina. So, though the object is a point, the shape of the image may be a line, a circle or any other shape except a point. This defect can be corrected by using a cylindrical lens, instead of a spherical lens.

Dispersion

White light consists of seven colours—violet, indigo, blue, green, yellow, orange, and red. These colours are called the **spectrum** of the white light. Violet has the minimum wavelength (or maximum frequency) and red the maximum wavelength (or minimum frequency). In a vacuum, all these colours travel with the same speed but in a transparent medium they have different speeds. Violet travels the slowest through glass while red travels the fastest. Due to different speeds, the colours are refracted through different angles and, therefore, when a narrow beam of white light passes through a glass prism, it is split up into its constituent colours . This separation of light into colours is called dispersion.

The Rainbow The most spectacular illustration of dispersion is the rainbow. When the sun shines soon after a shower of rain, a rainbow is seen in the sky opposite the sun. The beautiful colours of the rainbow are due to the dispersion of sunlight by water droplets suspended in the air after rain. The droplets act like prisms. In each droplet there is dispersion as well as total internal reflection. A similar effect is produced by droplets of water from a fountain in sunlight.

PRIMARYAND SECONDARY COLOURS: COLOUR ADDITION

Red, green and blue are known as the primary colours because it isn't possible to produce them by mixing light of any other colours together. Artists use different 'primary' colours, which will be explained later. When any two primary colours are combined, they give a secondary colour.

Producing new colours by mixing light of other colours together is known as colour mixing by addition. To the human eye:

Red + green = yellow

Green + blue = peacock blue (turquoise or cyan)

Red + blue = magenta

This secondary colours aren't really single colours at all; they only appear as such to the human eye. The eye cannot for example distinguish between pure yellow in the spectrum and secondary or compound, yellow which is really a mixture of red and green light. Both yellows stimulate the same colour-sensitive cells in the retina.

It is important to note that mixing coloured paints produces entirely different results from mixing coloured lights.

Scattering

Scattering of electromagnetic radiation is the process in which energy is removed from a beam of electromagnetic radiation and re-emitted with a change in direction, phase, or wavelength. All electromagnetic radiation is subject to scattering by the medium (gas, liquid, or solid) through which it passes. Light in the visible, infrared, or ultraviolet region interacts primarily with the electrons in gases, liquids, and solids, not the nuclei. The scattering process in these wavelength regions consists of acceleration from the acceleration changes. Scattering of light is a diffraction effect.

Dust particles and even the molecules of atmospheric gases interrupt the wave fronts of sunlight advancing into the atmosphere. The light that was advancing in a straight line from the sun to the earth is dispersed. A given obstacle "longer bigger" to a short wave of violet light than it does to the longer red. Therefore, the effect of the obstacle on the violet wave will be more drastic. Consequently, violet light is scattered most, blue somewhat less, and green, yellow, and orange still less, in that order. Red is affected least of all.

The sky generally looks blue because the short blue waves are scattered more than the longer waves of red light. It is true that the violet waves are dispersed even more than the blue. However, the sky does not appear violet because the sun is relatively weak in violet light. Deep water appears blue for the same reason. However, impurities in the water often absorb the blue and green, becomes the predominant tint. The sky looks red near the horizon because, at that angle, the path through the atmosphere is long and traverses much low-flying dust. As a result the bluer light is effectively scattered out of the direct beam before it can be observed by the viewer. Twilight is also the result of the light scattered by particles and molecules in the atmosphere.