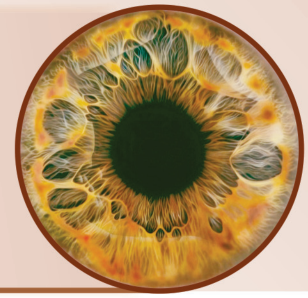
CHAPTER 1

Elementary Optics



Learning Objectives

After studying this chapter the reader should be able to:

- Describe the various theories proposed for light.
- Describe the different properties of light.
- Explain the diffraction, polarization, interference, coherence, scattering, transmission and absorption phenomenon of light and their applications.
- Explain the fluorescence and photoelectric effect of light.
- Understand and explain various photometry and radiometry terms used for measurement of light.
- Understand the basic mechanism and basic properties of LASER.
- Explain the sensitivity of human eyes for various spectrum of light.

Chapter Outline

- Introduction
  - History of nature of light
- Properties of light
  - Physical properties
    - Character of light
    - Propagation of light
    - Intensity of light
  - Optical properties
    - Diffraction
    - Polarization
    - Interference and coherence
    - Transmission and absorbance
    - Scattering
    - Illumination and brightness
      - Radiometry
      - Photometry
  - Special properties
    - Fluorescence
    - Photoelectric effect
    - LASER
- Visible light versus human eye

INTRODUCTION

Light is an electromagnetic energy. The visible portion of the light which lies in between the ultraviolet and infrared wavelengths is the one which gives us the sensation of seeing the objects. This visible spectrum has seven colors represented as VIBGYOR, an acronym of Violet, Indigo, Blue, Green, Yellow, Orange and Red. To understand the light we need to look into the history of nature of light.

History of Nature of Light

- ***Particle theory of Newton*:** In the year 1675, Sir Isaac Newton postulated that light emits from a source in the stream form and is made up of minute particles called corpuscles. These corpuscles move in the air medium unaffected by gravity and give the feeling of sight when enters the eye. Newton's theory was able to describe the properties like propagation of light in per pulse; whereas same laser beam with 50 mW power pulse for 0.2 second interval will deliver energy of 10 mjoule per pulse.

Tissue interactions of laser

Light energy had been used therapeutically to heat and to alter the target tissue permanently much before the invention of laser; however, laser does these tissue interactions in more controlled and precise way. Various tissue effects seen by laser beam are

- Photocoagulation
- Photodisruption
- Photoablation

Selective absorption of light energy and then conversion of this light energy into heat, which subsequently produces permanent structural changes in target tissue, is termed ***photocoagulation***. The process of photocoagulation and its therapeutic results are dependent on laser wavelength and laser pulse duration. At present several lasers clinically used for photocoagulation are blue–green (488–514 nm), argon, krypton red (647 nm), dye, diode infrared (810 nm), holmium and gallium arsenide.

The process where high peak powered pulsed lasers are used to ionize the target and rupture the surrounding tissue, is termed ***photodisruption***. In clinical practice photodisruptive laser is utilized like a virtual microsurgical scissor, cutting through ocular tissues such as lens capsule, iris, vitreous strands and inflammatory membranes; without disturbing the surrounding tissue. Currently Nd: YAG (1024 nm) laser is used as photodisruptive laser in ophthalmology practice.

A laser tissue interaction process where high powered ultraviolet laser pulse precisely engraves the cornea is termed ***photoablation***. During photoablation the energy state of only a single photon of ultraviolet light having wavelength 193 nm will exceed the covalent bond strength of corneal protein. A submicron layer of cornea is removed precisely by absorption of these laser pulses; without opacifying the adjacent corneal tissue because of the relative absence of thermal injury. Commonly used lasers for photoablation in ophthalmology are excimer ultraviolet (193 nm), holmium: yttrium-aluminum-garnet (Ho: YAG) infrared laser (2060 nm), erbium: yttrium-aluminum-garnet (Er: YAG) infrared laser (2940 nm) and CO_2 (10,600 nm) infrared laser.

Note: Pulsed Nd: YLF (1053) infrared laser is used in plasma ablation of tissue.

Clinical Applications

Lasers are used extensively in various ophthalmic conditions, for both diagnostic and therapeutic purposes.

VISIBLE LIGHT VERSUS HUMAN EYE

Light sensitivity of human eye

- Human eye is very sensitive to a wide range of light and can see light energy from a few photons (5–9) per milliseconds up to bright sunlight; means a difference of 10^{15} in sensitivity.
- Visible light is appreciated by human eye in the form of pulses or images. These images or light pulses repeatedly appear and/or disappear in front of the eyes. Consider a situation when the repetition frequency of these pulses crosses a specific threshold level; then the eye cannot feel two pulses as separate, rather feel them as single. The phenomenon where eye feel of the pulses of light as single is termed persistence of eye for light or image. Persistence of fovea for red light is 0.0209 second; for yellow light 0.0179 second; for blue–violet light is 0.0349 second. Hence on average light persistence time (time interval between two successive light pulses) is between 0.02 and 0.04 second.
- Daylight vision also called photopic vision, requires surrounding light levels in high range (luminance more than 3 cd/m^2); vice versa night time vision also called scotopic

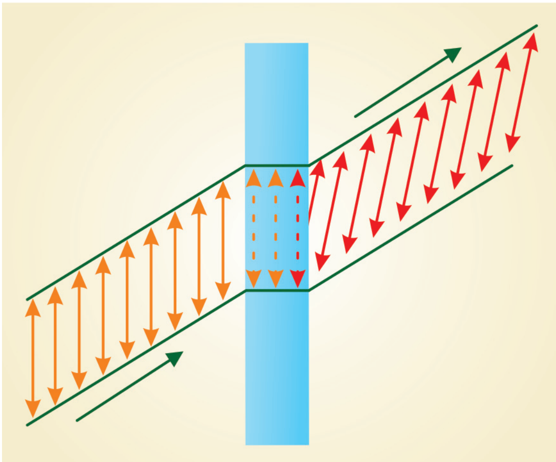


Fig. 2.18: Light wave moving oblique to medium

Refractive Index

As light travels through a medium it gets resistance from that medium also. The retardation of speed of light ray will depend on amount of resistance exerted by medium. More is the resistance exerted by medium, more will be decrease in the speed of light. This retardation of speed in turn is directly proportional to the amount of bending of light ray, means if there is more reduction in the speed of light ray, then emerging light ray will bend more acutely.

Property of any substance by which resistance is given to the light ray is called optical density of that substance. In simpler terms, if the density of the medium is more, then this medium will exert more resistance on the light ray as compared to less dense medium. For all practical aspects we know that the light usually travels through the air which is known as universal medium. Hence the optical density of air as a medium is considered standard and optical densities of various substances are compared with air. Similarly, the refractive power or bending capacity of any substance is also compared with refractive power of air. Thus, optical density which determines bending capacity of a substance is called refractive index of that substance. In other way, refractive index of substance indicates the measure of the bending of light beam when these light rays passes across one medium to another medium.

For all practical purposes the refractive index of air is taken as 1.00 and other substances are compared with air. For example, water has refractive index of 1.33, crown glass of 1.5, cornea of 1.376 and crystalline lens has refractive index of 1.41.

Laws of Refraction

- The incident light ray, the refracted light ray and the normal all are situated in the same plane.
- Incident light ray and refracted light ray lie opposite of the normal.
- **Snell's law** states that ratio of sin *i* (means sine of incidence angle) and sin *r* (means sine of refraction angle) is always a constant for all angles of incidence. Therefore,

$$\text{Constant (K)} = \frac{\sin i}{\sin r}$$

Here i = angle of incidence

r = angle of refraction

or $$\frac{\sin i}{\sin r} = \frac{\mu'}{\mu} = \text{Constant (K)}$$

Where, μ is the refractive index of medium 1 and μ′ is the refractive index of medium 2.

When one of these mediums is air (say μ), then this constant (K) becomes the refractive index of second medium (μ′); since refractive index of air is 1.00.

There are three factors which can influence the amount of refraction or degree of bending of light beam:

- ***Refractive index of the medium:*** Through which the light ray is travelling.
- ***Angle of incidence of ray (i):*** Higher is the value of incidence angle (*i*), greater will be the refraction or bending of the light ray. It means more obliquely the rays strike, more will be bending.
- ***Wavelength of light ray:*** Shorter is the wavelength of light ray, more will be the degree of its bending. For example, blue

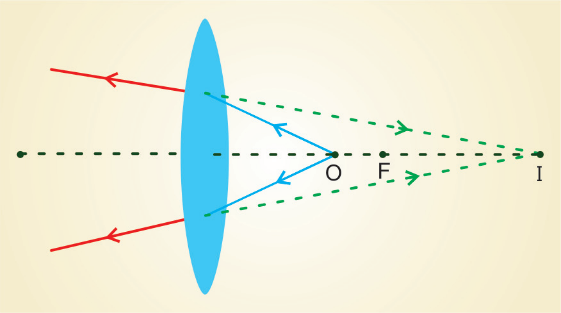


Fig. 3.12: Point light source between focal point and convex lens

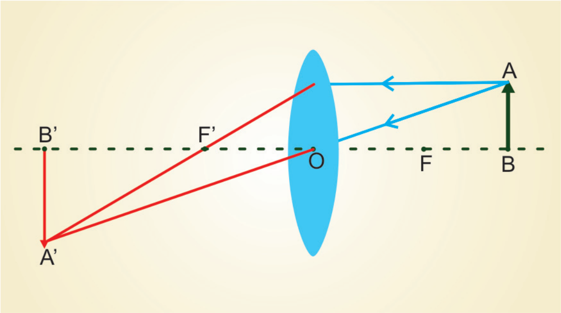


Fig. 3.13: Object AB between centre of curvature and focal point

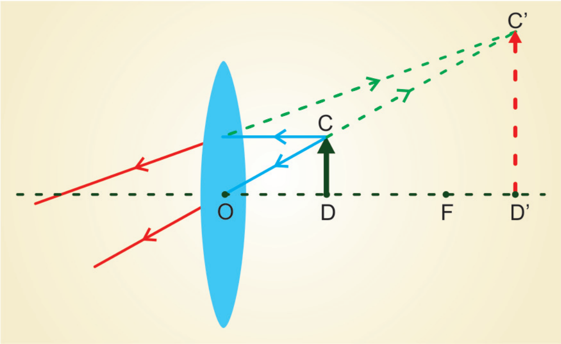


Fig. 3.14: Object CD between focal point and convex lens

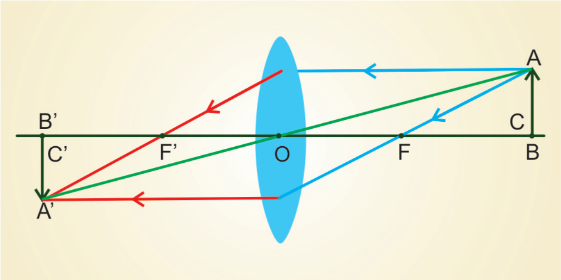


Fig. 3.15: Object AB at centre of curvature

Concave lens: Concave lenses can be considered as combination of two prisms, which are joined apex to apex as shown in Fig. 3.16.

Again by the rule of refraction through a prism the light ray bends towards base of the prism, so in case of a concave lens both the incident rays bend towards the base of prism or diverge from each other as shown in Fig. 3.17.

As we can see in Fig. 3.17, that the parallel rays falling on a concave lens are getting diverged from each other, thus these lenses are also called as divergent lenses. Similar to convex lens a central ray of light also passes through the concave lens unaffected and goes straight through the lens. The line in which this unaffected ray moves is called the

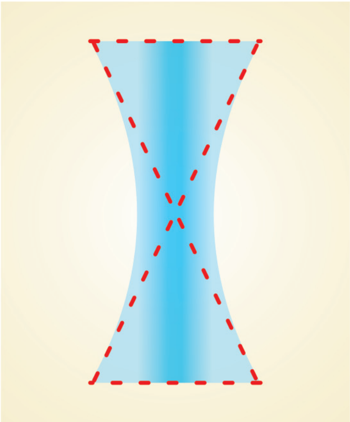


Fig. 3.16: Apex to apex joining of two prisms, making a concave lens

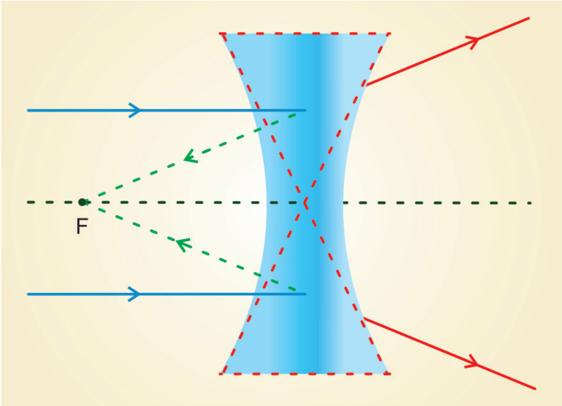


Fig. 3.17: Refraction through concave lens