Tullu Dimtu General Secondary School

Unit 6

Electromagnetic wave

Grade 10

Grade 10 Physics note	Unit 6 Electromagnetic wave	With Clear Explanation	2025

By Mr. Ibsa Dereje

Unit 6 Electromagnetic Waves and Geometrical Optics

Introduction

In this unit you will study electromagnetic waves and geometric optics. Electromagnetic wave is a wave that propagates by **simultaneous** ***periodic vibration*** of **magnetic field intensity** and **electric field intensity**. Optics is study of how light interacts with material. Geometric optics deals with shape of material and angle at which light rays hit it.

Optics- science concerned with the genesis and propagation of light and other phenomena closely associated with it. **Physical Optics** and **Geometrical Optics** are the two major branches of optics. **Physical Optics**- *deals primarily with the nature and properties of light itself.* **Geometrical Optics**- has to do with the principles that govern the image forming properties of ***lenses***, ***mirrors***… and also optical data processing.

Wave is a disturbance or vibration that transfers energy progressively from one point to another. Waves that need material (solid, liquid or gas) medium for their propagation are called **Mechanical Wave**. **Electromagnetic** Wave doesn't need material medium for its propagation. **Light**, **radio wave, microwaves and X-ray** are some examples of electromagnetic wave; while: **sound, ultrasound, water wave, spring wave and vibration of object** are examples of mechanical wave.

Objectives

By the end of this unit, you should be able to:

- **Understand the concept of Electromagnetic waves;**
- **Understand the properties and transmission of light in various media and their applications;**
- **Investigate the properties of light through experimentation and illustration using diagrams and optical instruments;**
- **Predict the behavior of light through the use of ray diagrams;**
- **Appreciate the contributions of optics in our day to day life.**

Revision on Wave

Wave is a disturbance or vibration that transfers energy progressively from one point to another. Common characteristics that all waves share are discussed below.

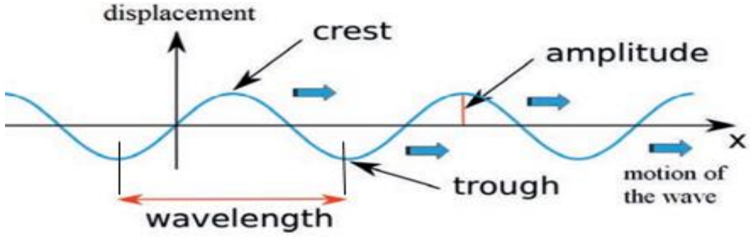


Figure 6.1 Characteristics of wave.

Rest position:	Rest position is the undisturbed position of particles when they are not vibrating.
Displacement (d):	Displacement is the distance that a certain point in the medium has moved from its rest position.
Trough:	Trough is the lowest point below the rest position.
Crest:	Crest is the highest point above the rest position.
Period (T):	Period is the time for one complete cycle of the periodic motion. It is also defined as the time taken for one complete wave to pass a given point.
Amplitude (A):	Amplitude is defined as the maximum displacement from equilibrium position. Amplitude is denoted by the symbol A and measured in meters (m).
Wavelength (λ):	Wavelength is defined as the distance between identical points on adjacent waves. For example, the distance between two adjacent crests or troughs of a wave is one wavelength. Wavelength is denoted by Greek letter λ (lambda).

Frequency, Wave Speed and Radiant Energy	
Frequency (f):	Frequency, denoted by symbol f, of a wave is defined as the number of complete cycles passing a given point per unit time. The higher the frequency, the greater the number of waves per second will be. A common unit for frequency is one cycle per second. This is defined as one Hertz (Hz). **F = 1/T** **T =1/f** **1Hz=1 cycle/s**
Wave speed (v):	Wave speed is defined as the distance the wave travels in one second. It is denoted by the symbol V and like all speeds it is measured in meter per second. **Wave speed = wavelength x frequency** $V = \lambda f$
Radiant energy (E)	Energy that is carried and transferred by electromagnetic wave. Electromagnetic wave transfers energy in the form of Photons (small packet of energy) energy contained within a photon is calculated by equation, $E = hf$ where h is Planks constant and f is frequency. Planks constant, **$h = 6.626 \times 10^{-34}$ J.s $= 4.09 \times 10^{-15}$ eV.s**. [electrovolt (eV) is unit of energy, $1eV = 1.62 \times 10^{-19}$ J]

Common properties of wave:

All waves have four common properties in nature. These are: reflection, refraction, diffraction and interference.

1	**Reflection**	Reflection is change in direction of wave at a surface that causes them to move away from the surface. When waves hit a plane surface, it will reflect off it. The frequency, speed or wavelength of the wave remains unchanged in reflection.
2	**Refraction**	A wave will become refracted if it travels from one medium to another medium with a different optical density. The speed of the wave changes and that causes a change in direction of the wave. When wave gets refracted, its speed, direction and wave length will be changed. But frequency remains unchanged. The extent of diffraction is dependent on the size of the gap in comparison to the wavelength of the wave.
3	**Diffraction**	Diffraction is the process by which waves spread out as a result of passing through a narrow gap or across an edge of an object.
4	**Interference**	Interference is intersection of two or more waves while moving along different path and meat. There are two types of interference: constructive interference and destructive interference. A. Constructive interference is interaction of waves by which they re-enforce each other. Their amplitudes get combined. And the combined amplitude is greater than that of any one of the waves. B. Destructive interference is interaction that makes the waves to cancel-out (neutralize) each other. This means combined amplitude is zero.

Transverse Wave and Longitudinal Wave:

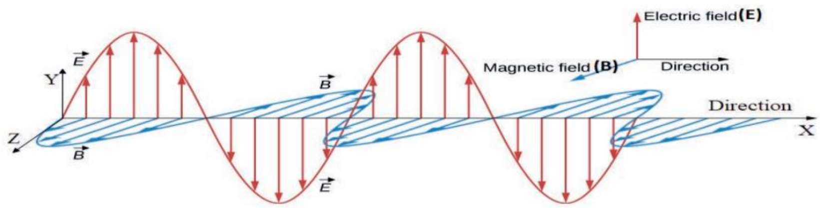
- Longitudinal wave is a wave that propagates in the direction of its vibration (oscillation). This means direction of propagation is parallel to direction of oscillation in longitudinal wave. E.g. sound wave, …
- Transverse wave is a wave that propagates at right angle to direction of its oscillation. This means direction of propagation is perpendicular to direction of oscillation in transverse wave. E.g. electromagnetic waves, water wave…

Mechanical Waves and Electromagnetic Waves:

- Mechanical wave is a wave that propagates in a medium and takes a form of an elastic deformation (of vibration of pressure) or vibration of electric potential (V) within the particles of the medium. Therefore mechanical wave can't propagate in vacuum. E.g. sound wave, water wave, spring wave…
- Electromagnetic wave: is a wave that propagates by simultaneous periodic vibrations of electric field intensity and magnetic field intensity. Since neither magnetic field nor electric field need material **medium for their** appearance, electromagnetic wave can propagate in vacuum also in medium. E.g. Visible light, X-ray, radio wave…

6.1. Electromagnetic Waves

Electromagnetic wave: is a transverse wave that propagates by simultaneous periodic vibrations of electric field intensity and magnetic field intensity.
In electromagnetic wave all magnetic field, electric field and direction of propagation (direction of wave speed) are perpendicular to each other. For instance: if magnetic field vibrates along Z- axis (on ZX-plane) and electric field intensity vibrates along X-axis (on XY-plane) then the electromagnetic wave propagates along X-axis. This can be seen in the following figure:



Electromagnetic waves are emitted from atoms. Electromagnetic waves can be emitted from shell of an atom or from the nucleus.

- Electromagnetic radiations are emitted from the shell of an atom when there is exchange in energy state of the electrons. Example: X-ray, Ultraviolet, visible light, infrared, microwave and radio wave. Electrons in an atom can move between different energy levels by absorbing or releasing energy in the form of electromagnetic ration. Electron jumps from low energy level to higher energy level by absorbing electromagnetic radiation. And the electron that absorbed electromagnetic radiation and jumped to the higher energy level is said to be in excited state. Electron jumps from higher energy level to the lower energy level (stable position) by emitting (releasing) electromagnetic radiation. This is how electromagnetic radiation is released from sell of atoms.
- Electromagnetic wave is released from shell of atom when electrons jump from higher energy level to lower energy level.
- Electromagnetic radiation can be released from unstable nucleus (nucleus of radioactive isotopes of atoms). Unstable nucleus becomes stable by emitting electromagnetic-radiation [that is Gamma-ray] or particle-radiation [that is alpha-ray or beta-ray].
- Note that: alpha ray and beta-ray are not electromagnetic radiation since they are particles.

Radiant Energy from the Sun

- Radiant energy is the energy carried by electromagnetic wave.
- Sun emits electromagnetic waves that travel through space and reaches the earth.
- Most (92%) of radiant energy from the sun is carried by visible light and infrared wave.
- Small amount of radiant energy reaches the earth in the form of ultra violet.

6.2. Electromagnetic Spectrum (EM-spectrum)

EM-spectrum is range of all possible frequencies of electromagnetic radiation. It includes every EM-radiation from radio wave (the largest wave length) to gamma rays (the shortest wave).
Table 3: Electromagnetic Spectrums in the order of ascending frequency Hint: $1J = 6.173 \times 10^{18}$eV

No	Spectrum	Frequency (Hz)	Wave length (m)	Energy (J)	Energy (eV)
1	Radio wave	$< 3 \times 10^9$	$> 1 \times 10^{-1}$	$< 2 \times 10^{-24}$	$< 1.235 \times 10^{-5}$
2	Microwave	$3 \times 10^9 - 3 \times 10^{11}$	$1 \times 10^{-3} - 1 \times 10^{-1}$	$2 \times 10^{-24} – 2 \times 10^{-22}$	$1.235 \times 10^{-5} – 1.235 \times 10^{-3}$
3	Infrared	$3 \times 10^{11} - 4 \times 10^{14}$	$7 \times 10^{-7} - 1 \times 10^{-3}$	$2 \times 10^{-22} – 3 \times 10^{-19}$	$1.235 \times 10^{-3} – 1.85$
4	Visible light	$4 \times 10^{14} - 7.5 \times 10^{14}$	$4 \times 10^{-7} - 7 \times 10^{-7}$	$3 \times 10^{-19} – 5 \times 10^{-19}$	1.85 – 3.1
5	Ultraviolet	$7.5 \times 10^{14} - 3 \times 10^{16}$	$1 \times 10^{-8} - 4 \times 10^{-7}$	$5 \times 10^{-19} – 2 \times 10^{-17}$	3.1 – 123.5
6	X-ray	$3 \times 10^{16} - 3 \times 10^{19}$	$1 \times 10^{-11} - 1 \times 10^{-8}$	$2 \times 10^{-17} – 2 \times 10^{-14}$	123.5 – 123456.79
7	Gamma ray	$> 3 \times 10^{19}$	$< 1 \times 10^{-11}$	$> 2 \times 10^{-14}$	> 123456.79

Table 4: electromagnetic spectrums: source, frequency, wavelength, usage and disadvantage/side-effect

1	Radio wave	Source	Stars, sparks, lightning, … Various transmitters (depending on their wave length)
		Frequency	500kHz – 1000MHz
		Wavelength	1m up to thousands of mater
		Usage	For communication (police radio, military air craft, TV-transmission…)
		Side effect	Large dose may cause: cancer, leukemia, and other disorders
		safety	Shielding with conductor while near the transmitters.
2	microwave	Source	Stars Various types of transmitters(depending on wavelength) [microwave is basically extremely high frequency radio wave]
		Frequency	In the order of 10^9-10^{11} Hz
		Wavelength	Usually a couple of centimeters
		Special property	It can be received by antenna It causes water and fat molecule to vibrate which makes the substance hot.
		Usage	For communication: in mobile phone, In radar (used by air craft, ships, and weather forecaster) In traffic speed cameras For cooking (In microwave oven)
		disadvantage	Prolonged exposure causes: * cataracts (clouding of cornea in eye) * brain damage
		safety	• Keep calls (mobile phone call) short. • Use headphones (or earphones) [ear craft technicians wear special suit that reflect microwaves while working on ear craft carrier decks]
3	Infrared wave	Source	Stars, lamps, flames, anything that is warm (including human body)
		Frequency	In the range of 10^{11}-10^{14}Hz
		Wavelength	Millimeters to micrometers.
		properties	They are just below visible red light in the EM-spectrum. They are given off by hot objects and causes sense of warmth on our skin. They can be received by Infrared-cameras
		Usage	In infrared-camera (camera that works with infrared ray rather than Visible light) To provide night sights for weapons with infrared detector In weather forecasting (photograph of patters of cloud are taken by infrared camera) In remote controls (for television) To measure temperature (using infrared-thermometer)
		disadvantage	Negligible, simply hot
		safety	Stay away or use thermal insulating shielding
4	Visible Light	Source	Sun, star, bulbs, lamps, fire, any glowing object
		Frequency	4 x 10^{14}Hz – 7 x 10^{14}Hz
		Wavelength	400nm – 700nm
		Usage	To see things (visible light produces sensation of vision in our eye) In photosynthesis In solar (Photovoltaic): cell to generate electric energy
		disadvantage	Intense (very bright) light can damage retina in eye.
		safety	Do not look into intense light
5	Ultraviolet	Source	Sun, UV-lams, stars, … very hot bodies
		Frequency	7.5 x 10^{14}Hz - 3 x 10^{16}Hz
		Wavelength	400nm – 0.6nm
		Usage	To detect forged bank notes To harden type of dental filling in dental clinic In industries to kill microbes and sterilize products To sterilize surgical equipment, and the air in operating theater Suitable dose helps body to synthesize vitamin D

			To make clothes glow in discos To treat Vitamin D deficiency and some skin disorder To read texts written in security marker
		disadvantage	Damage on retina Sun burn Skin cancer Cataract
		safety	Use eye glass that protect eye from UV-ray. Apply body lotions and ointments on your skin.
6	X-ray	Source	Stars and nebula X-ray machine (by firing electrons at a target)
		Frequency	3×10^{16}Hz - 3×10^{19}Hz
		Wavelength	0.01nm – 10nm
		Usage	In medicine: - medical diagnosis using X-ray scan, CT-scan, Mammography… - Treatment: to treat cancer
			In industry and construction: to see inside of thing and structures
			In airport: for security check
			In astronomy: to detect x-ray emitting objects in the universe.
		disadvantage	Cell damage, cancer
		safety	Use shielding Reduce length of time of exposure Stay away from the source (increase distance)
7	Gamma-ray	Source	Stars, Radioactive sources (radioactive isotopes such as: potassium-40, Caesium-137, barium-137, cobalt-60, iridium-192, Iodine-131, Lanthanum-140 …)
		Frequency	More than 3×10^{19}Hz
		Wavelength	Less than 1picometer
		properties	It penetrates most of materials and quite difficult to stop It can't penetrate thick lead plate and concrete It kills living cells and microbes
		Usage	In medicine: - for medical diagnosis (in PET-scan and Gamma-cameras) - to treat malignant and cancerous tumors (in Gamma-knife surgery) - to sterilize medical equipment (in medical centers)
			In food processing: to sterilize food products by killing microbes and used to keep the . food fresh for longer (the sterilized food is called irradiated food)
			In industries: radio-active tracer substances can be put in to pipes and machinery then where the substance go can be detected
		disadvantage	Cell damage Variety of cancers Mutations in growing tissues (specially, in unborn babies)
		safety	Use shielding Reduce length of time of exposure Stay away from the source (increase distance)

6.3. Light as a wave

Light have dual nature: particle nature and wave nature. In this topic we study wave nature of light. Light [visible light] is an electromagnetic wave that can be seen with eye. Visible light consist about eight narrow regions of spectrums that have different colors. Electromagnetic spectrums within range of visible light are: red, **orange**, **yellow**, green, cyan, blue, indigo and violet; respectively in ascending order of frequency.

Table 5: range of visible spectrum

	Color	wavelength	Frequency (in Terahertz, THz)	Energy of photon
1	Red (limit)	700nm	429	1.77 eV
	Red	650nm	462	1.91 eV
2	Orange	600nm	500	2.06 eV
3	Yellow	580nm	516	2.14 eV
4	Green	550nm	545	2.25 eV
5	Cyan	500nm	599	2.48 eV
6	Blue	450nm	666	2.75 eV
7	Indigo	425nm	700	2.86 eV
8	violet	400nm	750	3.10 eV

Medium of propagation

Like any electromagnetic wave light can propagate through vacuum and some material medium. Light travels in straight line, even though its direction and speed changes when it passes from one medium to another. Light propagates in vacuum with the highest speed called ***speed of light (C)*** which approximately ***3 x 10^{8}m/s***. This means light travels 300,000km within a second. Sun light reaches our planet earth within about 11.5 minute. Light propagates with lower speed when it travels in material medium. Materials that allow light to travel through them are called transparent while materials that doesn't allow light to pass through them are called opaque.

- Transparent: materials through which light can propagate. E.g. Air, glass, water…
- Opaque: materials through which light can't propagate. E.g. Ceramic, wood, stone, iron slab,

Speed of light

Speed of light is 2.99792458 x 10^{8}m/s. all EM-spectrum with this speed(C) in vacuum.

Wave speed = wave length x frequency

$V = \lambda \times f$

For EM-spectrum, V = C

$C = \lambda \times f$

$\Rightarrow \lambda = \frac{C}{f}$

6.4. Laws of Reflection and Refraction

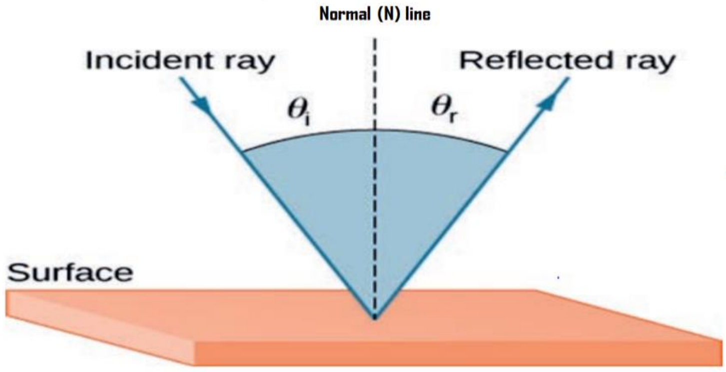
Reflection of Light

Reflection is change in direction of light rays at a surface that causes them to move away from the surface.

- Reflection of light: is return of light that occurs when a ray of light approaches (collides with) smooth surface and bounces back.
- Incident ray (i): is an incoming ray ⇨ incoming ray that collides with the surface.
- Reflected ray (r): is a ray that is bounced back ⟶ a light ray that is moving away.
- Normal (N): is an imagery line that is perpendicular to the surface.

- Normal (the normal to the surface, N) crosses the surface at the point where incident ray *reaches* the surface and reflected ray *leaves* the surface.

- Angle of incidence (θ_i): is angle between the incident ray (i) and the normal (N)
- Angle of refraction (θ_r): is angle between the refracted ray (r) and the normal (N)

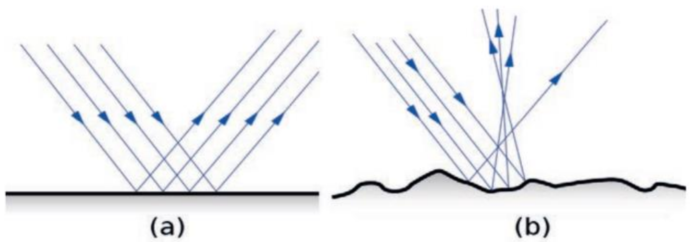


The law of reflection states that:

I. Angle of reflection (θ_r) is equal to angle of incidence(θ_i)
II. The incident ray, reflected ray and normal to the surface at the point of incidence all lie in the same plane.

Speculated reflection and diffuse reflection

Specular reflection: - reflection of light from smooth shiny surface.
In speculated reflection all reflected light ray moves in the same direction.
Diffuse reflection: - reflection of light that is sent-out in a variety of directions when light rays bounces of rough surface.

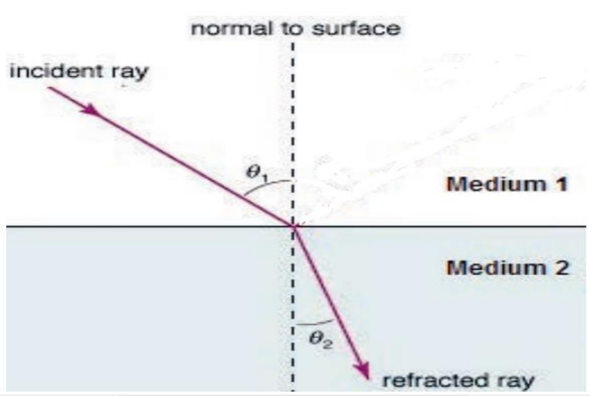


(a) Specular and (b) diffuse reflection.

Refraction of Light

Light does not travel in the same direction in all media. When light travel from one medium into another, (E.g. from air to glass) direction of its propagation in the second medium changes. This phenomenon is called refraction of light.

- Refraction is bending of light as it moves from one optical medium to another.
- Refraction happens in transparent materials such as: diamond, quartz, glass, water and ice.
- Incident ray (i): - is the light ray that comes through the first medium.
- Refracted ray ($\grave{r}$): - light ray that is passed to the second medium changing its direction.
- Normal (N): - imaginary line perpendicular to layer (surface) between the mediums.



- Light ray bends toward the normal when it passes from optically less dense medium to optically denser medium.
- Light ray bends away from the normal when it passes from optically denser medium to optically less dense medium.

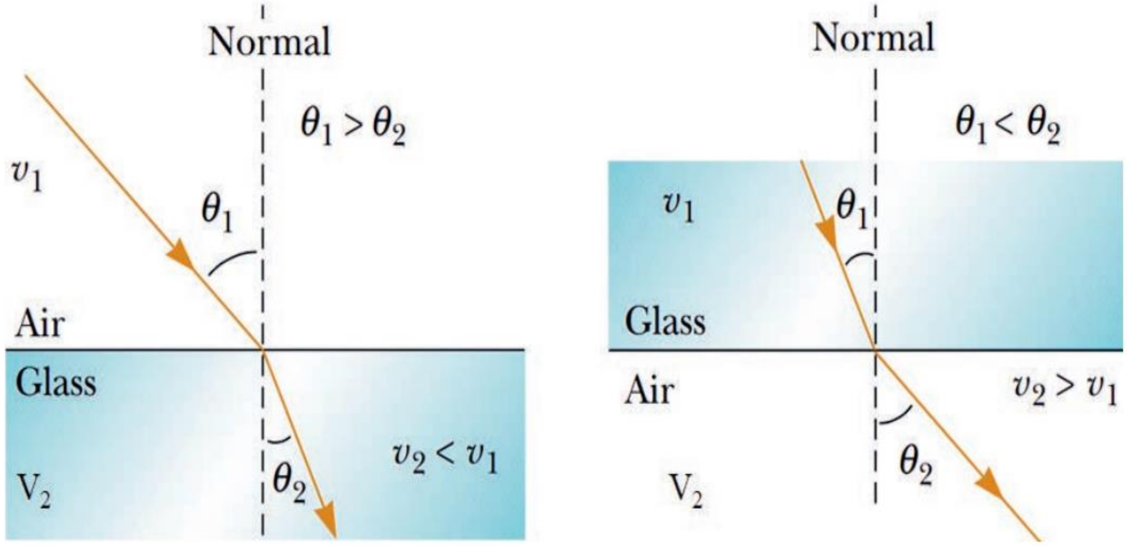


Figure Bending of a light ray (a) toward the normal and (b) away from the normal.

Laws of refraction of light

I. Incident ray, refracted ray and the normal to the interface of two transparent media at the point of incidence all lie in the same plane.

II. Ratio of sine of the angle of incidence to the sine of the angle of refraction is constant. If θ_1 is angle of incidence and θ_2 is angle of refraction, then:

$$\frac{\sin\theta_1}{\sin\theta_2} = constant$$

Refractive Index

Speed of light and degree of bending of the light depend on the refractive index of the material through which the light passes.

Refractive index is ratio of speed of light in one medium to speed of light in the second medium.

Refractive index of medium-2 with respect to medium-1 is given by:

$$n_{21} = \frac{speed\ of\ light\ in\ medium1}{speed\ of\ light\ in\ medium2} \qquad n_{21} = \frac{v_1}{v_2}$$

Refractive index of medium-1 with respect to medium-2 is given by:

$$n_{12} = \frac{speed\ of\ light\ in\ medium2}{speed\ of\ light\ in\ medium1} \qquad n_{12} = \frac{v_2}{v_1}$$

Absolute Refractive Index (n)

Absolute refractive index is refractive index of medium with respect to a vacuum.

Mathematically: $$Absoute\ refractive\ index = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ the\ medium}$$

$$n = \frac{c}{V}$$

Absolute refractive index of a material medium is intrinsic prorerty of the material.

Table 6: Absolute refractive index of some material mediums

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Canada Balsam	1.53
Ice	1.31		
Water	1.33	Rock salt	1.54
Alcohol	1.36		
Kerosene	1.44	Carbon disulphide	1.63
Fused quartz	1.46	Dense flint glass	1.65
Turpentine oil	1.47	Ruby	1.71
Benzene	1.5	Sapphire	1.77
Crown glass	1.52	Diamond	2.42

Snell's Law

Snell's law is named after the Dutch mathematician Willebrord Snellius. It describes how light waves change direction when they pass from one medium to another.

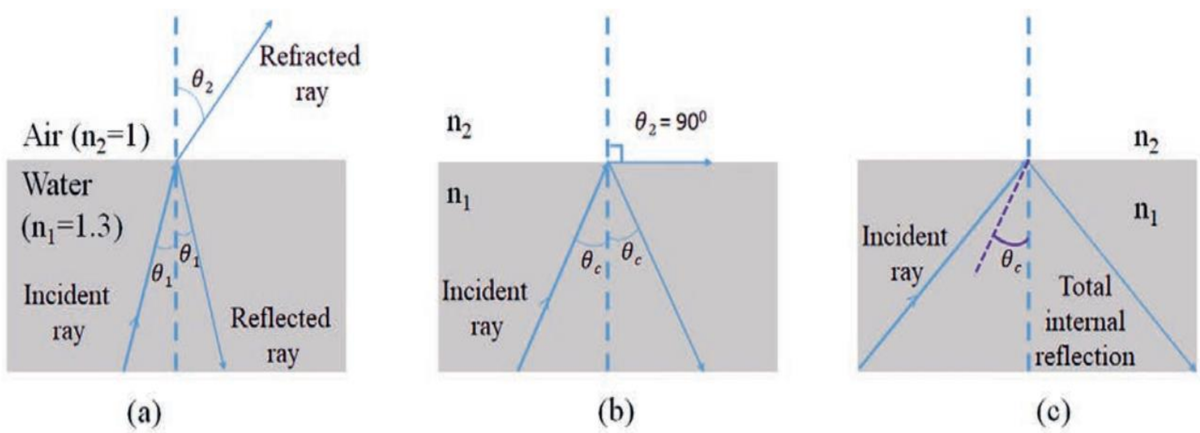
Snell's law states that the angle of incidence of a light ray is related to the angle of refraction by a ratio of the refractive indices of the two media. Mathematically,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Where, n_1= absolute refractive index of medium-1
θ_1= angle of incidence
n_2 = absolute refractive index of medium-2
θ_2 = angle of refraction

Total internal Reflection

- ✓ Total internal reflection is a phenomenon that occurs when a light ray travelling from one medium with a higher refractive index to a medium with low refractive index is reflected back into the higher refractive index instead of being refracted.
- ✓ Total internal reflection occurs when the angle of incidence is greater than the critical angle. Critical angle is an angle of incidence at which the refracted ray would be refracted at 90°.



- ✓ **Total internal reflection is powerful tool that can be used to confine and transfer light with undiminished intensity.**

Conditions for total internal reflection

1. **Light must travel from optically dense medium (e.i., a medium having a high refractive index) to an optically rare medium (a medium having a lower refractive index).**
2. **The angle of incidence in the denser medium must be greater than the critical angle.**

Critical angle

Critical angle is an angle of incidence at which angle of refraction is 90°.
Critical angle can be determined using Snell's law as follows:

$n_1 \sin\theta_1 = n_2 \sin\theta_2$ ------------------------ (Snell's law)
$n_1 \sin\theta_c = n_2 \sin 90^o$ --------------------- Angle of refraction is 90° if angle of incidence is critical angle (θ_c)
$n_1 \sin\theta_c = n_2\, x\, 1$ ----------------------------- $\sin 90^o = 1$
$\sin\theta_c = \frac{n_2}{n_1}$ ------------------------------------ dividing both sides by n_1
$\theta_c = \sin^{-1}(\frac{n_2}{n_1})$ ---------------------------------- solving for critical angle (θ_c)

Therefore, critical angle(θ_c) is calculated by equation:

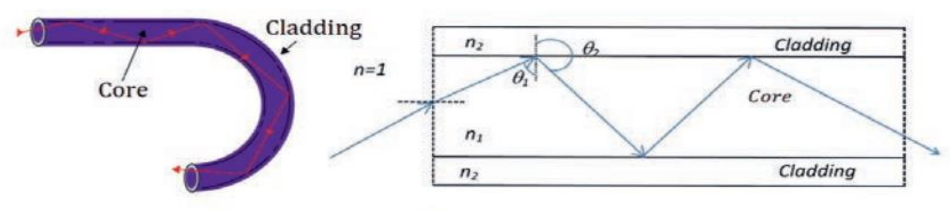
$$\theta_c = \sin^{-1}(\frac{n_2}{n_1})$$

Where, n_1 **= absolute refractive index of the optically dense medium (in which incident ray and reflected rays travel)**
n_2 **= absolute refractive index of the optically rare medium**

If angle of incidence of a given incident ray is greater than critical angle there will be no refracted ray. The incident ray will be reflected totally. This phenomenon is called total internal reflection.

Applications of total internal reflection in Fibre Optics

Fibre optics **(also fiber optics)** is a technology that uses thin strand of glass or plastic fibers to transmit data in the form of light.
Total internal reflection is the key principle that allows fiber optics to work effectively in transmitting data in the form of light.
Optical fiber is cable that is made up of glass or plastic strand and used to transmit data in the form of light.
Optical fibers are thinner than human hair.
In optical fiber, total internal reflection occurs when light travelling through the core of the fiber is reflected back into the core at interface between the core and cladding rather than being refracted out of the fiber.



(a) A light in glass fiber pipe (b) Light emerging from a bundle of glass fibers.

When light is incident on one end of the fiber at small angle it goes multiple total internal reflections along the fiber. Light finally emerges with undiminished intensity to other end. Even if the fiber is bent this process is not affected.

Applications of Optical Fibers

A, In Telecommunication

Optical fibers are used in telecommunication to transfer data over large distance. The following are features of optical fiber that makes preferable than copper-cable (even any electric conducting cable):

A. **Signal transmission**: - total internal reflection insures light signals remain confined with the core of the fiber, allowing for efficient transmission of data over long distance without significant loss of signal strength. This means, information is transported with minimal loss of data.
B. **Signal integrity: -** by keeping the light signals within the core through total internal reflection, fiber optics cab maintain signal integrity and prevent interference or distortion of data being transmitted.
C. **Band radius: -** total internal reflection allows optical fiber to be bent without losing signal strength or quality. This flexibility in bending the cables is crucial for installation in tight spaces or around corners.
D. **Data security: -** the phenomenon of total internal reflection in fiber optics makes it difficult for external sources to intercept or tap into the transmitted data, enhancing the security of communication over fiber optics networks.

E. **Data transferring speed:** - data is transmitted from one end of the optical fiber to another in the form of laser pulse (monochromatic narrow intense light). Optical fiber transfers data faster than copper-cable (which transfers data in the form of electric pulse); since, light travels much faster than electric current.

B, In medicine

1. Endoscope:

An endoscope is medical instrument that uses fiber optics and small camera to visualize and examine the inside of the body. The main part of endoscope is optical fiber. Endoscope is used in the following medical procedures.

- To examine the inside of a patient's stomach (gastrointestinal) by inserting the endoscope down the patient's throat.
- To examine respiratory system (including bronchi) and urinary tract
- In neurosurgery: - to treat variety of brain and spinal disorders.

The dispersion of light

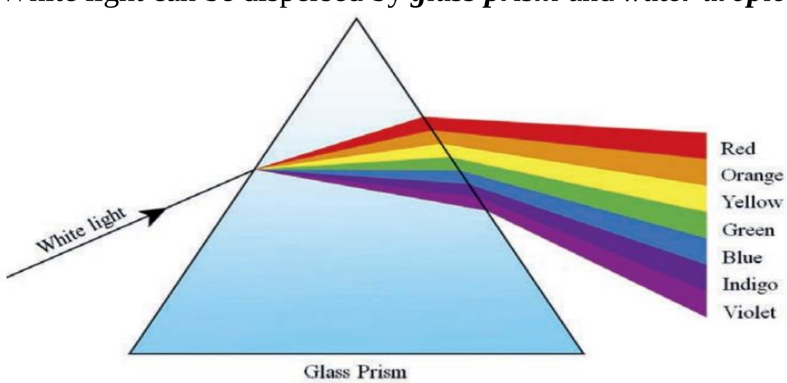
Dispersion is splitting of light into components depending on their wavelength. White light consists of wide range of visible light spectrum. Through mechanism of dispersion white light can be split into narrow range spectrum (monochromatic = single color). These monochromatic spectrums are: red, orange, yellow, green, blue, indigo and violet respectively, in the order of decreasing wave length.

Angle of refraction of the spectrum (color) is inversely proportional to wavelength (λ) **of its incident ray**

Mathematically, $\sin\theta_2 \propto \frac{1}{\lambda_1} \Rightarrow \theta_2 \propto \sin^{-1}(\frac{1}{\lambda_1})$ **Where,** λ_1 = wave length of incident spectrum.

So, light with large wavelength refracts least; and light with small wavelength refracts most. Therefore red light refracts least and ultraviolet refracts most.

White light can be dispersed by ***glass prism*** and ***water droplets.***



Rainbow

Rainbow is a natural spectrum appearing in the sky after a rain shower. Rainbow is formed by the dispersion of sunlight by tiny **water droplets** present in the atmosphere. Rainbow is always formed in the direction opposite to that of the sun. The water droplet acts like glass prisms. They refract and disperse the incident sunlight, then reflect it internally, and finally refract it again when it comes out of the raindrop. Due to the dispersion of light and internal reflection, different colors reach the observers' eye.

6.5. Mirror and Lenses

6.5.1. Mirror

Mirror is a reflective surface that surface that doesn't allow the passage of light and instead bounces it off, thus producing an image. There are two types of mirror: plane mirror and spherical mirror.

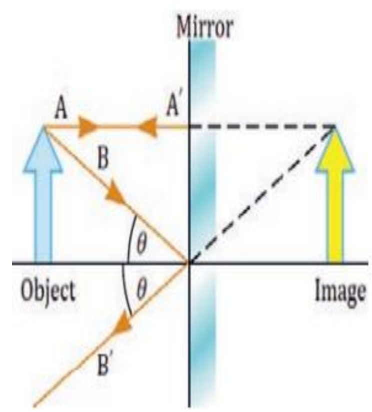
A. Plane mirror

Plane mirror is a mirror that has a flat reflective surface.

Image formation by plane mirror

Let's explain how image is formed in plane mirror using the diagram at right side.

The rays that originate from the object (arrow head) are labeled A and B while the reflected rays are labeled A′ and B′.
Ray A that leaves the arrow head and hits the mirror at angle of incidence of zero ($\theta = 0$) reflects directly back (ray A′). Because, $\theta_r = \theta_i = 0$.
Ray B hits the mirror at an angle and it is reflected at an angle of incidence [$\theta_r = \theta_i$ (the law of reflection)]; the reflected ray is labeled B′.
Notice that reflected rays A′ and B′ do not converge, but diverge (spread apart after reflection).
In this case image is formed by extending the reflected rays back to find the point where they appear to come from.
The point where they intersect is then the location of the image of the arrow head (show in yellow). This type of image is called virtual image.



Properties of image formed by plane mirror:

- It is virtual (appear to be behind the mirror).
- It is located at the same distance behind the mirror as the object distance.
- Height of image is identical to the height of the object.
- It is upright.
- Left to right inverted (image of a right hand is left hand).

Number of images formed by two plane mirrors

If two plane mirrors are placed inclined to each other at an angle, θ the number of images formed by mirror is:

$$N \approx \left(\frac{360^\circ}{\theta} - 1\right), if\ \left(\frac{360^\circ}{\theta}\right)\ is\ even\ integer$$

$$N \approx \left(\frac{360^\circ}{\theta}\right),\ if\ \left(\frac{360^\circ}{\theta}\right)\ is\ an\ odd\ integer.$$

- If θ is given by n is unique but, if n is given θ is not unique.
- The number of images seen may be different from the number of images formed and depends on the position of the observer relative to the object and mirrors. For example, if $\theta = 120^\circ$, the maximum number of images formed will be 3 but the number of images seen may be 1, 2 or 3.

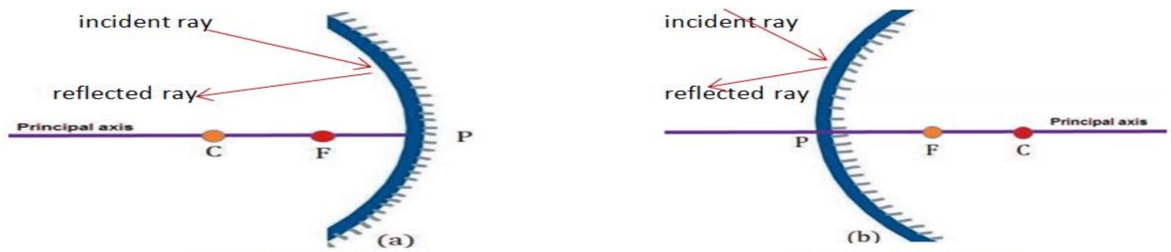
Uses of plane mirror

A plane mirror is used;

- In looking glasses
- For seeing round the corners.
- As reflector of light

Spherical Mirrors (Concave and Convex)

Spherical mirror is formed by the inside (concave) or outside (convex) surfaces of sphere.



Concave mirror Convex mirror

Concave Mirror (Converging Mirror):

Concave mirror is formed by inside of surface of sphere

Concave mirror has reflective surface that is curved inward, like a bowl of spoon.

Concave mirror cause light rays to came together (coverge)

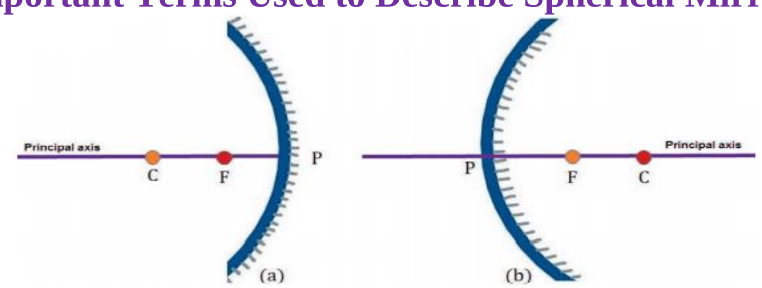
Convex Mirror (Diverging Mirror)

Convex mirror is formed by outside of surface of sphere

Convex mirror has reflective surface that is curved outward, like the back of spoon.

Convex mirror cause light rays to spreadout (diverge)

Important Terms Used to Describe Spherical Mirrors



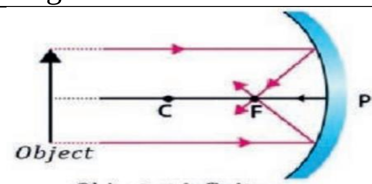
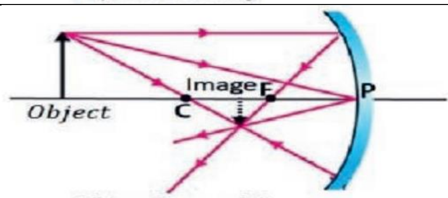
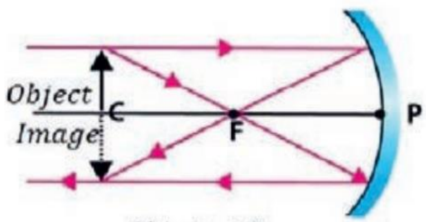
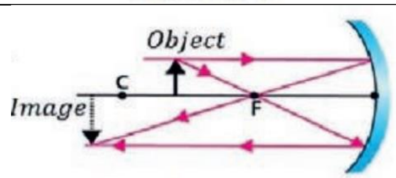
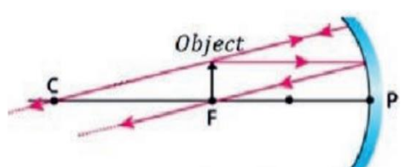
1. **Center of Curventure (C):** - It is center of the sphere of which the mirror is apart.
2. **Radius of Curventure (R):** - It is radius of the sphere of which the mirror is apart.
3. **Pole (P):** - It is the middle point of the reflecting surface of the mirror.
4. **Aparture:** - It is circular outline (or perifery) of the mirrror.
5. **Prirncipal Axis:** - It is straight line passing through the center of curventure and the pole.
6. **Principal Focus (F):** - It is a point from where a beam of incident light on spherical mirror parallel to the principal axis converges to (or appear to diverge)
7. **Focal Length (f);** - it is distance between pole and principal focus.
   - For spherical mirrors of small aparture, the radius of curventure is found to be equal to twice of the focal length. $\boldsymbol{R = 2f}$
   - Principal focus of a spherical mirror lies midway between the pole and center of cuventure.

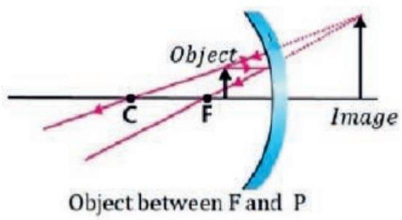
Ray Diagrams Used to Form Images by Spherical Mirror

1. **Ray Striking the Pole:** - a ray of light striking the pole of the mirror at angle is reflected back at the same angle on other side of the principal axis.
2. **Parallel ray:** - for a concave mirror, the ray parallel to the principal axis is reflecter in such a way that after reflection it passesthrough the principal focus. But for the convex mirror, the parallel mirror is so reflected that it appear to come from the principal focus
3. **Ray through center of curventure:** - a ray passing through a center of curventure hits the mirror at that point and retraces its path.

Position of image is formed by intersection of atleast two reflected rays.

Images Formed by a Concave mirror (converging mirror)

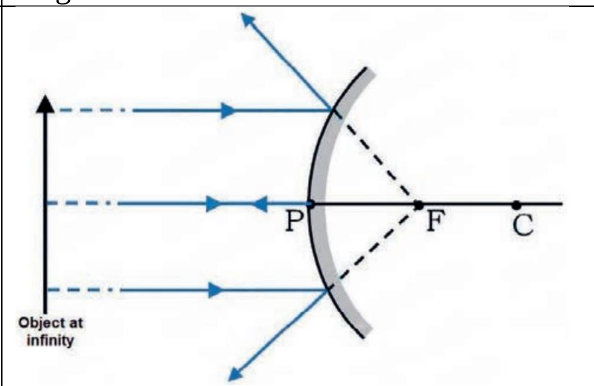
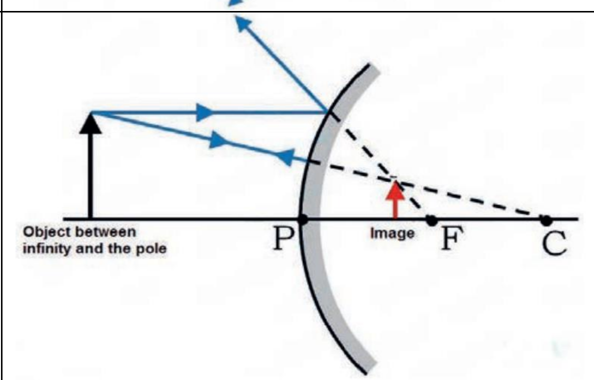
Image Formation by Concave (Converging) mirrors			
	Position of the object	diagram	Nature of the image
1	Object at infinity	 Object at infinity	Formed at F Real Inverted Highly diminished, point size
2	Object beyond C	 Object beyond C	Formed between C & F Real Inverted Diminished
3	Object at C	 Object at C	Formed C Real Inverted The same size
4	Object between C and F	 Object between C and F	Formed at beyond C Real Inverted Elarged
5	Object at F	 Object at F	At infinity Real Inverted Highly elarged

6	Objet between P and F		○ Formed at behind the mirror ○ Virtual ○ Erect (upright) ○ Elarged

Uses of Concave Mirror:

- In torches, search-lights and vehicles' head-lights.
- In shaving mirrors to see larger image of face.
- In dental clinic to see larger image of tooth.
- In solar furnaces to concentrate sun light to produce heat.

Image Formation by Convex (diverging) mirror

Image Formation by Convex (diverging) mirror		
Position of the object	diagram	Nature of image
At infinity		➡ Formed at F (behind the mirror) ➡ Virtual ➡ Erected (upright) ➡ Highly diminished, point size
Between infinity and the pole P of the mirror		▪ Formed at between P & F (behind the mirror) ▪ Virtual ▪ Erected (upright) ▪ diminished

Uses Of Convex Mirror

Convex mirror is used for rear view (wing) mirrors of vehicles.

Convex mirror are prefered because they always give an erect and diminished image.

Convex mirror has wider field of view as they are curved outward

Mirror formula and magnification

Terminology

- Object distance (u): - distance of object from the pole (of spherical mirror)
- Image distance (v): - distance of image from pole
- Focal length (f): - distance of principal focus from the pole.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ .... (mirror formula)}$$

Magnification power

Magnification power is relative extent to which the image of an object is magnified with respect to the object size.

$$magnicifation\ (m) = \frac{height\ of\ the\ image}{height\ of\ the\ object}$$

$$m = \frac{h'}{h} \qquad m = -\frac{V}{u}$$

Sign conventions for spherical mirrors		
Quantity	Positive when	Negative when
Object location, U	Object infront of the mirror (real object)	Object is back of the mirror (virtual)
Image location, v	Image infront of the mirror (real image)	Image is in the back of the mirror (virtual image)
Object height, h	Object is up-right	Object is inverted
Image height, h'	Image is upright	Imaage is inverted
Focal length, f	Mirror is concave	Mirror is convex
Magnificatio, m	Image is up-right	Imaage is inverted

Lenses

lense is curved piece of transparent material that is smooth and regularly shaped so that when light strikes it, the light refracts in a predictable and useful way.

Lense is formed by transparent material bound by two surfaces of which one or both are spherical.

Lens is bound by at least one spherical surface (the other surface would be a plane).

Convex (Converging) Lens

Convex (converging) lens is a lens that is formed by at least one spherical surface bulging outward on one side.

Convex (converging) lens is thicker at the middle compared to the edges.

Doubele convex lens (or simply, convexlens): - a lens that has two spherical surfaces bulging outward.

Plano-convex lens:- a lens that has one plane surface and one spherical surface bulging outward.

Concave (diverging) lens

Concave (diverging) lens is a lens that has at least one inwardly curved spherical surface.

Concave (diverging) lens is a lens that is thicker at the edge compared to the middle.

Double concave lens (or simply, concave lens) is bounded by two inwardly curved spherical surfaces.

Plano-concave lens: - is a lens that is bound by one plane surface and one inwardly curved spherical surface.

Important terms used to describe Lenses

- **Centers of curvature (C):** - centers of the sphere that form the lens. Lens has two centers of curvature **(C_1 & C_2)**
- **Principal axis:** - an imaginary line passing through the two centers of curvature.
- **Optical center (O):** - central point if a lens.

  A ray of light through optical center (0) of a lens passes without suffering any deviation
- **Aperture:** - effective diameter of the circular outline of the lens.
- **Principal focus (F):** - a point on principal axis where light rays after refraction from lens are converging to one point. A lens has two principal foci **(F_1 & F_2)**
- **Focal length (f):** - distance of principal focus from optical center of the lens.

Ray Diagrams used to form image in lens

1. A ray of light from the object, parallel to the principal axis, after refraction from a convex lens, passes through the principal focus on the other side of the lens as shown in Figure ** (a). In the case of a concave lens, the ray appears to diverge from the principal focus located on the same side of the lens as shown in Figure ** (b).
2. A ray of light passing through a principal focus, after refraction from a convex lens, will emerge parallel to the principal axis. This is shown in Figure ** (a). A ray of light appearing to meet at the principal focus of a concave lens, after refraction, will emerge parallel to the principal axis. This is shown in Figure ** (b).
3. A ray of light passing through the optical center of a lens will emerge without any deviation.

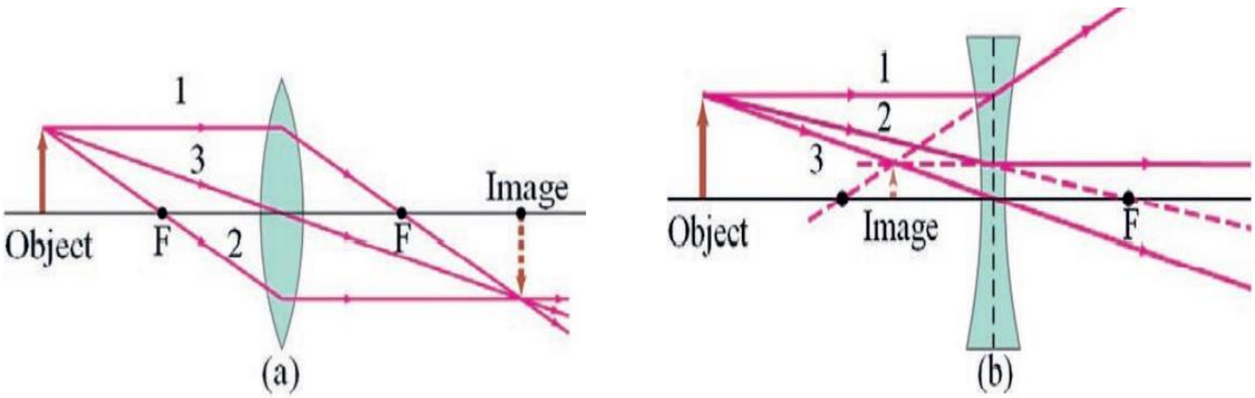
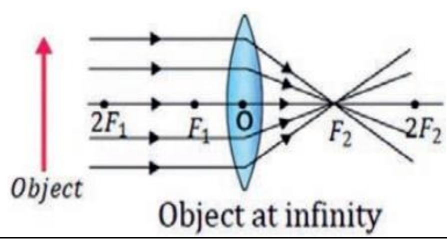
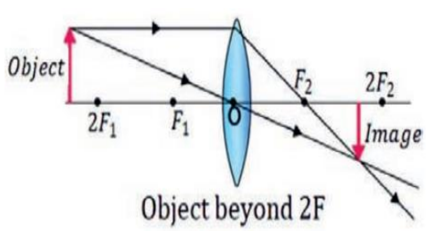


Figure **: Ray diagram for (a) convex lens (b) Concave lens.

Image formation Convex by and convex lens

Image Formation by Convex (Converging) lens			
	Position of the object	diagram	Nature of the image
1	Object at infinity		Formed at F_2 Real Inverted Highly diminished, point size
2	Object beyond $2F_1$		Formed between F_2 and $2F_2$ Real Inverted Diminished

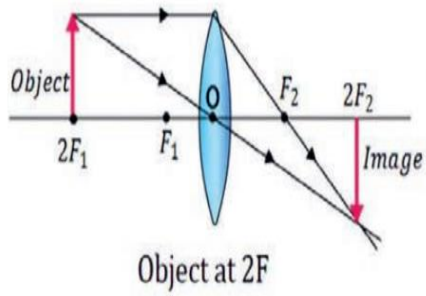
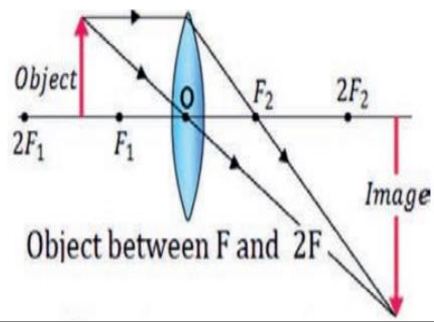
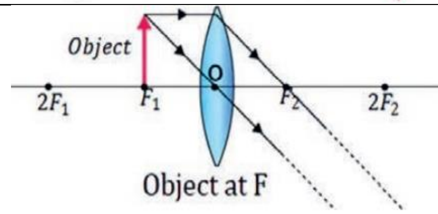
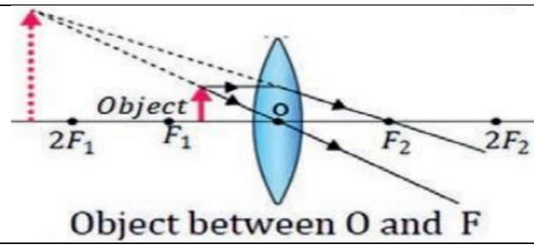
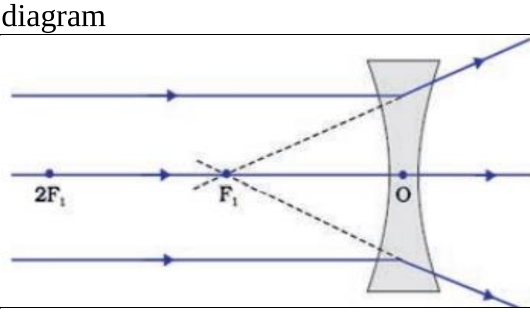
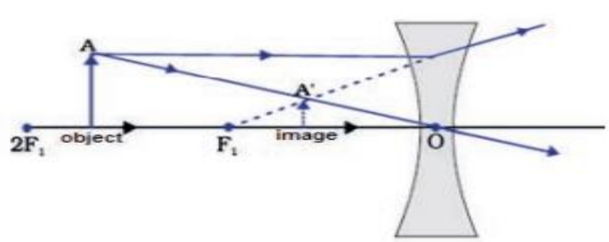
3	Object at $2F_1$		➢ Formed $2F_2$ ➢ Real ➢ Inverted ➢ The same size
4	Object between $2F_1$ and F_1		❖ Formed at beyond $2F_2$ ❖ Real ❖ Inverted ❖ Elarged
5	Object at F_1		At infinity Real Inverted Highly elarged (infinitely large)
6	Objet between O and F_1		○ On the same side of the lens as the object. ○ Virtual ○ Erect (upright) ○ Elarged

Image Formation by Concave Lens

Image Formation by concave (diverging) mirror		
Position of the object	diagram	Nature of image
At infinity		Formed at F_1 Virtual Erected (upright) Highly diminished, point size
Between infinity and optical center of the lens		▪ Formed at between O & F_1 ▪ Virtual ▪ Erected (upright) ▪ diminished

Lens formula and magnification

Equations of lens are the same as that of mirror. This equation gives the relationship between object distance (u), image distance (v) and the focal length (f). It is expressed as:

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{h}$$

Magnification produced by lens (m) is given by:

$$m=\frac{h'}{h}=-\frac{v}{u}$$

Sign convention		
Quantity	**Positive when**	**Negative when**
Object location, u	Object in front of lens (real object)	Object is in back of lens (virtual object)
Image location, v	Image is in back of lens (real image)	Image is in front of the lens (virtual image)
Image height, h’	Image is upright	Image is inverted
Focal length	Converging lens	Diverging lens
R_1 and R_2	Center of curvature is in back of lens	Center of curvature is in front of lens

Uses of lens

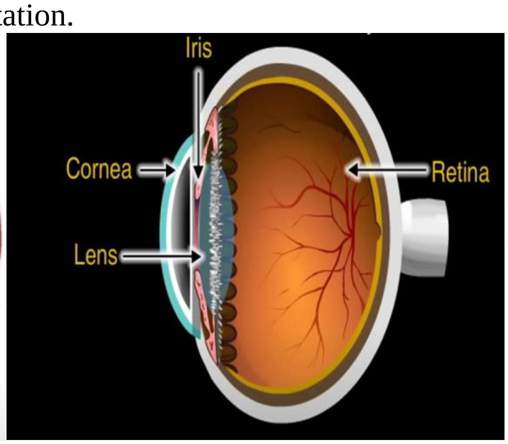
Lenses are widely used in:

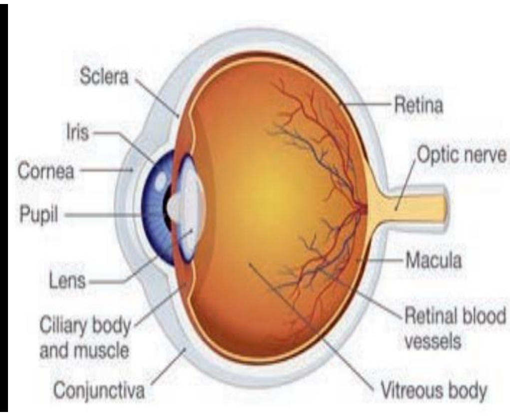
- Hand lens (simple microscope)
- Compound microscope
- Goggle, eyeglass
- Binocular, camera
- Telescope, …

6.6 Human Eye and Optical Instrument

The Human Eye

An eye is sense organ used for vision. Human eye is like camera. Its lens system forms an image on a light sensitive screen called retina. Light-sensitive cells on retina generate electrical signals and send to brain through optical nerve for interpretation.





Structures within eye and related to vision

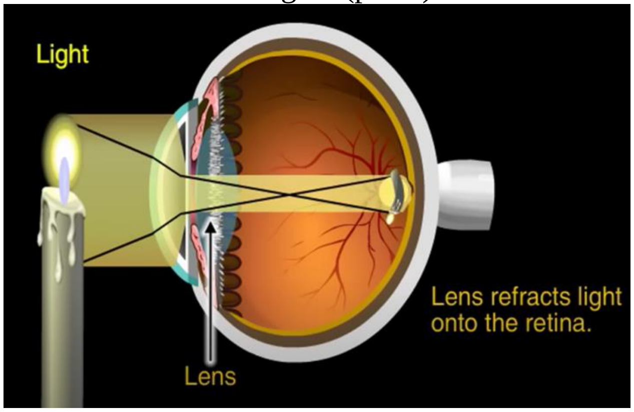
- Eyeball: - it is approximately spherical in shape with a diameter of about 2.3cm.
- Cornea: - the clear dome shaped covering at the front of eye.

- It has fluid filled space at its back called ***anterior chamber***. The fluid in the anterior chamber is called ***aqueous humor***

- Lens:- It is crystalline lens composed of fibrous, jelly like material.
  - It has ability to change its focal length by changing its curvature.
  - It provides finer adjustment of focal length required to focus images of *objects at different distances* on the retina.
  - It forms inverted image on retina.
- Pupil: - It readjust-able opening at the center of iris.
  - It regulates and controls the amount of light entering the eye.
- Iris:-it is a dark muscular diaphragm that controls the size of the pupil.
- Sclera (white of the eye):- It strong tissue that wraps around eye ball.
  - It helps to maintain eye's shape
  - It protects eye from injury
- Ciliary body and muscle: - changes curvature of eye lens being stretched and contracted.
  - When the muscles are relaxed the lens becomes thin. Thus, focal length of the lens increases. This enables to see distant objects
  - When the muscles are contracted the lens becomes thicker. Thus focal length of the lens decreases. This enables to see closer objects.
- Vitros body: - it modifies curvature of eye-lens
- Retina: - It is light sensitive screen
  - It is a delicate membrane with an enormous number of light sensitive cells.
- Light sensitive cells: - They are within retina.
  - They get activated upon illumination and generate electric signal
- Optical nerve: - transports electric signal generated by light sensitive cells.
- Optical lobe: - It is part of brain where the electric signals from optical nerve are interpreted.

How objects can be seen?? (Processes step by step)

1. Reflection of light rays comes from objects to cornea.
2. Light rays passes in cornea getting refracted.
3. The primarily refracted light rays passes through pupil (readjust-able opening at the center of iris)
4. The primarily refracted light rays passes eye lens and gets refracted again.
5. The twice refracted ray passes through vitreous body and reaches retina where the image is formed.
6. Rod cell and cone cell within retina gets stimulated and generate electric signal (pulse).
7. The electric signal (pulse) is sent to brain (optical lobe) and interpreted. [now you have seen the object]



Generally image formed in the eye is always:

- *Formed at focal point*
- *Real*
- *Inverted*
- *Diminished*

Note that:-

- Most of refraction of the light rays entering the eye occurs at the outer surface of cornea.
- The lens merely provides the finer adjustment of the focal length required to focus objects on the retina.

Power of Accommodation

Accommodation is ability of eye lens to adjust its focal length. Ciliary muscles change curvature of eye lens by being stretched and contracted. When the muscles are relaxed the lens becomes thin. Thus, focal length of the lens increases. This enables to see distant objects. When the muscles are contracted the lens becomes thicker. Thus focal length of the lens decreases. This enables to see closer objects.

Focal length of eye lens cannot decrease below certain minimum limit. The minimum distance at which eye can see clear image of objects comfortably and without feeling of strain is called ***near point***. For a young adult for normal vision, near point is about 25cm. The farthest point up to which the eye can see objects clearly is called ***far point***. Far point of normal eye is infinity.

- Note that: human eye can see objects clearly that are between 25cm to infinity.

Defects of Vision and Their Correction

(A)Myopia/ near-sightedness/ short sightedness

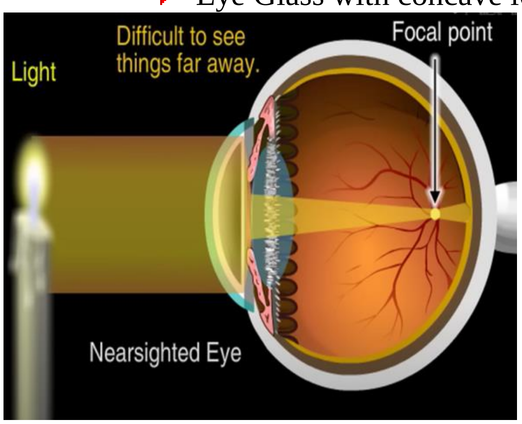
A person with this defect can see nearby objects clearly but cannot see distant objects distinctly. Far point of such person is few meters [not infinite]. In myopic eye, the image of a distant object is formed in front of retina not on retina, since its focal point lies in front of retina.
Myopia is caused by:

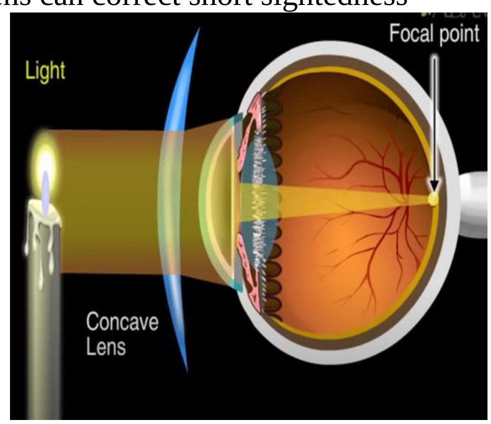
- Excessive curvature of eye lens
- Elongation of the eye ball

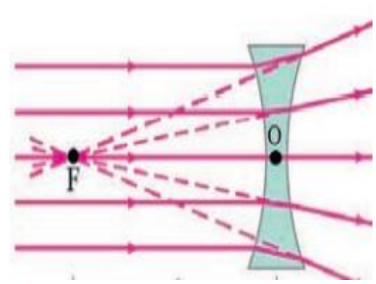
Correction

A concave lens with of suitable power will bring image back on to the retina. The lens widens the plane of the light rays coming through the cornea that pushes focal point back to retina.

- Eye Glass with concave lens can correct short sightedness







(A) Myopic eye (B) correction of myopic by Concave lens

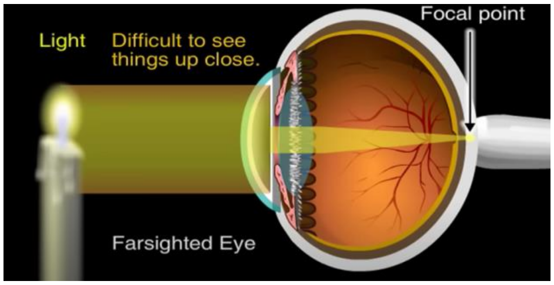
(B)Hyper-metropia/ far-sightedness

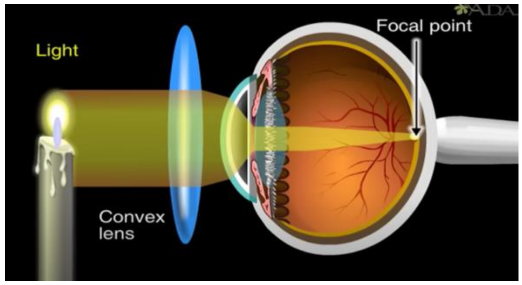
A person with this defect can see distant objects clearly but cannot see near objects distinctly. Near point of such person is farther away from ***normal near point*** [more than 25cm]. In hyper-metro-pic eye, the image of near object is formed at the back of retina, not on retina, since its focal point lies in at the back of retina.
Hypermetropia is caused by:

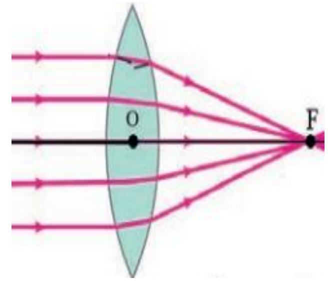
- Excessive elongation of focal length of eye lens: this rises as curvature of the lens decreases.
- Eye ball become too small: the distance between eye lens and retina becomes short then focal point will be behind the retina.

Correction:
A convex (converging) lens with of suitable power will bring image back on to the retina. The lens narrowes the plane of the light rays coming through the cornea that pulls focal point back to retina.

- Eye Glass with convex (converging) lens can correct Far sightedness







(A)

hyper-metro-pic eye (B) Correction of hyper-metro-pic eye by convex lens

(C)Presbyopia

Presbyopia is difficulty in seeing the nearby objects comfortably and clearly. For most people, the near point gradually recedes (becomes more than 25cm), as the power of accommodation of eye usually decreases with age.
Presbyopia is caused:

- Due to the gradual weakening of the ciliary muscles and diminishing flexibility of the eye lens, because of aging.

Correction:

- Refractive defects can be corrected with contact lenses or through surgery

for people with myopia and hypermertopia:

- Can be corrected by bi-focal lens (consist both concave and convex): upper portion consists of concave lens. It facilitates distant vision. The lower part is convex lens. It facilitates near vision.

Optical Instruments

(a) Simple microscope (hand lens)

Hand lens (simple microscope) is single (one) converging lens of small focal length.

- The lens must be held near the object one focal length away or less, and the eye is positioned close to the lens on other side to get an ***erect***, ***magnified*** and ***virtual*** image.
- Simple microscope has limited maximum magnification (up to 10x)
- Generally, simple microscope is used to form:
  - An erect
  - Virtual
  - Magnified image.

Hand lens (simple microscope) is used to: ***see tiny objects*** and ***to read very small calibrations***

(b) Compound microscope

Compound microscope has two lens systems (objective lens and eyepiece lens) compounding the effects of the other for larger magnification and resolution. Objective lens can be one (in monocular microscope) or two (in binocular microscope).
Compound microscope has more than one objective lenses (usually four) with different magnification (4x, 10x 40x, and 100x).
Objective lens (convex) produces an enlarged image inside the microscope tube. The image then passes through a second convex lens (eyepiece lens). This further magnifies the image formed by the objective lens.
Total magnification of compound microscope is product of magnification of objective lens and magnification of eyepiece lens.

$$Total\ magnification = \begin{pmatrix} magnification \\ of\ objective\ lens \end{pmatrix} \times \begin{pmatrix} magnification \\ of\ eyepiece\ lens \end{pmatrix}$$

Note that both simple microscope and compound microscope are made up of convex lens.
An overall image formed by Compound Microscope is:

- Twice inverted (left-right and up-down)
- virtual
- Magnified

(c) Light Telescope

C.1. Refracting Telescope

Refracting telescope uses combination of lenses to form an image. The simplest refracting telescope uses two convex lenses to form an image of distant objects.
Light passes through objective lens that forms the image. That is image is then magnified by eyepiece lens.
The two lenses (objective lens and eyepiece lens) are arranged so that the objective lens forms: diminished, real and inverted image of distant object very near to the focal point of the eyepiece. And eyepiece lens magnifies the image.

C.2. Reflecting Telescope

Reflective telescope has concave mirror instead of objective lens. Reflecting telescope is much larger than refracting telescope.
The large concave mirror focuses light on to the secondary mirror that directs it to the eyepiece which magnifies the image.

Because of only one reflecting surface on the mirror needs to be made and kept clean, telescope mirrors are less expensive than lenses of similar size. Telescope mirrors can be supported not only by their edges but by their back sides.
An overall image formed by light telescope:

- Inverted
- Virtual
- diminished

6.7. Primary Colors of Light and Human Vision

6.7.1 Primary Colors (RGB)

The colors of red, green and blue light are classically considered as primary colors (primary additive colors). Primary colors are fundamental to human vision. All other colors of visible light spectrum can be produced by properly adding different combination of primary colors.

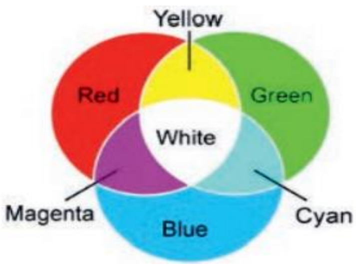
6.7.2 Human Vision

The retina is covered with millions of light receptive cells called cones (which are sensitive to colors) and rods (which are sensitive to intensity). When these cells detect light they send signals to brain. There are three sets of cones in our eye. These are:

1. cone cells that are most sensitive to red light
2. cone cells that are most sensitive to green light
3. cone cells that are most sensitive to blue light

6.8. Color Addition of Light

Additive color system reproduces different colors by adding primary colors of light: red, green and blue. All colors can be reproduced by three color additive.
* Addition of primary colors of light can be demonstrated using a light box.
* The light box illuminates a screen with the three primary colors: red, green and blue.



Red + Green = Yellow
Red + Blue = magenta
Blue + Green = Cyan
Red + Green + blue = White

Secondary colors (Yellow, Magenta and Cyan) can be produced by the addition of equal intensities of two primary colors of light.
When equal proportions of red green and blue are added it results in white light.
Absence of all three light results in black
Additions of primary colors of light with varying degrees of intensity will result in the countless other colors (violet, purple, rose, pink, indigo, orange, brown…)

6.9. Color subtraction of light using color filters

The colors that are absorbed are subtracted from the reflected light that is seen by eye.
A black object absorbs all colors where as a white object reflects all colors.
A blue object reflects blue and absorbs all other colors.
The primary and secondary colors of light for the subtractive colors are opposite to the colors addition.

Cyan – Blue = (Green + Blue) – Blue = Green
Yellow – Green = (Red + Green) – Green = Red
Magenta – Red = (blue + Red) – Red = Blue

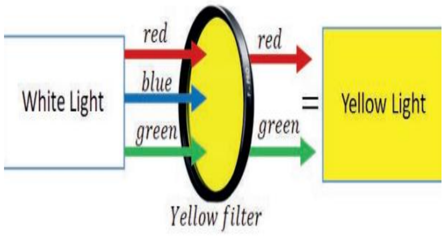
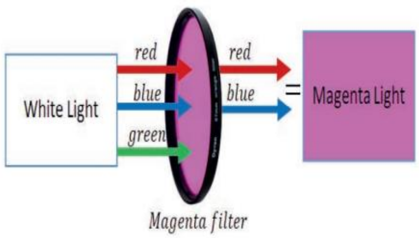
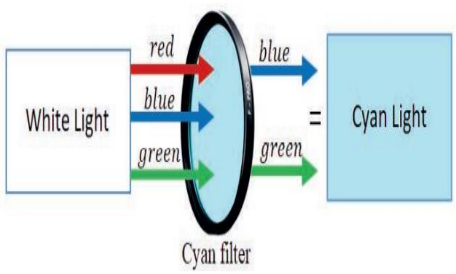
Thus: yellow, magenta and cyan are considered as subtractive primary colors. While red, green and blue are secondary subtractive colors.
The complimentary colors are the colors that are absorbed by the subtractive primaries.
Cyan’s compliment is red; magenta’s compliment is green; and yellow’s is blue.
Note that: The subtractive primary colors are obtained by subtracting one of the three additive primary colors from white light.

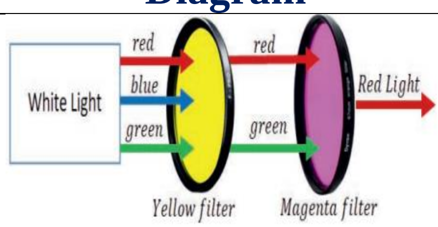
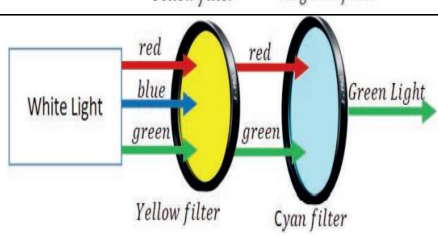
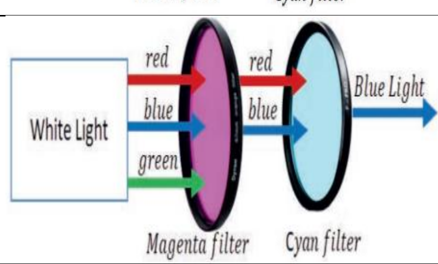
Pigments

Pigments are substances which give an object its color by absorbing certain frequencies of light and reflecting other frequencies. For example, a red pigment absorbs all colors of light except red which it reflects. Paints and inks contain pigments which give the paints and inks different colors.
When you mix colors using paint, or through the printing process, you are using the subtractive color method. Subtractive color mixing means that one begins with white and ends with black; as one add color, the result gets darker and tends to black.

Color Filter

A filter is a substance or device that prevents certain things from passing through it while allowing certain other things to pass. Color filters allow only certain colors of light to pass through them by absorbing all the rest. When white light shines on a red filter, for example, the orange, yellow, green, blue, and violet components of the light are absorbed by the filter allowing only the red component of the light to pass through to the other side of the filter.
The following shows the color subtraction of light using filters or pigments.

Color subtraction by single Color filter (pigment)					
	Diagram	Color filters	Absorbed color	Reflected (transferred) colors	result
I		Yellow filter (or a pigment)	Blue	Red Green	Yellow light
II		Magenta filter (or a pigment)	Green	Red Blue	Magenta light
III		Cyan filter (or pigment)	Red	Blue Green	Cyan light

Color subtraction by double filter (pigment)				
	Diagram	**Color filter**	**Filtered color**	**result**
IV		Yellow filter and magenta filter in combination	Blue (by yellow filter) Green (by magenta filter)	Red light
V		Yellow filter and cyan filter in combination	Blue (by yellow filter) Red (by cyan filter)	Green light
VI		Magenta filter and cyan filter in combination	Green by magenta filter Red by cyan filter	Blue light