RAY OPTICS

Photons : Photons are the packets of energy. Their energy is given by

$$E = h\nu = \frac{hc}{\lambda}$$

where, h = Planck's constant
ν = frequency of photons
c = velocity of light = velocity of photons
λ = wavelength of photons

Photometry : Photometry is that branch of physics which deals with the measurement of light energy.

Principle of photometry : Principle of photometry states that when two sources of light produce equal illumination on a screen, the ratio of illuminating powers of the sources is equal to the ratio of squares of their respective perpendicular distance from the screen. i.e.,

$$\frac{I_1}{I_2} = \frac{r_1^2}{r_2^2}$$

Photo-electric effect : The phenomenon of emission of electrons from the surface of metals when light radiations of suitable frequency fall on them, is called photo-electric effect.

Photo-luminescence or luminescence : The phenomenon of emission of visible light after absorbing some electromagnetic radiations is called as photo-luminescence or simply luminescence.

Threshold frequency (ν_0) : The minimum frequency of the incident light radiations which is just able to eject photo-electrons from the surface of a metal is called threshold frequency. It is represented by ν_0.

$$\text{Hence, } \phi_0 = h\nu_0$$

where, ϕ_0 = work function of a metal

Work function of a metal (ϕ_0) : The minimum energy which must be supplied to the electron so that it can just come out of the surface of the metal is called work function of that metal. It is represented by ϕ_0.

Stopping potential or Cut-off potential (V_0) : The minimum negative potential applied to the anode of a photo cell at which the photo-electric current becomes zero, is called as the stopping potential or cut-off potential.

Hence, $eV_0 = \frac{1}{2} mv_{max}^2$

where, m = mass of photo-electron

v_{max} = maximum velocity of photo electrons.

Laws of photo-electric effect :

(i) The number of photoelectrons emitted per second (i.e., photoelectric current) is directly proportional to the intensity of the incident light and is independent of its frequency.

(ii) The maximum kinetic energy of the emitted photoelectrons depends upon the frequency (or wavelength) of the incident light and is independent of its intensity.

(iii) For a given metal, there exists a certain minimum frequency of the incident light radiations below which no emission of photo-electrons takes place.

(iv) The emission of photoelectrons is an instantaneous process, i.e., it starts immediately as the light falls on the surface of the metal.

Einstein's photo-electric equation :

$$\frac{1}{2} mv^2 = h\nu - \phi_0$$

where symbols have their usual meanings.

de-Broglie hypothesis : According to de-Broglie, a moving material particle has dual nature—wave nature as well as particle nature. The wave associated with moving particle is called de-Broglie wave.

de-Broglie wavelength of an electron :

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}} = \frac{12.27\ \text{Å}}{\sqrt{V}}$$

where, V = accelerating voltage of the electron.

Reflection of light : The phenomenon of change in the path of the light without change of medium is called reflection of light.

Law of reflection : When a ray of light falls on a reflecting surface, then

(*i*) the incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane, and

(*ii*) the angle of incidence is equal to the angle of reflection, i.e.,

$$\angle i = \angle r.$$

Total internal reflection : When light travelling from denser to rarer medium, is incident at an angle greater than the critical angle, the whole light is reflected back in the denser medium. This phenomenon is called as total internal reflection.

Conditions of total internal reflection :

(*i*) The light should travel from a denser medium to rarer medium.

(*ii*) The angle of incidence in the denser medium should be greater than the critical angle for the two media.

Refraction of light : The phenomenon of change in the path of the light when it passes from one medium to another medium is called refraction of light.

Law of refraction : When a ray of light passes from one medium to another medium, then

(*i*) the incident ray, the refracted ray and the normal at the point of incident all lie in the same plane, and

(*ii*) the ratio of sine of angle of incidence to the sine of angle of refraction is constant for a pair of media. i.e.,

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is represented by μ and is called as the refractive index of the second medium with respect to first medium. This is also called as Snell's law.

Hence, according to Snell's law,

$$\frac{\sin i}{\sin r} = \mu$$

Real and apparent depths :

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$

Refraction through multiple refracting media : Let there be three media a, b and c. Light enters from medium a, crosses medium b and then leaves from medium c, then

$$^a\mu_c = {}^a\mu_b \times {}^b\mu_c.$$

Critical angle : When light travels from denser to rarer medium, then that angle of incidence for which angle of refraction is 90°, is called as critical angle. It is represented by C.

Then $\mu = \dfrac{1}{\sin C}$, where μ is the refractive index of denser medium w.r.t. rarer medium.

Some definitions of spherical refracting surfaces :

(i) **Principal axis :** The line joining the pole and the centre of curvature of the spherical surface, extended on both sides, is called principal axis of the spherical refracting surface.

(*ii*) **Pole :** The centre of the spherical refracting surface is called its pole. It is represented by point P.

(*iii*) **Centre of curvature :** The centre of the sphere, of which the spherical surface forms a part, is called the centre of curvature of the spherical surface. It is represented by point C.

(*iv*) **Radius of curvature :** The radius of the sphere, of which the spherical surface forms a part, is called the radius of curvature of the spherical surface. It is the distance between the pole and the centre of curvature. It is represented by R.

(*v*) **Aperture :** The diameter of the spherical refracting surface is called its aperture.

Refraction at spherical refracting surface :

$$-\frac{\mu_1}{u}+\frac{\mu_2}{v}=\frac{\mu_2-\mu_1}{R}$$

or $$-\frac{1}{u}+\frac{\mu}{v}=\frac{\mu-1}{R} \quad \left(\text{If } \frac{\mu_2}{\mu_1}=\mu\right)$$

where, μ_1 = refractive index of rarer medium

μ_2 = refractive index of denser medium

u = distance of the object from the pole

v = distance of the image from the pole

R = radius of curvature of the spherical surface.

Some definitions of spherical mirrors :

(i) ***Pole or vertex :*** The centre of the spherical mirror is called its pole or vertex. It is generally represented by point P.

(ii) ***Aperture :*** The diameter of the mirror is called its aperture.

(iii) ***Principal axis :*** The line joining the pole and the centre of curvature of the mirror, extended on both sides, is called principal axis of the mirror.

(iv) ***Principal focus :*** The point on the principal axis of the mirror, at which incident rays parallel to the principal axis after reflection from the mirror actually meet or appear to come from, is called the principal focus of the mirror. It is represented by point F.

(v) ***Focal length :*** The distance between the pole and the principal focus of the mirror is called focal length of the mirror. It is represented by f and

$$f = \frac{R}{2} \text{ (for spherical mirror)}$$

(*vi*) **Centre of curvature :** The centre of the sphere, of which the mirror forms a part, is called the centre of curvature of the mirror. It is generally represented by point C.

(*vii*) **Radius of curvature :** The radius of the sphere, of which the mirror forms a part, is called the radius of curvature of the mirror. It is the distance between the pole and the centre of curvature of the mirror. It is represented by R.

(*viii*) **Normal :** A line joining any point of the mirror to the centre of the curvature, is called normal to the mirror at that point.

Mirror formula :

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

where, u = distance of the object from the mirror.

v = distance of the image from the mirror.

f = focal length of the mirror.

Linear magnification produced by a mirror : The ratio of the size of the image formed by the spherical mirror to the size of the object is called as linear magnification or simply magnification. It is represented by m.

$$m = \frac{\text{size of the image}}{\text{size of the object}} = \frac{I}{O} = \frac{-v}{u}$$

Differences between real and virtual images

Real image	Virtual image
(i) These are formed when reflected rays actually meet at a point.	*(i)* These are formed when reflected rays appear to come from a point.
(ii) These images can be projected on a screen.	*(ii)* These images can't be taken on a screen.
(iii) These are always inverted.	*(iii)* These are always erect.

Luminous flux : Luminous flux of a source of light is defined as the amount of luminous energy emitted from the source per second. It is represented by ϕ. Its unit is lumen (lm).

Lumen (lm) : One lumen is defined as the amount of luminous flux emitted per unit solid angle by a point source of luminous intensity one Candela. It is also called as Candela Steradian (Cd Sr).

Positions and nature of image formed by spherical mirrors

	Position of object	Position of image	Size of image	Nature of image
	Concave mirror			
(a)	At infinity (∞)	At F	Highly diminished	Real and inverted
(b)	Between ∞ and C	Between F and C	Diminished	Real and inverted
(c)	At C	At C	Same size	Real and inverted
(d)	Between F and C	Between infinity	Enlarged	Real and inverted
(e)	At	At ∞	Highly enlarged	Real and inverted
(f)	Between F and mirror	Behind the mirror	Enlarged	Virtual and erect
	Convex mirror			
	Anywhere on the axis	Behind the mirror (Between F and P)	Diminished	Virtual and erect

Luminous Intensity or Illuminating Power : Luminous intensity of a source of light is defined as the luminous flux emitted by it per unit solid angle. It is also called as illuminating power of the source and is represented by I. Its unit is candela.

Candela (Cd) : One candela is defined as the luminous intensity of the source in a given direction which emits monochromatic radiations of wavelength 555 nm and has radiant intensity of $\frac{1}{683}$ watt per Steradian in that direction. Also

1 Candela (Cd) = 1 lumen/steradian (lm Sr^{-1})

Illuminance or Intensity of Illumination : Illuminance of a surface is defined as the luminous flux incident normally on unit area of the surface. It is also called as intensity of illumination and is represented by E. Its SI unit is lux and CGS unit is phot.

Hence, $$E = \frac{\phi}{A}$$

where, ϕ = luminous flux

A = area of the surface.

Lux : The illuminance of a surface is called to be one lux when a luminous flux of 1 lumen falls on $1 m^2$ area of the surface held in a direction normal to the light rays. It is also called as metre-candle. Hence,

$$1 \text{ lux} = 1 \text{ metre candle} = 1 \text{ lumen m}^{-2}$$

$$\text{Also } 1 \text{ phot} = 1 \text{ cm candle} = 1 \text{ lumen cm}^{-2}$$

Hence, 1 phot = 10^4 lux

Some definitions of thin lenses :

(i) **Principal focus :** The points on the principal axis of the lens, at which incident rays parallel to the principal axis after refraction from the lens actually meet or appear to come from, are called the principal focii of the lens. These are represented by F.

(ii) **Optical centre :** It is a point inside the lens on the principal axis such that if a refracted ray passes through it then its incident ray and emergent ray both will be parallel to each other.

(iii) **Focal length :** The distance between the optical centre and the principal focus of the lens is called focal length of the lens. It is represented by f.

Lens maker's formula : Lens maker's formula is,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, f = focal length of the lens

μ = refractive index of the material of the lens.

R_1 and R_2 = radii of curvature of the two surfaces of the lens.

Lens formula : $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

where, v = distance of the image from the lens

u = distance of the object from the lens

f = focal length of the lens

Linear magnification produced by a lens : The ratio of the size of the image formed by the lens of the size of the object is called as linear magnification or simply magnification. It is represented by m.

$$m = \frac{\text{size of the image}}{\text{size of the object}} = \frac{I}{O} = \frac{v}{u}$$

Power of lens : It is the ability of the lens to converge or diverge a beam of light and is defined as the reciprocal of its focal length measured in metres. Its unit is diopter (D).

Hence, $P = \frac{1}{f}$. Here, f is in metre.

Therefore one diopter is the power of a lens of focal length one metre.

Combination of two thin lenses :

(i) **In contact**

The focal length (F) of the combination is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

The power of the equivalent lens is given by

$$P = P_1 + P_2$$

The magnification of the equivalent lens is given by

$$m = m_1 \times m_2$$

(ii) Separated by a finite distance (d)

The focal length (F) of the combination is given by,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

Dispersion of light : The phenomenon of splitting of white light into its constituent colours is called as dispersion of light.

Spectrum : A band of seven colours obtained due to dispersion of light is called as spectrum.

The seven colours are : VIBGYOR, i.e.,

V = Violet

I = Indigo

B = Blue

G = Green
Y = Yellow
O = Orange
R = Red

Refraction through a prism :

(i) Angle of deviation : $\delta = (\mu - 1) A$

(ii) Angular dispersion : $\delta_v - \delta_r = (\mu_v - \mu_r) A$

where δ, δ_v and δ_r = angles of deviation for mean ray, violet ray and red ray respectively.

μ, μ_v and μ_r = refractive index of the material of the prism for mean ray, violet ray and red ray respectively.

A = Angle of prism

(iii) $A = \delta = i + e$

where, i = angle of incidence

e = angle of emergence

(iv) **Prism formula**

$$\mu = \frac{\sin \frac{A + \delta_m}{2}}{\sin \frac{A}{2}}$$

where, δ_m = angle of minimum deviation.

Position and nature of images formed by lenses

Position of object	Position of image	Size of image	Nature of image
For convex lens			
(a) At ∞	At F	Highly diminished	Real and inverted
(b) Beyond 2F′	Between F and 2F	Diminished	Real and inverted
(c) At 2F′	At 2F	Same size	Real and inverted
(d) Between F′ and 2F′	Beyond 2F	Enlarged	Real and inverted
(e) At F′	At infinity	Highly enlarged	Real and inverted
(f) Between F′ and lens	Behind the object	Enlarged	Virtual
For concave lens			
Anywhere on the axis	on the same side of the lens	Diminished of the lens	Virtual and erect

(*v*) **Dispersive power**

The ratio of angular dispersion to the mean deviation produced by the prism is called dispersive power of its material. It is represented by ω. Hence

$$\omega = \frac{\text{Angular dispersion}}{\text{Mean dispersion}}$$

$$= \frac{\mu_v - \mu_r}{\mu - 1}$$

Magnifying power of microscope : Magnifying power of a simple microscope is defined as the ratio of the angles subtended by the image and the object on the eye, when both are at the least distance of distinct vision. It is represented by m. Hence for simple microscope,

$$m = 1 + \frac{D}{f};$$

where, D = least distance of distinct vision.

f = focal length of the lens.

For compound microscope,

$$m = m_o \times m_e$$

$$= \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

where, L = length of microscope tube.

f_0 = focal length of object lens.

f_e = focal length of eye lens.

Magnifying power of a telescope (astronomical) : Magnifying power of a telescope is defined as the ratio of the angle subtended at the eye by the final image formed at the least distance of distinct vision to the angle subtended at the eye by the object at infinity when seen directly.

Also, $$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

where, f_o = focal length of object lens.

f_e = focal length of eye lens.

D = least distance of distinct vision.

Resolving power of a microscope : It is defined as the reciprocal of the least distance (d) between two close object which appear just separated through the microscope. Hence,

$$\text{R.P.} = \frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$$

where, μ = refractive index of the medium.

λ = wavelength of the light used.

θ = half angle of the cone of light from the point object to the object lens.