

Chapter 9 Formulae List

Ray Optics

1. Reflection by Spherical Mirrors

- (image in multiple mirrors) Number of images formed when two mirrors are placed at angle θ

$$n = \frac{360^\circ}{\theta} \text{ when } n \text{ is odd number}$$

$$n = \frac{360^\circ}{\theta} - 1 \text{ when } n \text{ is even}$$

- Mirror formula: $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ and $R = 2f$
- Magnification: $M = \frac{h'}{h} = -\frac{v}{u} = \frac{f}{u-f} = \frac{f-v}{f} = 1 - \frac{v}{f}$
- $m = -ive$ (negative) then real image is formed
- $m = +ive$ (positive) then virtual image is formed
- $m = 1$ then image formed is of same size
- $m > 1$ then magnified image is formed
- $m < 1$ then diminished image is formed
- for convex mirror and convex lens focal length f and power P is +ive (positive)
- for concave mirror and concave lens focal length f and power P is -ive(negative)
- Relation between Object speed and image speed formed by spherical mirrors
 speed of object = $V_o = \frac{du}{dt}$

$$\text{speed of image} = v_i = \frac{dv}{dt} = -v_o \left(\frac{v}{u}\right)^2 = -v_o \left(\frac{f}{u-f}\right)^2 = -v_o \left(\frac{f-v}{f}\right)^2$$

2. Refraction at Plane Surfaces

- when light refracted from rarer to denser it bends towards the normal
- when light refracted from denser to rarer it bends away from the normal
- when light goes from one medium to another the frequency and phase of light does not change but its wavelength and velocity change
- wavelength of light decreases when it travels from air(vacuum) to any medium

- absolute Refractive index μ_a, μ_w, μ_g

- Relative Refractive index (light goes from glass to water) ${}^g\mu_w = \frac{\mu_w}{\mu_g} = \frac{v_g}{v_w}$

$$\text{(light goes from medium 1 to medium 2)} \mu_{12} = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2}$$

v_g, v_w = velocity of light in glass and water respectively

$$\mu \propto \frac{1}{\text{speed of light}}$$

- Snell's Law: $\mu_1 \sin i = \mu_2 \sin r$ or $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$

- Refraction through rectangular glass slab:

Lateral Displacement or lateral shift = $\frac{t \times \sin(i-r)}{\cos r}$, t = thickness of glass slab

- Real and Apparent depth: (when light goes from denser to rarer medium)

$$\frac{(\text{Real depth}) \times}{(\text{Apparent depth})} = (\text{refractive index of the medium}) \mu_m$$

- apparent depth $y = \frac{x}{\mu_m}$
- Lateral or apparent shift $\Delta x = \text{Real depth}(x) - \text{Apparent depth}(y)$

$$\Delta x = x \left(1 - \frac{1}{\mu_m} \right)$$

- Total Internal Reflection (TIR)
- Critical angle C :
The angle of incidence ($i = C$) in denser medium correspondence to which angle of refraction is $r = 90^\circ$ in rarer medium

$$\sin C = \frac{1}{\mu_{\text{medium}}} \text{ (for air-medium)}$$

- Condition: $i > C$ and $\mu_1 > \mu_2$ when light goes from medium 1(denser) to 2(rarer)
- $\mu \propto \frac{1}{\lambda} \propto \frac{1}{\sin C}$
- Critical angle C for glass is 42°

3. Refraction at Spherical Surfaces

- Formula: Rarer to denser medium (object in rarer medium)

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

Denser to rarer medium (object in denser medium)

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

4. Lens Formulae

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

- Lens Maker's Formula: $\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$
- Lens immersed in liquid: $\frac{1}{f_{\text{liquid}}} = \left(\frac{\mu_{\text{lens}}}{\mu_{\text{liquid}}} - 1 \right) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$
- Combination of lenses:
 - When lenses in contact: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$ and $P = P_1 + P_2$
 - When lenses are separated by distance d : F resultant focal length of combination

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$
 - Newton's Relation (Conjugate points):

$$f = \frac{D^2 - x^2}{4D}$$

D = distance between object and screen ($D > 4f$)

x = displacement of the lens (i.e. distance between two conjugate positions of the same lens)
- Magnification: $m = \frac{h'}{h} = \frac{v}{u} = \frac{f}{u+f} = \frac{f-v}{f}$
- Power: $P = \frac{100}{f}$ (in cm), $P = \frac{1}{f}$ (in m)
- Equivalent focal length: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \dots$

5. Prism Formula

- Deviation: $\delta = i_1 + i_2 - A$
- Minimum deviation: $\mu = \sin \left(\frac{(A + D_m)}{2} \right) / \sin \left(\frac{A}{2} \right)$

6. Dispersion

- Angular dispersion: $\theta = \delta_v - \delta_r$
- Dispersive power: $\omega = (\mu_v - \mu_r) / (\mu_y - 1)$

7. Optical Instruments

- Simple Microscope: $M = 1 + \frac{D}{f}$
- Compound Microscope: $M = \left(\frac{v_o}{u_e}\right) \left(1 + \frac{D}{f_e}\right)$
- Telescope (Normal adjustment): $M = -\frac{f_o}{f_e}$
- Telescope (Least distance): $M = -\left(\frac{f_o}{f_e}\right) \left(1 + \frac{D}{f_e}\right)$
- Angular Magnification: $M = \theta' / \theta$