PC237 Optics

Summary part I

- ***Nature of Light (chapter 1)***
- ***Geometrical Optics (chapter 2)***
- ***Optical Instrumentation (chapter 3)***

Nature of Light

- Light behaves like waves in its propagation and in the phenomena of interference and diffraction; however, it exhibits particle-like behavior when exchanging energy with matter, as in the Compton and photoelectric effects

- Photon energy:

$$\boxed{E = h\nu} \qquad h\text{ : Planck constant (}6.626\text{x}10^{-34}\ J\text{-}s\text{)}$$

- Energy unit eV: $\boxed{1eV = 1.6\times 10^{-19} J}$

- Relations between wavelength, frequency, and speed:

In air: $\boxed{c = \lambda\nu \quad \text{or} \quad \lambda = c/\nu}$

In media: $\boxed{\upsilon = c/n, \quad \lambda = \dfrac{\upsilon}{\nu} = \dfrac{c}{n\nu} = \dfrac{\lambda_o}{n}}$

Geometrical Optics

Law of reflection: $\boxed{\theta_i = \theta_r}$

Law of refraction (Snell's Law): $\boxed{n_i \cdot \sin\theta_i = n_t \cdot \sin\theta_t}$

- Wavefront : The surfaces joining all points of <u>equal phase</u> are known as wavefronts.
- Huygens's Principle : every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.
- Principle of Least Time: The actual path between two points taken by a beam of light is the one that is traversed in the least time
- Re-state Fermat's Principle : $\boxed{t = OPL / c}$

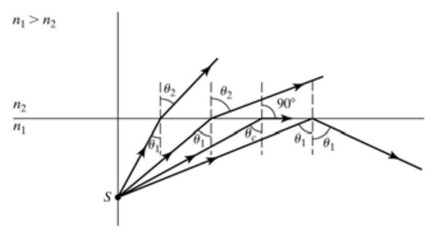
  Light, in going from point S to P, traverses the route having the smallest *OPL*
- Prove Snell's law

Geometrical Optics

- Total Internal Reflection:

  $\boxed{n_1 > n_2}$ $\boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$

  <u>Critical angle:</u> is the incident angle when refraction angle is equal to 90°



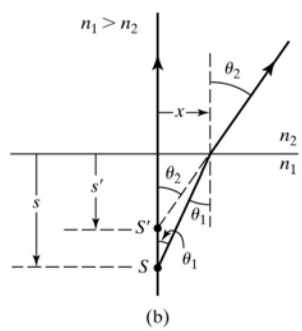
(c)

- <u>Refraction</u> through <u>Plane</u> Surfaces:

  Paraxial rays: $\boxed{\sin\theta \cong \tan\theta \cong \theta}$

  $\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$

  $\Rightarrow$ $\boxed{s' = \left(\frac{n_2}{n_1}\right) s}$



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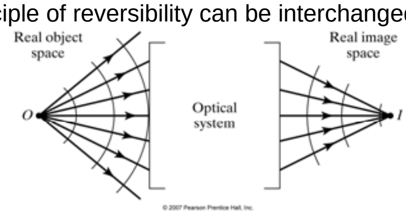
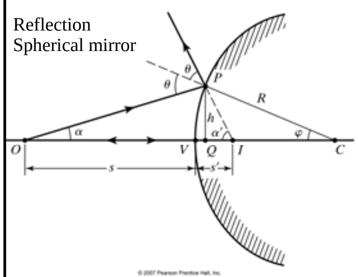
Geometrical Optics

- O and I are conjugate points – any pair of object-image points …. by the principle of reversibility can be interchanged



1. Reflection at a spherical surface

Reflection
Spherical mirror



- Mirror equation: $\boxed{\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}}$ with $\boxed{f=-\frac{R}{2}}$

Convex mirror: $f < 0$
Concave mirror: $f > 0$

- Lateral magnification: $\boxed{m=\frac{h_i}{h_o}=-\frac{s'}{s}}$

Sign convention		
s	+	O is to the left of V
s'	+	I is to the left of V
R	+	C is to the right of V
f	+	F is to the left of V

Geometrical Optics

2. Refraction at a spherical surface:

- Refraction equation: $\boxed{\frac{n_1}{s}+\frac{n_2}{s'}=\frac{n_2-n_1}{R}}$
- Special case: plane refracting surface $\boxed{R\to\infty}$ $\Rightarrow$ $\boxed{s'=-\left(\frac{n_2}{n_1}\right)s}$ s': apparent depth
- Lateral magnification: $\boxed{m=\frac{h_i}{h_o}=-\frac{n_1 s'}{n_2 s}}$

Sign convention		
s	+	O is to the left of V
s'	+	I is to the right of V
R	+	C is to the right of V

Describe images:
- Type: Virtual or real
- Orientation: erect or inverted
- Relative size

Meanings associated with the sign		
Quantity	Sign	
	+	-
s	real object	virtual object
s'	real image	virtual image
m	erect image	inverted image

Geometrical Optics

3. Thin Lenses:

- Thin-lens equation: $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$

Lensmaker's equation: $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

- Lateral magnification: $m = \frac{h_i}{h_o} = -\frac{s'}{s}$

Sign convention		
s	+	O is to the left of V
s'	+	I is to the right of V
$R_{1,2}$	+	C is to the right of V

Meanings associated with the sign		
Quantity	Sign	
	+	-
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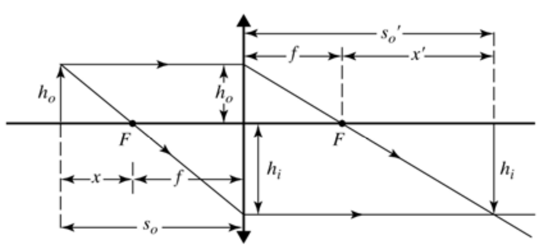
m	erect image	inverted image

- Rules for ray tracing:

- Ray 1 parallel to central axis will pass through the right focal point of a converging lens (or the left focal point of the diverging lens)
- Ray 2 passing through the left focal point of a converging lens (or the right focal point of the diverging lens) will emerge from lens parallel to central axis
- Ray 3 is the undeviated ray through center of lens (Ray 3 is also called central ray)

Geometrical Optics

- Newtonian Equation for Thin Lens: $xx' = f^2$
- Lateral magnification: $m = \frac{h_i}{h_o} = -\frac{s'}{s} = -\frac{x'}{f} = -\frac{f}{x}$

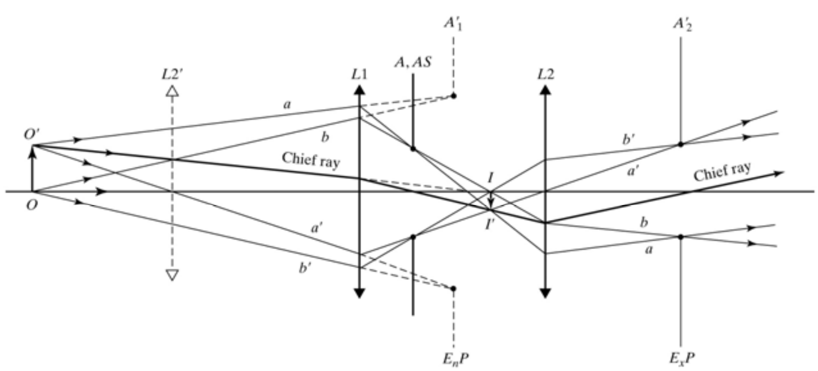


Optical Instrumentation

3.1 Stops, Pupils, and Windows:

- Apertures are used to control *Image Brightness* and limit *Field of view*.
- Apertures for controlling Image Brightness : *Aperture stops and Pupils*
  - o *Aperture stop* AS: The *real* element in an optical system that limits the size of the cone of rays accepted by the system from an axial object point
  - o *Entrance pupil* (E_nP): The image of the aperture stop formed by the optical elements (if any) that *precede* it
  - o *Exit pupil* (E_xP): The image of the aperture stop formed by the optical elements (if any) that *follow* it
- Chief Ray: The chief is a meridional ray that start at the edge of the object, and passes through the center of E_nP, AS, and E_xP
- Apertures for Limiting Field of view : *Field stops and Windows*
  - o *Field stop FS:* The *real* element that limits the angular field of view formed by an optical system
  - o *Entrance Window (E_nW):* The image of the field stop formed by the optical elements that *precede* it
  - o *Exit Window (E_xW):* The image of the field stop formed by the optical elements that *follow* it

Optical Instrumentation

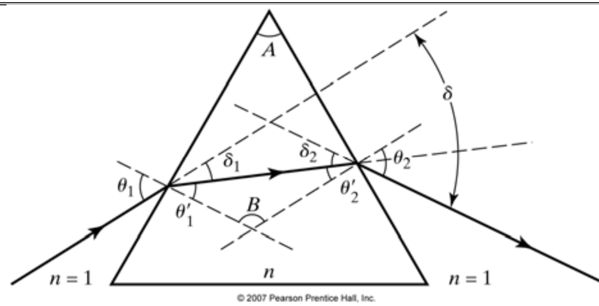


- o *Aperture stop* AS
- o *Entrance pupil* (E_nP)
- o *Exit pupil* (E_xP)

- Chief Ray: The chief is a meridional ray that start at the edge of the object, and passes through the center of E_nP, AS, and E_xP

Optical Instrumentation

3.3 Prisms:



- The deviation angle is: $\boxed{\delta = \theta_1 + \theta_2 - (\theta_1' + \theta_2') = \theta_1 + \theta_2 - A}$

$$\boxed{\delta = \theta_1 + \sin^{-1}\left(\sqrt{n^2 - \sin^2\theta_1}\,\sin A - \sin\theta_1 \cos A\right) - A}$$

- Condition of Minimum deviations: The ray for which the deviation is a minimum traverses the prism symmetrically, that is, parallel to its base.
- Applications : Determination of refractive index n of transparent material

$$\boxed{n = \frac{\sin\left[(\delta_m + A)/2\right]}{\sin(A/2)}}$$

δ_m : Minimum angular deviation

Optical Instrumentation

- Empirical relation ---Cauchy Relation:

$$\boxed{n_\lambda = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \cdots}$$

A, B, C … are Cauchy constants

- Dispersion: $\boxed{\dfrac{dn}{d\lambda} \simeq -\dfrac{2B}{\lambda^3}}$
- Resolving power: $\boxed{\mathscr{R} = \dfrac{\lambda}{(\Delta\lambda)_{\min}} = b\dfrac{dn}{d\lambda}}$

3.4 The Camera:

$$\boxed{s_1 = \frac{s_o f(f + Ad)}{f^2 + Ads_o}} \qquad \boxed{s_2 = \frac{s_o f(f - Ad)}{f^2 - Ads_o}}$$

$$\boxed{\text{depth of field} = \frac{2Ads_o(s_o - f)f^2}{f^4 - A^2d^2s_o^2}}$$

Optical Instrumentation

3.5 Simple Magnifiers and Eyepieces:

- Angular magnification M: *the ratio of the retinal image as seen through the instrument over the size of the retinal image as seen by the unaided eye at normal viewing distance.*

1. Image viewed at infinity: $M = \frac{25}{f}$ (Object is moved to the focal point)
2. Image viewed at normal near point: $M = \frac{25}{f} + 1$ (Object is just inside the focal point)
   s' = - 25 cm

- Eyepieces or Oculars: To reduce transverse chromatic aberration, two lens are most often used. The effective focal length f of the two thin lenses separated by a distance L is given:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{L}{f_1 f_2}$$

with

$$\frac{1}{f_1} = (n-1)\left(\frac{1}{R_{11}} - \frac{1}{R_{12}}\right) = (n-1)K_1$$

$$\frac{1}{f_2} = (n-1)\left(\frac{1}{R_{21}} - \frac{1}{R_{22}}\right) = (n-1)K_2$$

To correct transverse chromatic aberration: $\frac{d(1/f)}{dn} = 0$

Optimum separation: $L = \frac{1}{2}(f_1 + f_2)$

Optical Instrumentation

3.6 Microscopes:

- Compound Microscope : Objective + Eyepiece (it may provide high MP)

  Objective: form a real, inverted, magnified image → Lateral Magnification - M_o
  Eyepiece: further magnify the intermediate image → Angular Magnification - M_e

- The intermediate image is at or just inside of the 1st focal point f_e of the eyepiece.

- The separation of the two lens: $d = f_o + L + f_e$

- Magnification: $M = M_o M_e = -\left(\frac{L}{f_o}\right)\left(\frac{25}{f_e}\right)$ Unit: cm

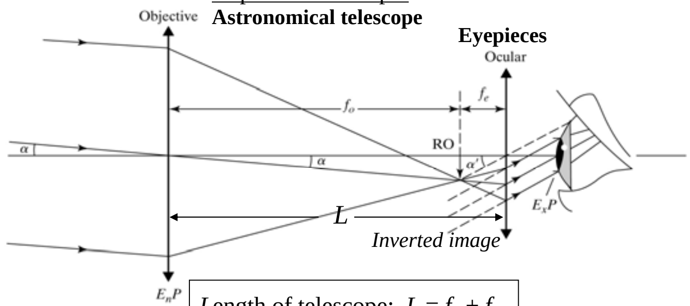
or $M = \frac{25}{f_{eff}}$ with $\frac{1}{f_{eff}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

d: Separation of the two lenses
L: Distance between the 2nd focal point and the objective image

Optical Instrumentation

3.7 Telescopes:

Keplerian telescope:
Astronomical telescope

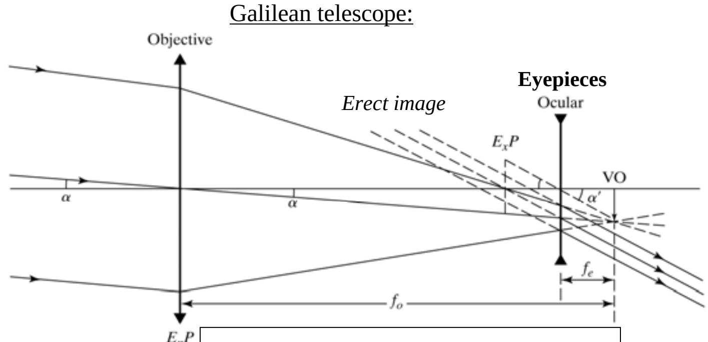


Length of telescope: $L = f_o + f_e$

- Eyepiece is located so that 1st focus overlaps 2nd focus of Objective
- Nearly parallel rays of light from a distant object are collected by a positive lens--Objective, formed a real inverted image in its focal plane
- Then the intermediate image, located at or near the focal point of eyepiece, serves as a real object for the Ocular
- Angular magnification (when image is viewed at infinity): $M = \frac{\alpha'}{\alpha} = -\frac{f_o}{f_e}$

Optical Instrumentation

Galilean telescope:



Length of telescope: $L = f_o + f_e$ ($f_e < 0$)

- Angular magnification: $M = \frac{\alpha'}{\alpha} = -\frac{f_o}{f_e}$