

Laws of refraction

Snell's law: $n_1 \sin i_1 = n_2 \sin i_2$

The refracted ray is in the same plane as the incident ray and the normal to the medium at the point of incident but on the opposite side of the normal from the incident ray.

Critical angle:

$if\ i = c\ and\ r = 90^\circ,\ \frac{n}{n_a} = \frac{1}{\sin c}$

$\frac{n_2}{n_1} = \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{t}{t'}$ (light passes from 1 to 2)

Combination of thin lenses:

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

Power of a lens:

$P = \frac{1}{f}$, f is in metres

Difference between real and apparent depth:

$d = t(1 - \frac{1}{n})$

Conjugate points:

$xx' = f^2$

Refraction at prism:

Angle of deviation : $d = i_1 + i_2 - A$ where $A = r_1 + r_2$

Minimum Angle of deviation : $d = 2i - A$, ($i_1 = i_2 = i$, $r_1 = r_2 = r$, $A = 2r$) or $n = \frac{\sin \frac{A+D}{2}}{\sin \frac{A}{2}}$

Maximum Angle of deviation : $i_1 = 90^\circ$ or $i_2 = 90^\circ$

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Astromomical telescope (Keplerian telescope)

convex lenses with

$f_o < f_e$, $f_o + f_e = d$, $u_o = \infty$, $v_o = f_o$, $u_e = f_e$

first image is diminished, inverted real, second is magnified inverted

Normal adjustment : $v_e = \infty$, $M = \frac{\beta}{\alpha} = m_o \times m_e = \frac{f_o}{f_e}$

Abnormal adjustment : $v_e = D$, $M = \frac{\beta}{\alpha} = m_o \times m_e = (\frac{D+1}{D})(\frac{f_o}{f_e})$

Compound Microscope:

convex lens, $f_o < f_e$, first image is magnified inverted real, second is magnified inverted virtual.

Normal adjustment : $v_e = D$, $M = \frac{\beta}{\alpha} = m_o \times m_e = (\frac{v_o}{f_o} - 1)(\frac{-D}{f_e} - 1)$

Abnormal adjustment : $v_e = \infty$, $M = \frac{\beta}{\alpha} = m_o \times m_e = (\frac{v_o}{f_o} - 1)(\frac{D}{f_e})$

Magnifying glass:

convex lens, $u < f$, erect, magnified and virtual image

Normal adjustment : $v = D$, $M = \frac{\beta}{\alpha} = \frac{D}{f} - 1$

Abnormal adjustment : $v = \infty$, $M = \frac{D}{f}$ ($D = -25cm$)

Laws of Reflection

The angle of reflection equals the angle of incidence. ($i = r$)

The reflected ray is in the same plane as the incident ray and the normal to the mirror at the point of incidence.

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ (where u = object distance, v = image distance, f = focal length)

Linear magnification : $m = \frac{v}{u} = \frac{l}{h} = \frac{v}{f} - 1$

Angular magnification : $m = \frac{\beta}{\alpha} = \frac{v}{f} - 1$

Number of images

$n = \frac{360^\circ}{\theta} - 1$ (if n is even or n is odd when object lies on angle bisector)

$n = \frac{360^\circ}{\theta}$ (if n is odd when object does not lie on angle bisector)

Refraction

Optics

Reflection

Convex lens with fixed object and image:

$f = \frac{s^2 - l^2}{4d}$, (where $d = u + v$ and l = distance between two convex lens)

$u + v > 4f \Rightarrow 2$ real images

$u + v = 4f \Rightarrow 1$ real image

$u + v < 4f \Rightarrow$ no real images

Lensmaker's equation:

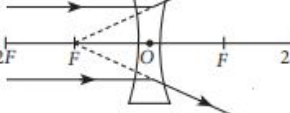
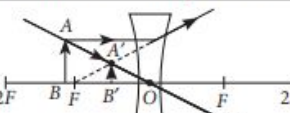
$\frac{1}{f} = (\frac{n_2}{n_1} - 1)(\frac{1}{r_1} + \frac{1}{r_2})$, (r is + when convex towards optically less dense medium)

| Curved | | | |
|--|-------------|--|---|
| Object distance, u | Ray diagram | Image distance, v | Characteristics |
| • At infinity • $u = \infty$ | | • At F • $v = f$ (focal length) • $v = \frac{1}{2}r$ (r = radius of curvature) | • Image is real, inverted and diminished. |
| • Slightly beyond C • $u > 2f$ • $u > r$ | | • Between C and F • $f < v < 2f$ • $\frac{1}{2}r < v < r$ | • Image is real, inverted and diminished. |
| • At C • $u = 2f$ • $u = r$ | | • At C • $v = 2f$ • $v = r$ | • Image is real, inverted and same size as object. |
| • Between C and F • $\frac{1}{2}r < u < r$ | | • Beyond C • $v > 2f$ • $v > r$ | • Image is real, inverted and magnified. |
| • At F • $u = f$ • $u = \frac{1}{2}r$ | | • At infinity • $v = \infty$ | • Image is virtual, upright and very large (magnified). • Reflected rays are parallel. |
| • Between F and P • $u < f$ • $u < \frac{1}{2}r$ | | • Behind the mirror • v = negative | • Image is virtual, upright and magnified. |

| Convex mirror | | | |
|---------------|-------------------------------|--|--------------------------------|
| Ray diagram | Object position | Image position | Nature of image |
| (a) | Between infinity and the pole | Behind the mirror between the focus and the pole | Virtual, smaller and erect |
| (b) | At infinity | Behind the mirror at the focus F | Virtual, point-sized and erect |

| Convex lens | | | | |
|----------------------------------|-------------|-------------------------|-------------------|--------------------------------------|
| | Ray diagram | Position of object | Position of image | Nature of image |
| (a) | | At infinity | At F | Real, inverted and highly diminished |
| $u = -ve, v = +ve$ and $f = +ve$ | | | | |
| (b) | | Between infinity and 2F | Between F and 2F | Real, inverted and diminished |
| $u = -ve, v = +ve$ and $f = +ve$ | | | | |

| | | | |
|----------------------------------|------------------|------------------------------|-------------------------------|
| (c) | At 2F | At 2F | Real, inverted and same sized |
| $u = -ve, v = +ve$ and $f = +ve$ | | | |
| (d) | Between F and 2F | Beyond 2F | Real, inverted and enlarged |
| $u = -ve, v = +ve$ and $f = +ve$ | | | |
| (e) | At F | At infinity | Real, inverted and enlarged |
| $u = -ve, v = +ve$ and $f = +ve$ | | | |
| (f) | Between F and O | On the same side of the lens | Virtual, erect and enlarged |
| $u = -ve, v = -ve$ and $f = +ve$ | | | |

| Concave lens | | | | |
|--------------|---|--------------------------|---------------------|--------------------------------------|
| | Ray diagram | Position of object | Position of image | Nature of image |
| (a) |  $u = -ve, v = -ve$ and $f = -ve$ | At infinity | At F | Virtual, erect and highly diminished |
| (b) |  $u = -ve, v = -ve$ and $f = -ve$ | Between infinity and O | Between F and O | Virtual, erect and diminished |