Thin Lenses \[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]

\[ m = \frac{h_i}{h_o} = \frac{-d_i}{d_o} \]

Converging Lens - Projector

For object \(\rightarrow\) real inverted image, could be enlarged or reduced

Converging Lens - Magnifying Glass

Near object \(\rightarrow\) virtual image, upright, always enlarged for converging lens

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]

\( L_{\text{big}} \) \( L_{\text{small}} \) \( L_{\text{negative}} \)
Camera / Eye

- Lens projects real image onto sensor or film
- Aperture controls amount of light and depth of field
- Shutter controls when and for how long the image is allowed to reach the sensor or film

Real Image is inverted. Limited Depth of Field.

Near Point \( (d_{np}) \) - Closest allowed obj.
Far Point \( (d_{fp}) \) - Furthest obj.

Typical person 25 cm - \( \infty \)
Corrective lenses

Farsighted - can see far things
  - needs weakly diverging rays.
  - Rays diverge too strongly.
  - Use converging lens

Strongly Weakly
Diverging Diverging

Place object a desired dist: \( d_0 = 25 \text{ cm} \)
Place virtual image at near point: \( d_f = -d_0 \)

Ex: Person can't see closer than 3 m.
\[
\frac{1}{d_0} + \frac{1}{d_f} = \frac{1}{0.25} + \frac{1}{-3} = 3.67 \text{ m}^{-1}
\]
Lens power in diopters

Focal length = \( f = \frac{1}{3.67} = 0.273 \text{ m} \)
Nearsighted ex: \( d_{fp} = 3 \text{ m} \)

Actual object @ infinity.

\[
\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{\infty} + \frac{1}{-3} = -0.333 \text{ m}^{-1}
\]

Focal length \( f = -0.333 = -3 \text{ m} \)

Virtual image at focal point.
Angular Size

\[ \tan \Theta_0 = \frac{h_0}{d_0} \]

Typically consider small angles,

\[ \sin \Theta \approx \Theta \quad \tan \Theta \approx \Theta \]

Magnifying Glass

Easy, relaxed viewing image @ \( \infty \).

Place object @ focal point.

\[ f = 5 \text{ cm} \]
\[ d_0 = 5 \text{ cm} \]

\[ \frac{1}{f} + \frac{1}{d_i} = \frac{1}{5} \]

\[ m = \frac{h_i}{h_0} = -\frac{d_i}{d_0} \]

\[ \theta = \frac{h_0}{f} \quad \text{with} \]

\[ \Theta_0 = \frac{h_0}{d_\text{np}} \quad \text{without} \]

Compare:

Angular Mag = \( \frac{h_0}{f} = \frac{d_\text{np}}{h_0/d_\text{np} - f} \)

Can get one more "notch" of magnification by straining eyes.

\[ \text{Max mag} = \frac{d_\text{np}}{f} + 1 \]
Compound Microscope

Objective: Projector - object just outside $f_o$
Image is inside microscope, $d_i = L$
Place image at distance $L$.

Gain Linear mag: $m = \frac{-d_i}{d_o} = \frac{-L}{F_o}$

Eyepiece: Magnifying Glass

Gain Angular mag: $M = \frac{d_{np}}{F_e}$

Overall Mag $M = \frac{-L \cdot d_{np}}{F_o \cdot F_e}$

Short $F_o, F_e \rightarrow$ big mag
Telescope or Binoculars

Object is huge, but stuck at infinity.

Without instrument: \( \theta_o = \frac{h_o}{d_o} \)

Given \( \theta_o \) \( d_o \) Both \( \infty \)

Objective - projects real intermediate image.
\( d_o \approx \infty \) \( d_i = f_o \)

The intermediate is relatively small.

Eye piece - magnifying glass.

\[
\theta_o = \frac{h_i}{f_o} \quad \theta_{with} = \frac{h_i}{f_e}
\]

\( h_i = \theta_o f_o \quad h_i = \theta_{with} f_e \)

\( \theta_o f_o = \theta_{with} f_e \)

\( \frac{f_e}{f_o} = \frac{\theta_{with}}{\theta_o} = \text{magnification} \)