$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

d_o: object - device distance

$d_o > 0$

d_i: image - device distance

$d_i > 0$: real

$d_i < 0$: virtual

f: focal length of device

$f > 0$: Converging

$f < 0$: diverging

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

$$\frac{1}{d_i} = \frac{d_o - f}{f\, d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

use any unit for distance

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$|M| = -\frac{f}{d_o - f}$$

If $f > 0$ Converging Device

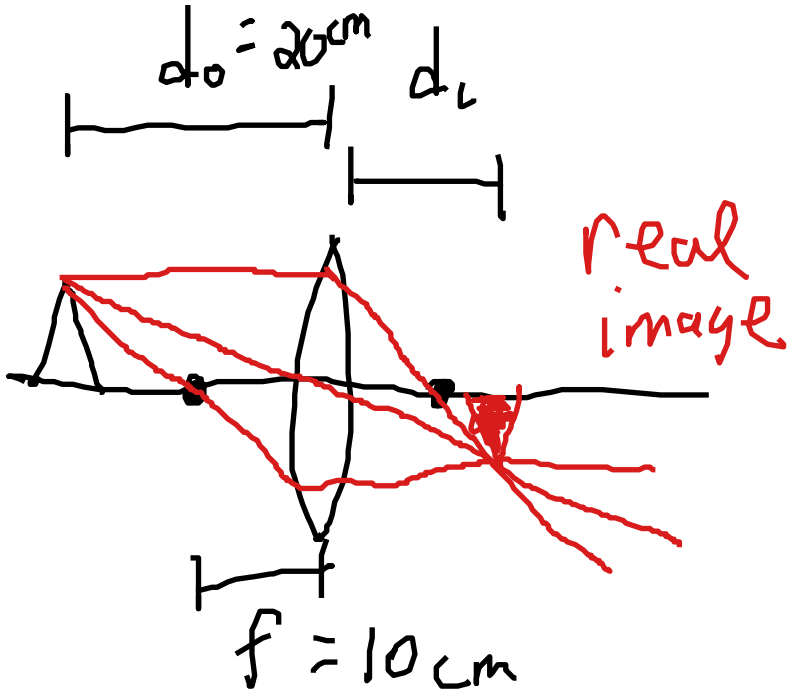
$$d_i = \frac{d_o f}{d_o - f}$$

$d_o f$ ← positive

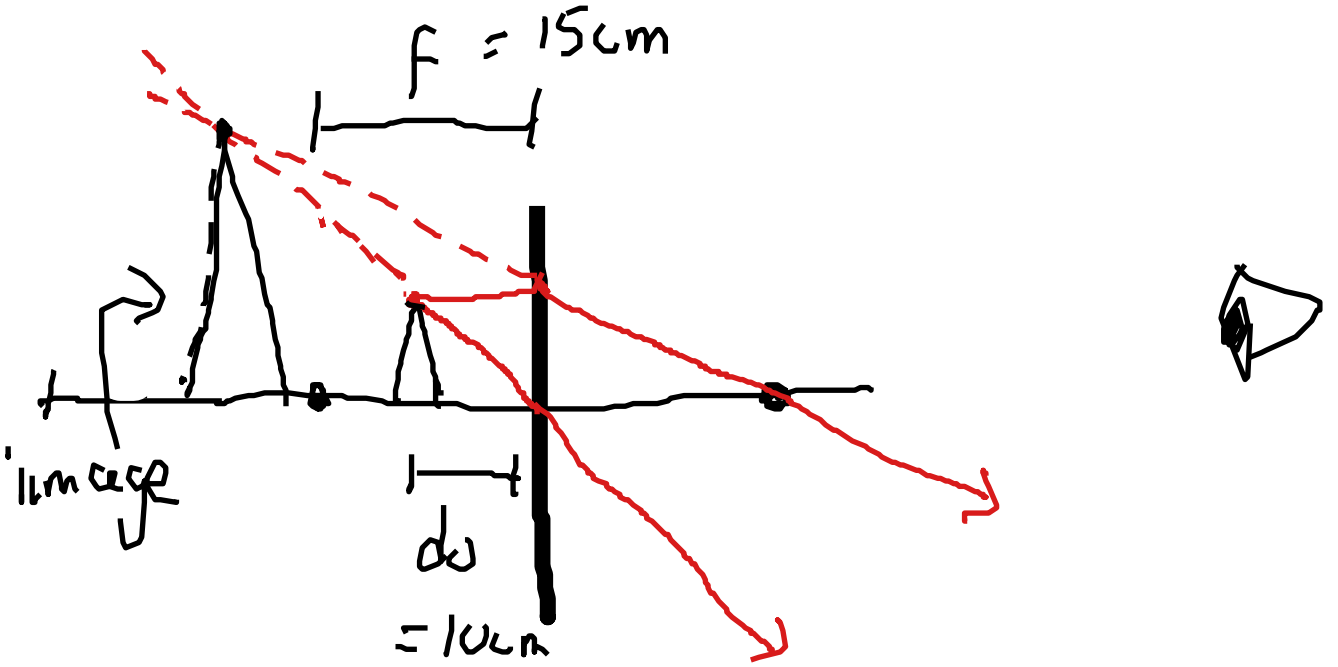
$d_o - f$ ↖

if $d_o > f$, $d_i > 0$: real

if $d_o < f$, $d_i < 0$: virtual



$$d_i = \frac{(20\,cm)(10\,cm)}{20\,cm - 10\,cm} = \frac{200}{10}\,cm = 20\,cm$$



$$d_i = \frac{(10)(15)}{10-15} = \frac{150}{-5} = -30\text{cm}$$

- negative d_i → virtual

- lens → virtual images on same side as object

- rays:
  draw two rays from object to lens, have them turn as if they are coming from the image

$$m = -\frac{f}{d_o - f}$$

if $d_o < f$

$$m = \frac{f}{f - d_o}$$

f ← positive

$f - d_o$ ← positive

$$f > f - d_o$$

→ $M > 1$ for virtual images

erected by converging devices

e.g. magnifying glass

if $d_o > f > 0$

$$M = -\frac{f}{d_o - f} < 0$$

$f \downarrow +$

$d_o \uparrow +$

real images

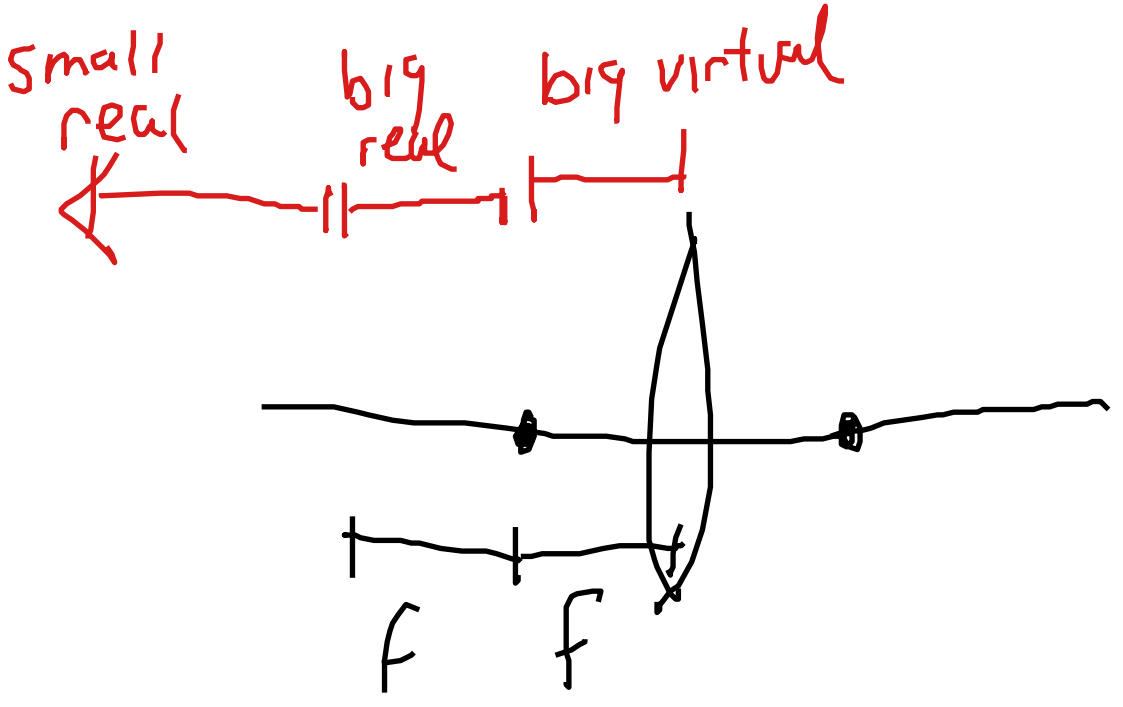
$M < -1$ (big image)

$$-\frac{f}{d_o - f} < -1$$

$$\frac{f}{d_o - f} > 1$$

$f > d_o - f \rightarrow 2f > d_o$

big images if object is close to focal point


small
real
big
real
big virtual
f
f

Diverging Devices ($f < 0$)

$$d_i = \frac{d_o f}{d_o - f}$$

$d_o f$ ← negative

$d_o - f$ ← positive

$d_i < 0$ always virtual

negative

$$m = \frac{f}{d_o - f}$$

f ← negative

$d_o - f$ ← positive

$$m = \frac{|f|}{d_o + |f|}$$

$|f|$ ← bigger

$m < 1$

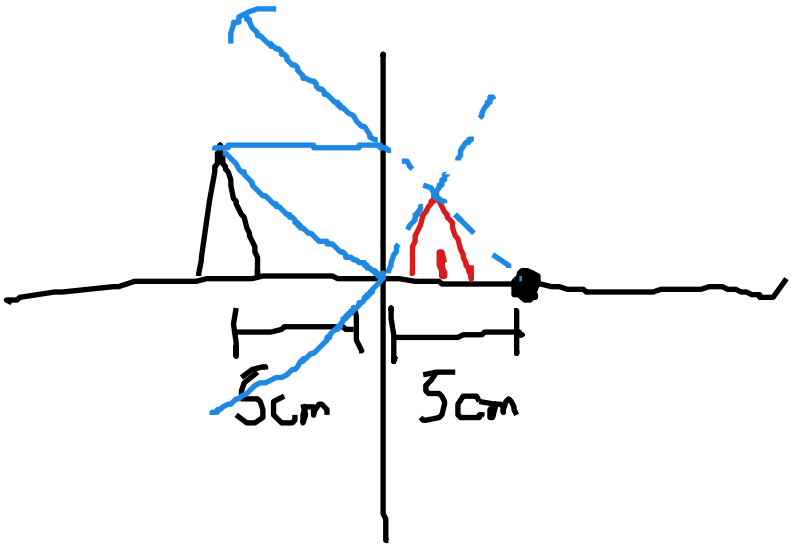
Diverging Devices

Create smaller virtual images

e.g. peepholes

convenience store mirrors

diverging mirror

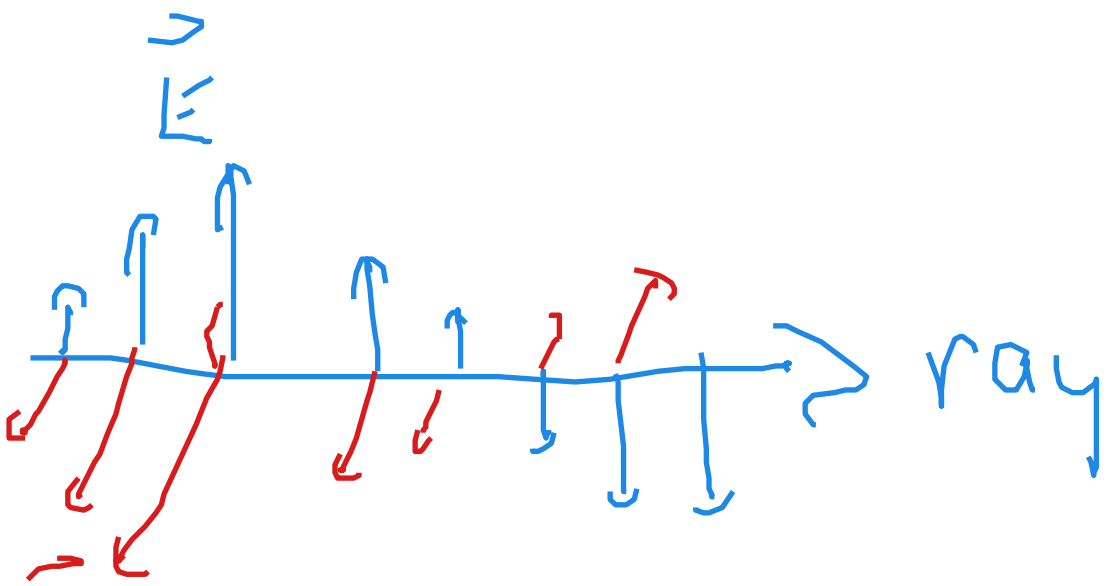


$$d_i = \frac{d_o f}{d_o - f} = \frac{(5)(-5)}{5-(-5)}$$

$$= \frac{-25}{10} = -2.5$$

$$M = -\frac{di}{d_o} = -\frac{-2.5}{5} = 0.5$$

Polarization



B

Polarization: direction of $\vec{E}$'s oscillation

- reflected light is partially polarized
- polarizers block one direction of polarization
- Crossed polarizers (90^0 apart) can block all light