



Thin lenses

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

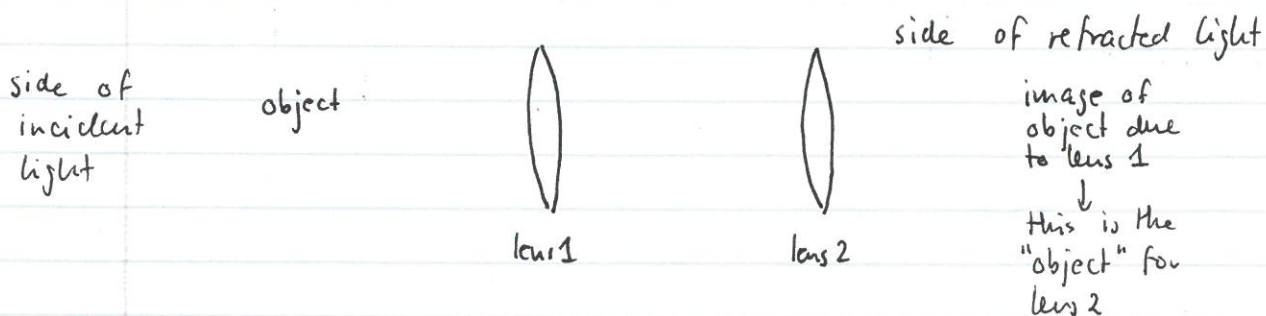
magnification $m = \frac{y'}{y} = -\frac{s'}{s}$

power of lens $P = \frac{1}{f}$ units: diopter [m^{-1}]

sign convention:

	+	-
object distance s	on the side of the incident light	on the side of the refracted light ⊗
image distance s'	on the side of refracted light ("on the other side") → real image	on the side of the incident light → virtual image
focal length f	converging lens  ("positive lens")	diverging lens  ("negative lens")
magnification m	upright	inverted

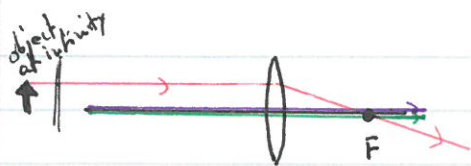
⊗ a negative object distance occurs in a system of two lenses where the image produced by the first lens is beyond the second lens



rays for ray diagram: parallel ray
focal ray
central ray

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

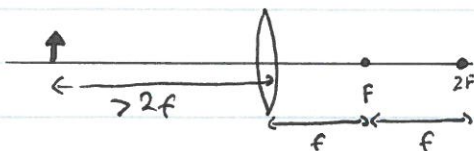
converging lens



$$s = \infty$$

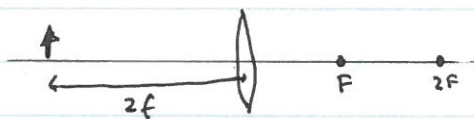
image is a point in F
 $\frac{1}{\infty} + \frac{1}{s'} = \frac{1}{f} \Rightarrow s' = f$ positive \rightarrow real image

(f positive)



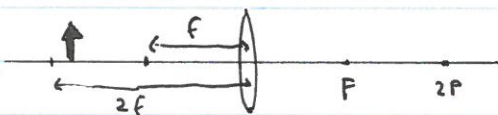
$$s > 2f$$

$f < s' < 2f$ s' positive \rightarrow real image
 $m = -\frac{s'}{s}$: m negative \rightarrow inverted
 $|m| < 1 \rightarrow$ smaller



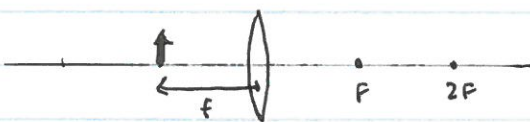
$$s = 2f$$

$\frac{1}{s'} = \frac{1}{f} - \frac{1}{2f} \Rightarrow s' = 2f$ positive \rightarrow real image
 $m = -\frac{s'}{s} = -1$ m negative \rightarrow inverted
 $|m| = 1 \rightarrow$ same size



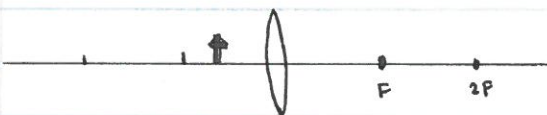
$$f < s < 2f$$

$s' > 2f$ positive \rightarrow real image
m negative \rightarrow inverted
 $|m| > 1 \rightarrow$ enlarged



$$s = f$$

$\frac{1}{s'} = \frac{1}{f} - \frac{1}{f} = 0 \Rightarrow s' = \infty$ no image

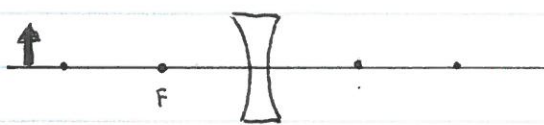


$$s < f$$

$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s}$ s' negative \rightarrow virtual image
 $m = -\frac{s'}{s}$ m positive \rightarrow upright
 $|m| > 1 \rightarrow$ enlarged

diverging lens

(f negative)



$$s = \infty$$

$\frac{1}{s'} = \frac{1}{f}$ or $s' = f$ f negative $\Rightarrow s'$ negative \rightarrow virtual

always virtual, upright, smaller

$0 < s < \infty$ $\frac{1}{s'} = \frac{1}{f} - \frac{1}{s}$ where f is negative

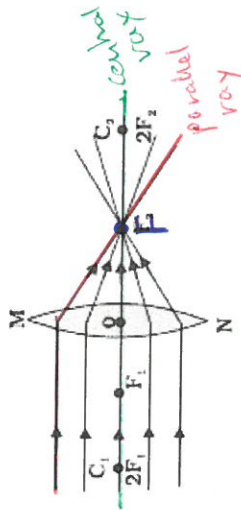
$\Rightarrow s'$ negative \rightarrow virtual

$m = -\frac{s'}{s}$ positive \rightarrow upright

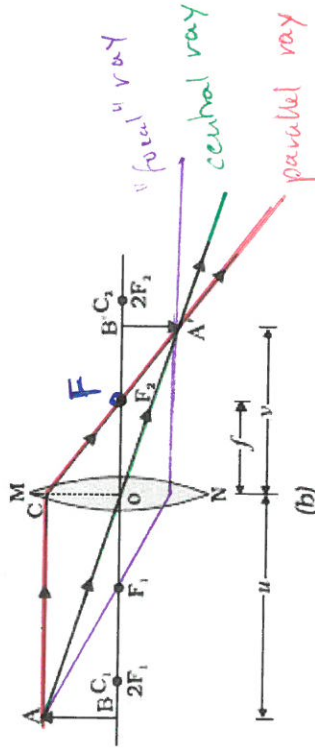
$|m| < 1 \rightarrow$ smaller

parallel ray
focal point
central ray

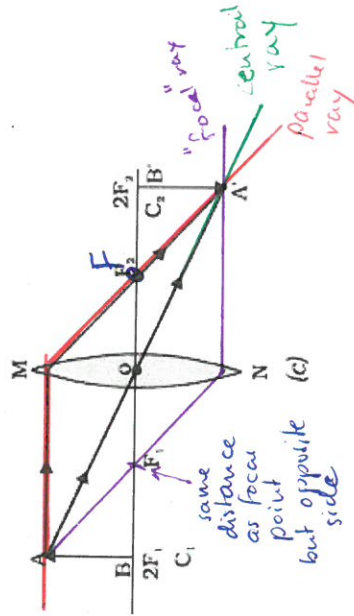
Converging (convex) lens



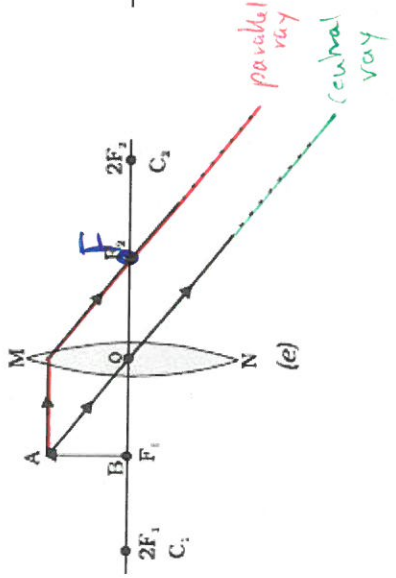
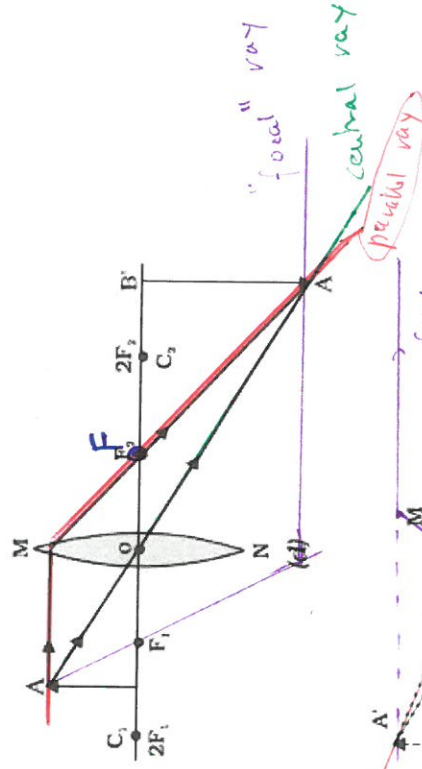
(a)



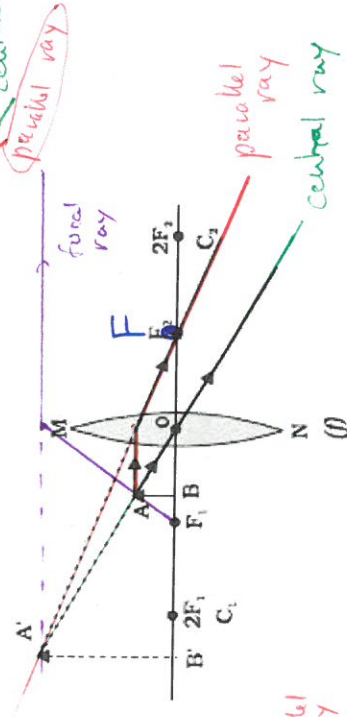
(b)



(c)

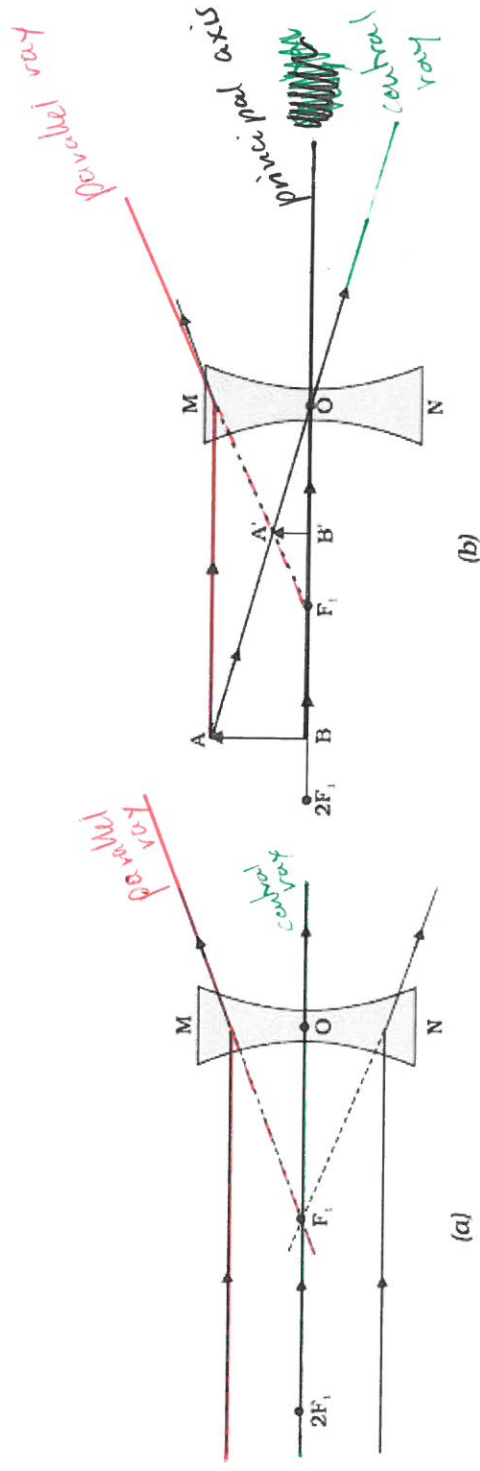


(e)



(f)

Diverging (concave) lens



→ Image is always virtual, upright, and smaller