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 $[m^{-1}]$

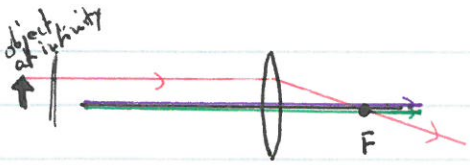
sign convention:	+	−
object distance s	on the side of the incident light	on the side of the refracted light ⊛
image distance s'	on the side of refracted light ("on the other side") → real image	on the side of the incident light → virtual image
focal length f	converging lens (⬯) ("positive lens")	diverging 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

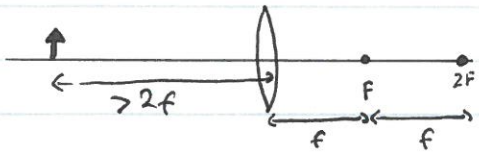
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

converging lens (f positive)



$s = \infty$ — image is a point in F

$\frac{1}{\infty} + \frac{1}{s'} = \frac{1}{f} \Rightarrow s' = f$ positive → real image

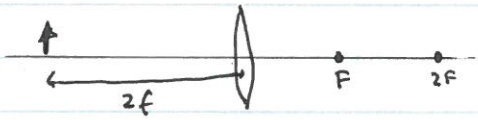


$s > 2f$

$f < s' < 2f$ s' positive → real image

$m = -\frac{s'}{s}$: m negative → inverted

$|m| < 1$ → smaller

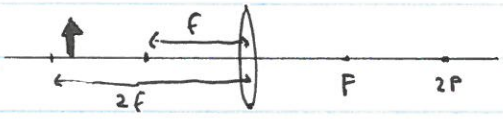


$s = 2f$

$\frac{1}{s'} = \frac{1}{f} - \frac{1}{2f} \Rightarrow s' = 2f$ positive → real image

$m = -\frac{s'}{s} = -1$ m negative → inverted

$|m| = 1$ → same size

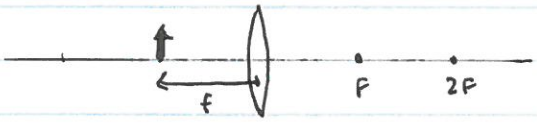


$f < s < 2f$

$s' > 2f$ positive → real image

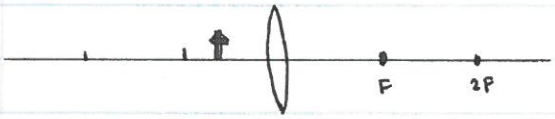
m negative → inverted

$|m| > 1$ → 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 → virtual image

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

$|m| > 1$ → enlarged

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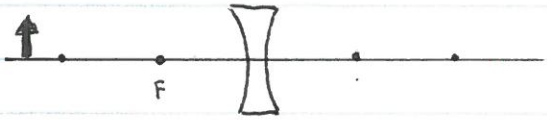
diverging lens (f negative)



$s = \infty$ $\frac{1}{s'} = \frac{1}{f}$ or $s' = f$ ⇒ f negative ⇒ s' negative → virtual

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

⇒ s' negative → virtual

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

$|m| < 1$ → smaller

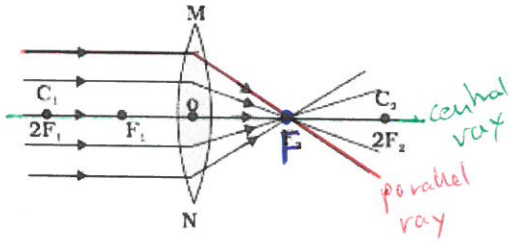
always virtual, upright, smaller

parallel ray

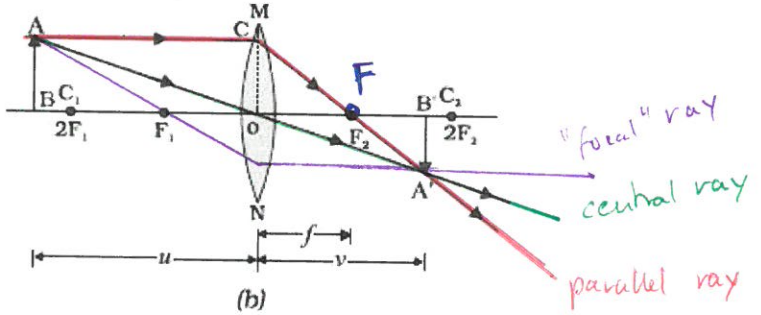
focal point F

central ray

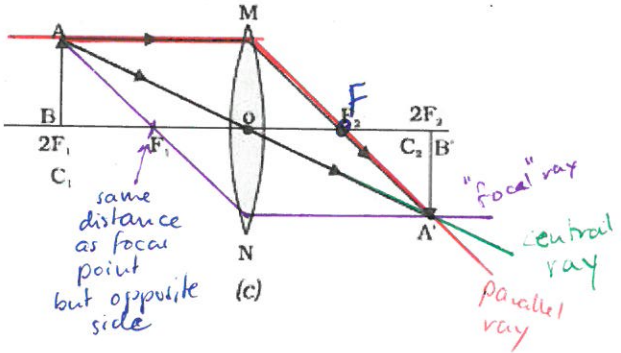
Converging (convex) lens



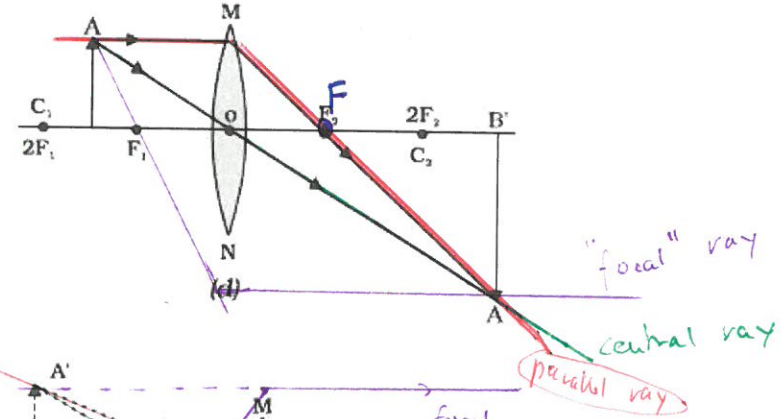
(a)



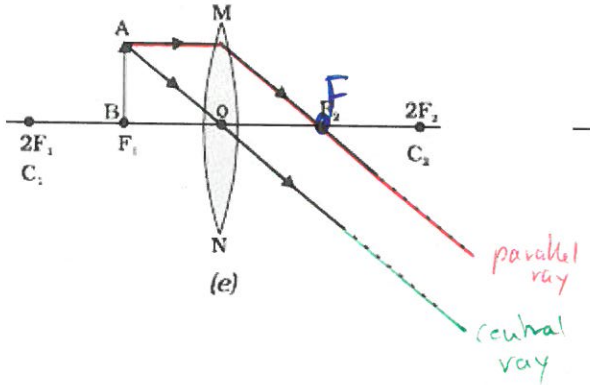
(b)



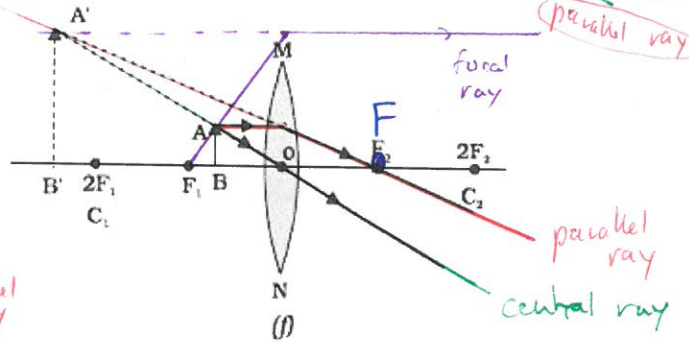
(c)



(d)

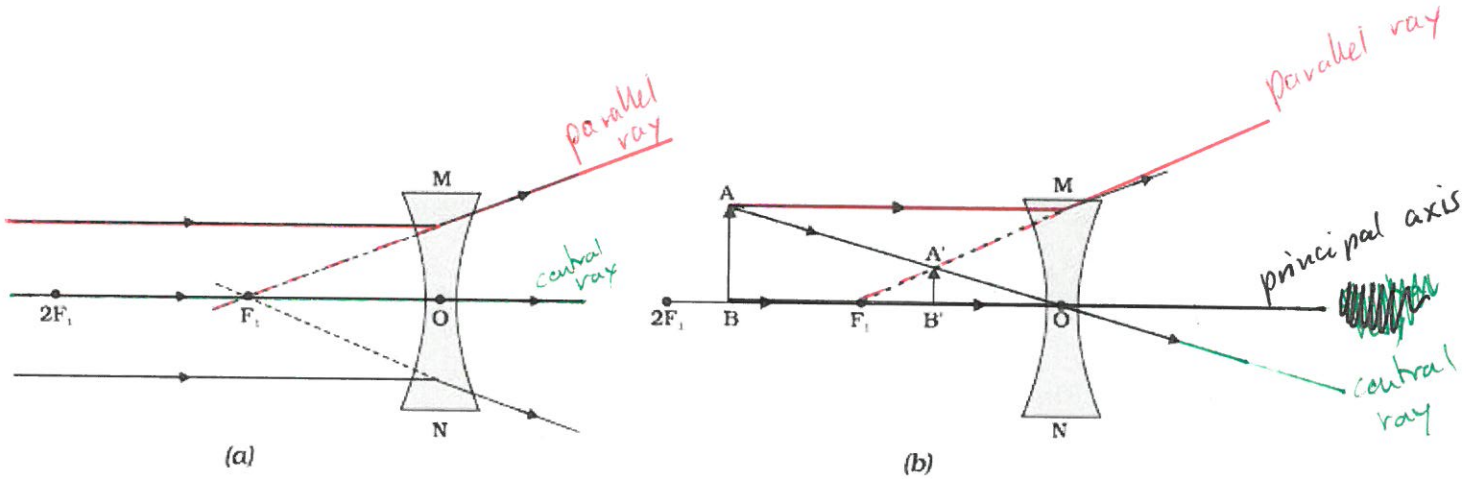


(e)



(f)

Diverging (concave) lens



→ Image is always virtual, upright, and smaller