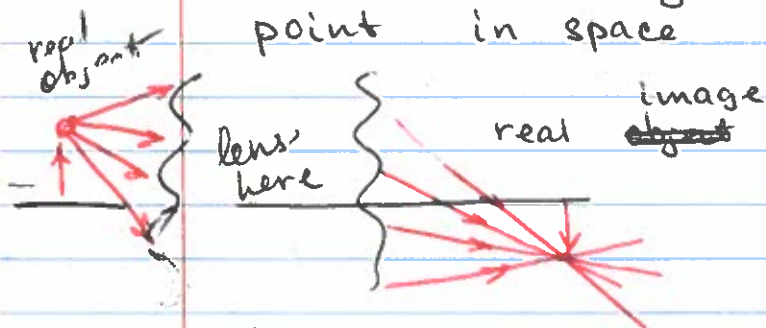


Imaging with lenses (cont)

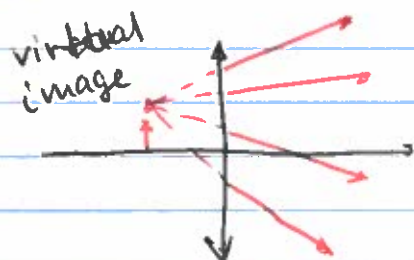
Real image — the rays emitted from an object and bent by the lens converge in one point in space after the lens



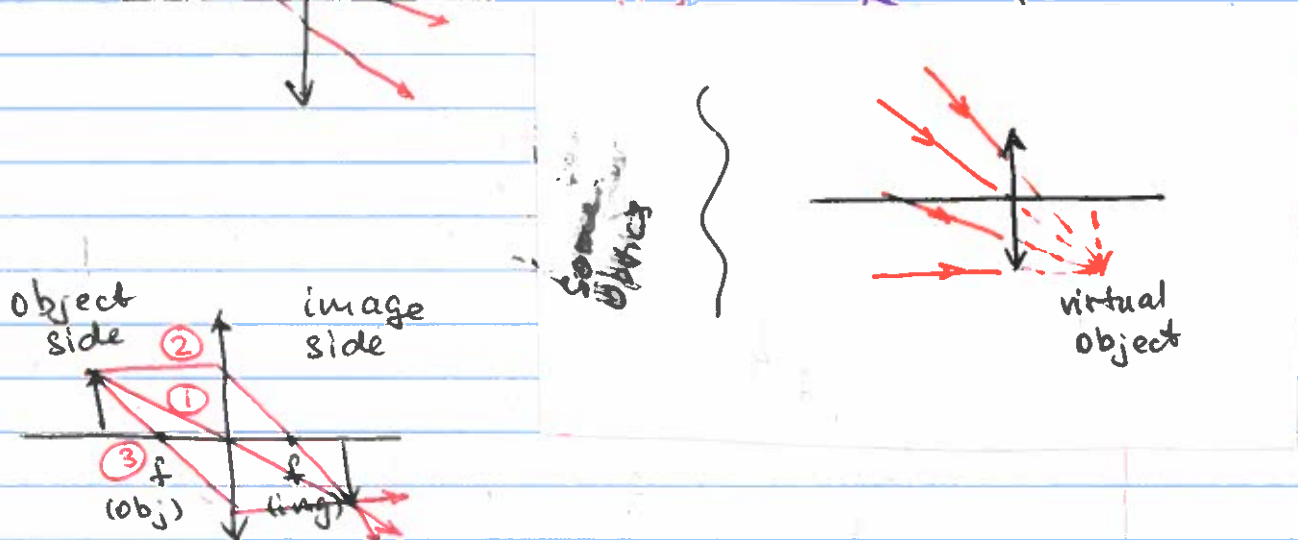
(Similarly, real object is a point in space all emitted rays emerge from)

V:

Virtual image : after the lens beams diverge as if they originate from a single point before the lens



virtual object (usually created by some optical element)



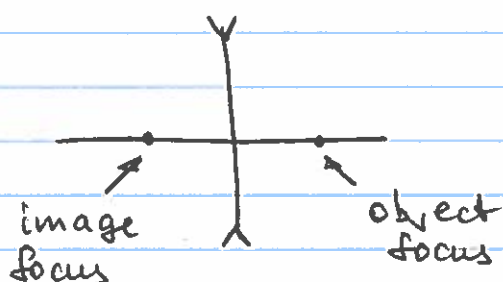
real object	(on the object side)	$d_o > 0$
virtual object	image side	$d_o < 0$

real image	(on the image side)	$d_i > 0$
virtual	object side	$d_i < 0$

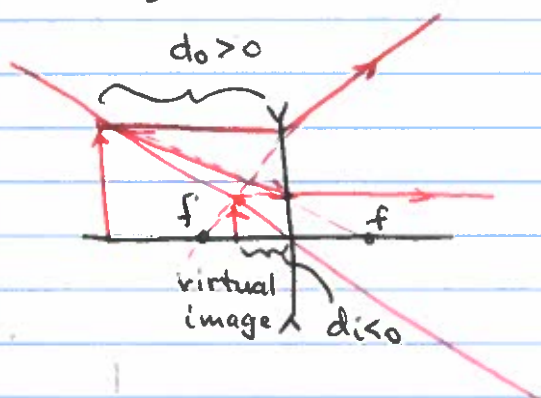
Three predictable imaging rays

- ① Through the center of the lens $\rightarrow$ no change
- ② Parallel on the object side $\rightarrow$ through the image focus
- ③ Through the object focus $\rightarrow$ parallel on the image side

Divergent lens is a negative lens
its focal length is negative



Remember: "negative distance" means "on the wrong side of the ~~lens~~ lens"



$$d_o > 0 \quad d_o > |f| \quad d_o > 0 \quad f < 0$$

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

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} < 0$$

$d_i < 0$ always
(for real object)

always a virtual image

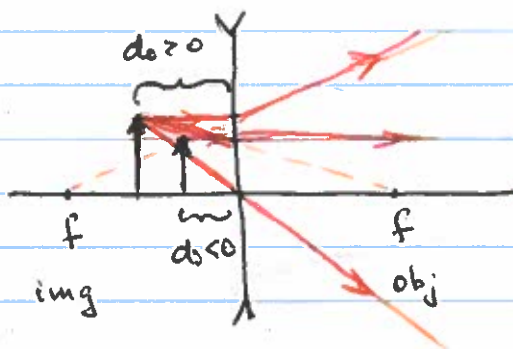
If $d_i < 0$ and $m = \frac{d_i}{d_o}$

the magnification is $m = -\frac{d_i}{d_o}$ then $m > 0$
and image is always erect

And it is always shrunk

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{d_o - f}{d_o \cdot f} = \left\{ f - |f| \right\} = -\frac{d_o + |f|}{d_o |f|}$$

$$d_i = -\frac{d_o \cdot |f|}{d_o + |f|} \quad m = \frac{d_i}{d_o} = \frac{|f|}{d_o + |f|} < 1$$



image

Converging/positive lens

$$d_i = \frac{d_o \cdot f}{d_o - f} \quad m = -\frac{f}{d_o - f}$$

$d_o > 2f$

real, inv, shrunk

$f < d_o < 2f$

real, inv, magn

$d_o < f$

virtual, erect, magn

Divergent/negative lens

for any d_o

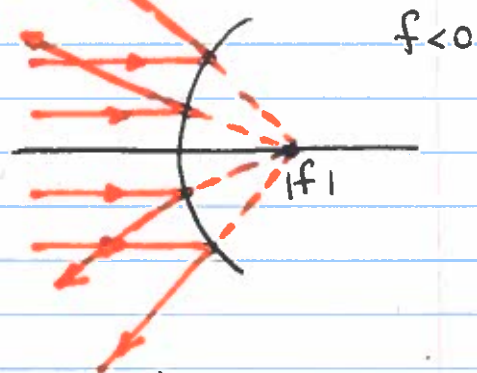
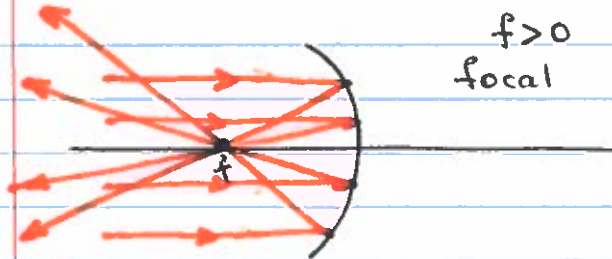
virtual, erect,
shrunk

$$d_i = -\frac{|f|}{d_o + |f|} < 0 \quad 0 < m = \frac{|f|}{d_o + |f|} < 1$$

Mirrors are like lenses but one sided

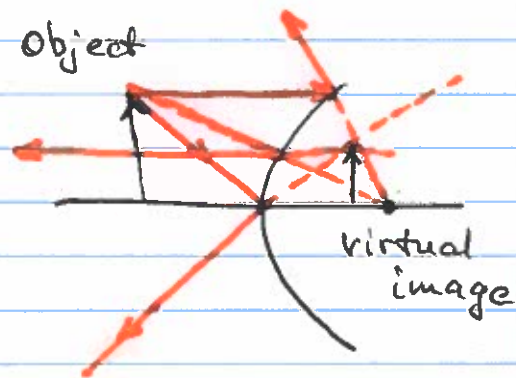
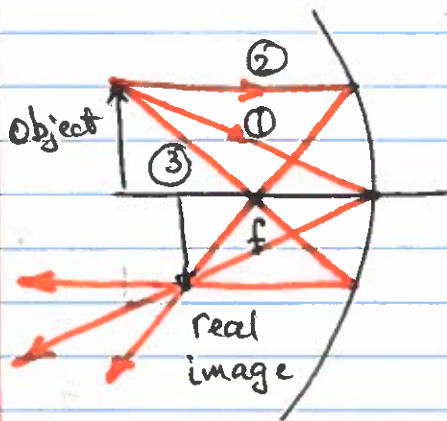
Real stuff is before the mirror, virtual stuff is behind the mirror

Mirrors also have focus



For spherical mirrors $f = \frac{1}{2} R$

Image formation is done the same way



- ① The ~~beam~~ ray hitting the center reflects as from a regular flat mirror
- ② The ~~beam~~ ray going parallel to the optical axis reflects to pass through the focus
- ③ The ray going through the focus reflects to travel parallel to the optical axis

Same formula works for lenses and mirrors

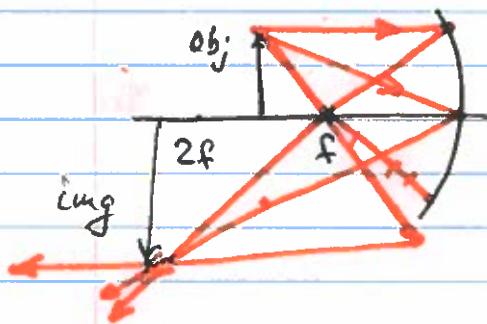
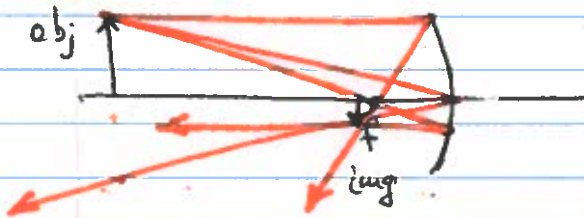
$$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$$

Concave mirror

$$d_i = \frac{f \cdot d_o}{f - d_o} \quad m = -\frac{f}{f - d_o}$$

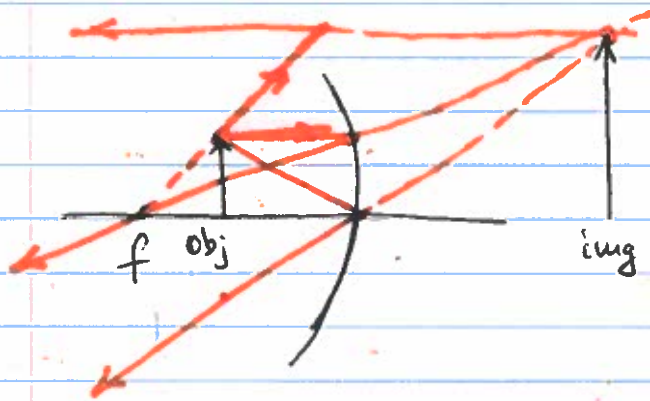
$$d_o > 2f$$

real, inverted, shrunk image



$$f < d_o < 2f$$

real, inverted, enlarged



$$d_o < f$$

virtual, erect, enlarged

Convex mirror

$$d_i = -\frac{|f| \cdot d_o}{|f| + d_o} \quad m = \frac{|f|}{|f| + d_o}$$

and d_o
virtual, erect, shrunk

