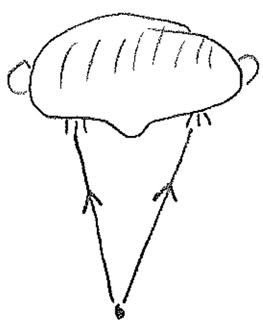
Binocular vision

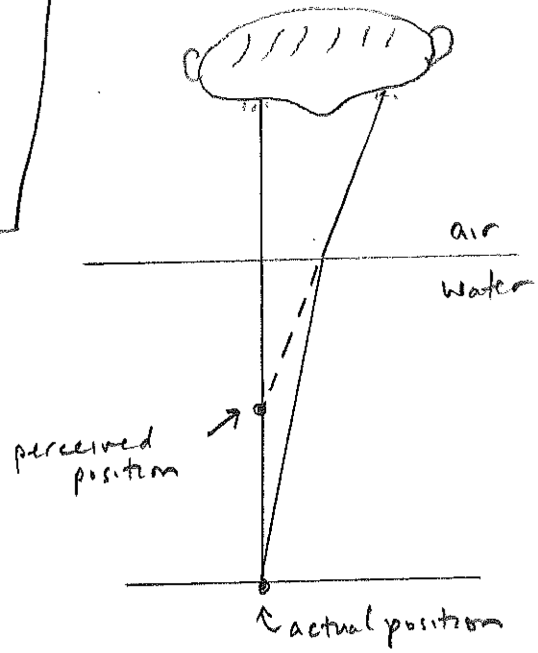
Both eyes are needed for depth perception.

DEMO: close one eye,
then try to bring your finger down on partner's



Your brain can fool you
when refraction occurs

[→ OH]

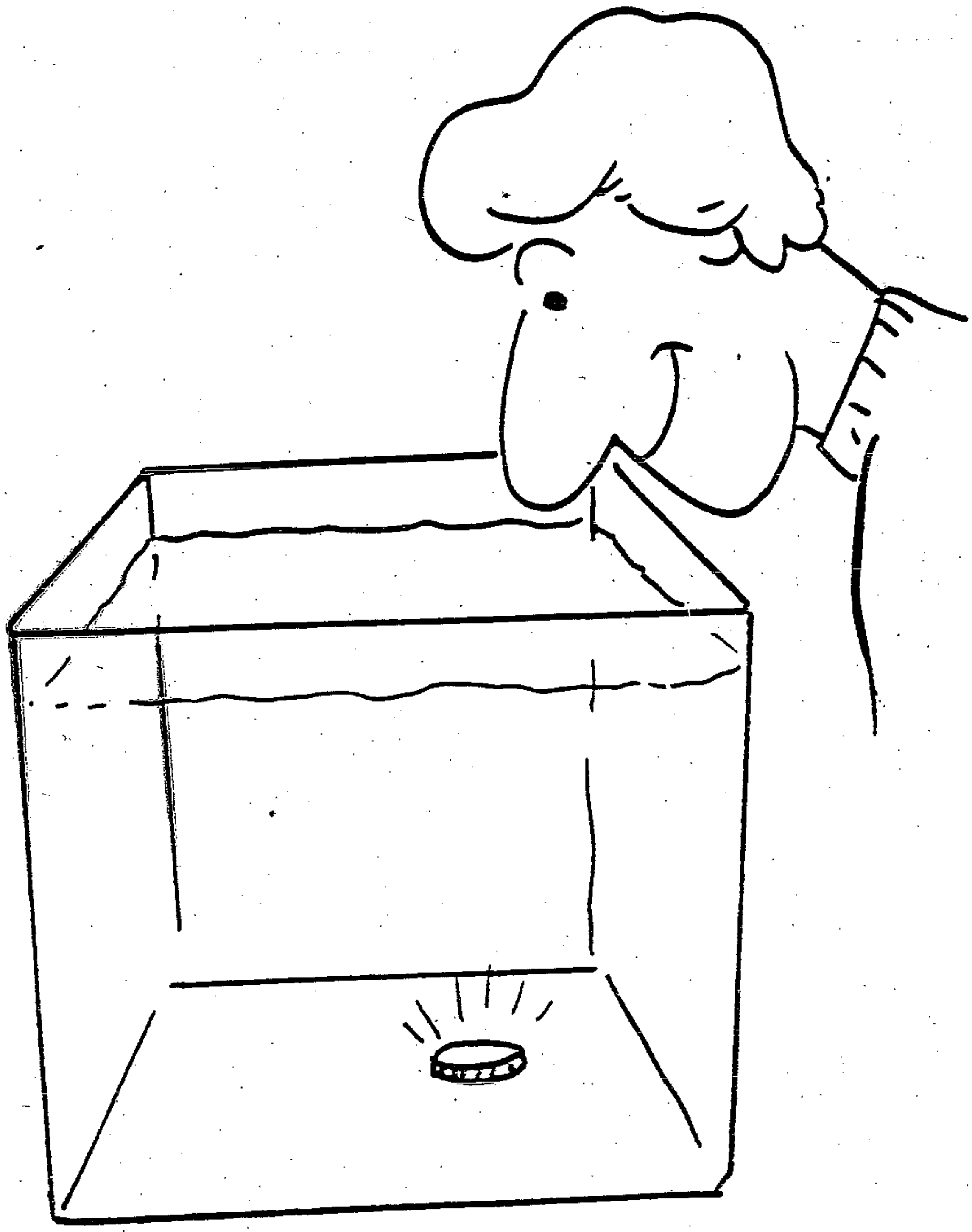


I COULD ALMOST TOUCH IT

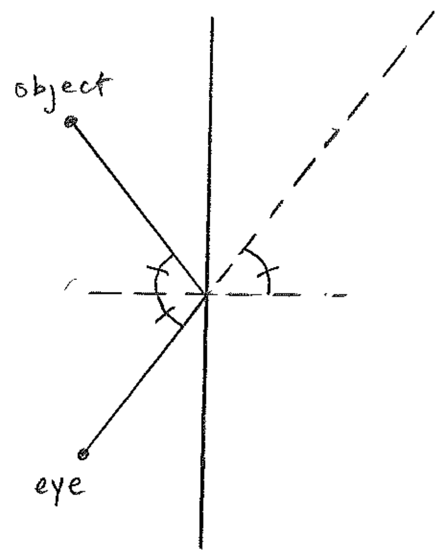
N2

A coin is under water. It appears to be

a) nearer the surface than it really is
b) farther from the surface than it really is
c) as deep as it really is



Virtual image formation by a plane mirror



Where is the image?

Need both eyes to tell.

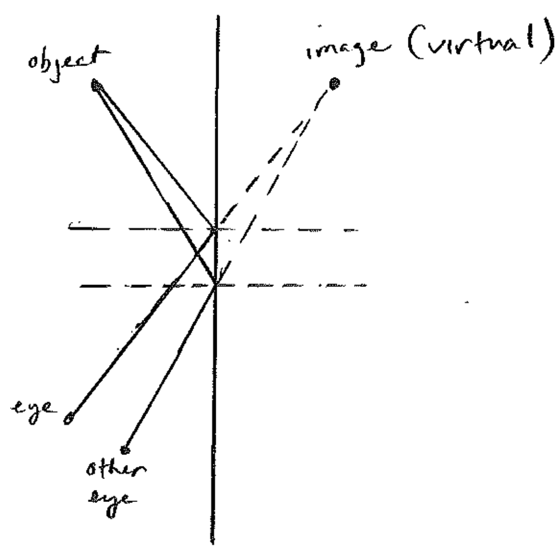
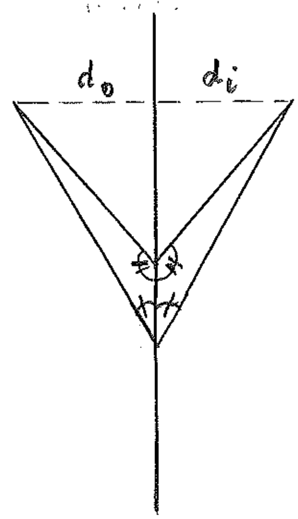


Image is located at point from which both rays appear to come.

Image is virtual because no rays actually come from it

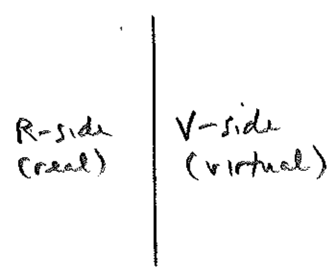
[brick wall behind mirror]

To show: image is located at equal distance from mirror as the object



congruent triangles $\Rightarrow$ $|d_i| = |d_o|$

[We assign signs to d according to whether they are on the R-side or V-side]



Distances on R-side are positive, so $d_o > 0 \Rightarrow d_o = |d_o|$
Distances on V-side are negative, so $d_i < 0 \Rightarrow d_i = -|d_i|$

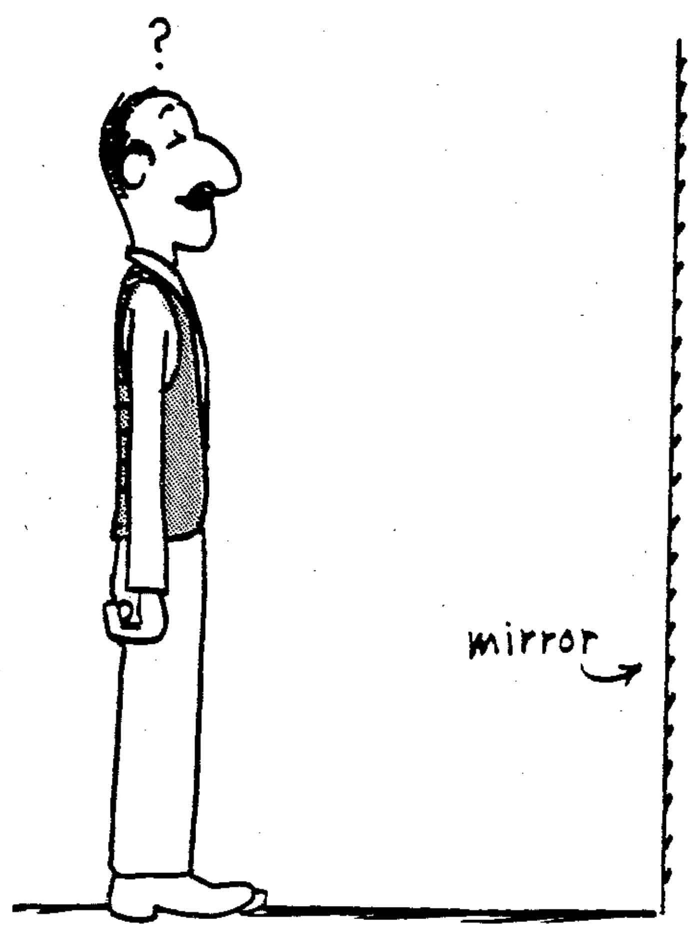
$$\boxed{d_i = -d_o \text{ for a plane mirror}}$$

PLANE MIRROR

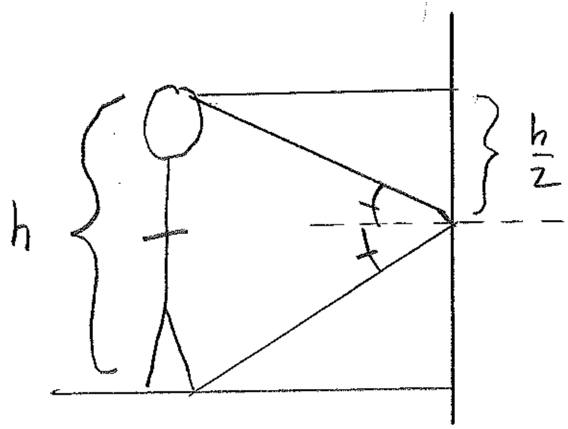
NS

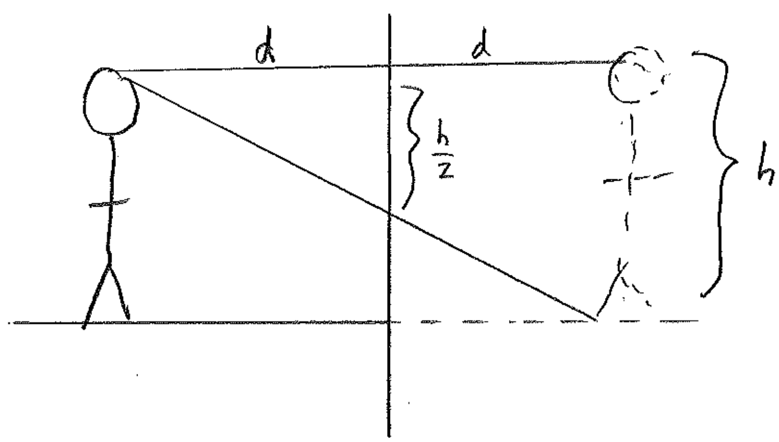
What must be the minimum length of a plane mirror in order for you to see a full view of yourself?

a) One-quarter your height
b) One-half your height
c) Three-quarters your height
d) Your full height
e) The answer depends on your distance.



[Two approaches]





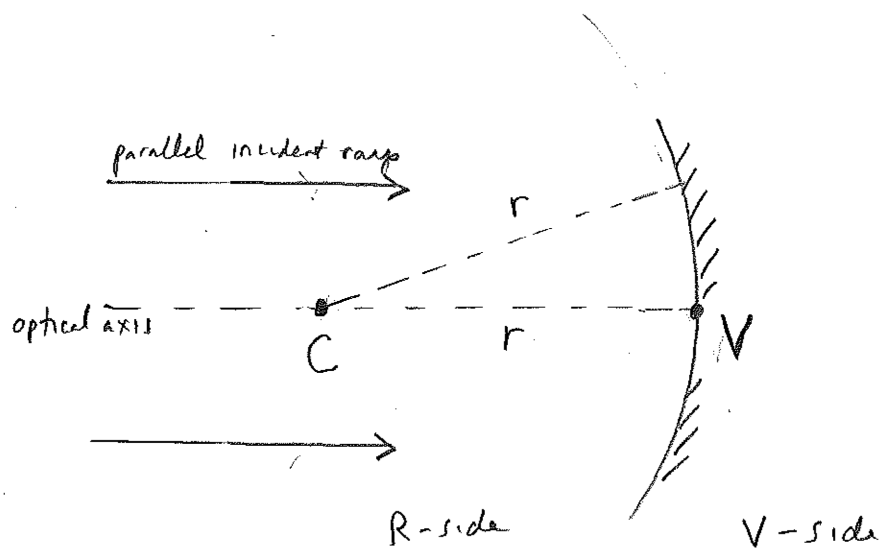
possible demo: hold a mirror against a wall ask a volunteer to move toward and away from mirror, and ask how much of their image they can see

Spherical mirrors (part of a sphere)

[show examples:
soup spoon: 2 in 1]

Convex

Concave



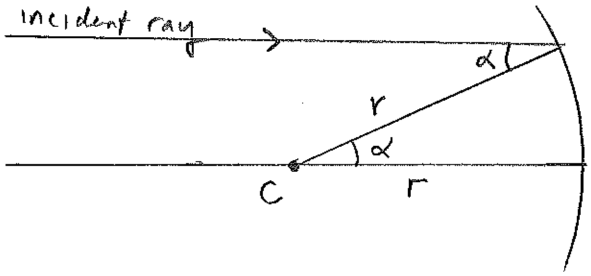
C = center of curvature

optical axis = line through C parallel to incident rays

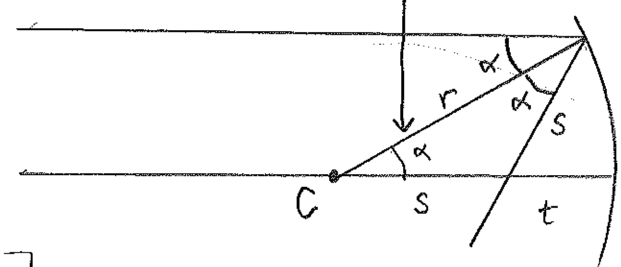
V = vertex, point where axis intersects mirror

r = CV = radius of curvature

$r > 0$ because C is on R-side



[alternate interior angles for parallel lines]



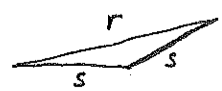
[law of reflection]

[isosceles]

[Alternatively,
$\alpha = \frac{mV}{CV}$
$2\alpha \approx \frac{mV}{FV}$
$\Rightarrow FV \approx \frac{1}{2} CV$]

$$s + t = r$$

Define paraxial rays as parallel rays close to optical axis so that angles α are small:

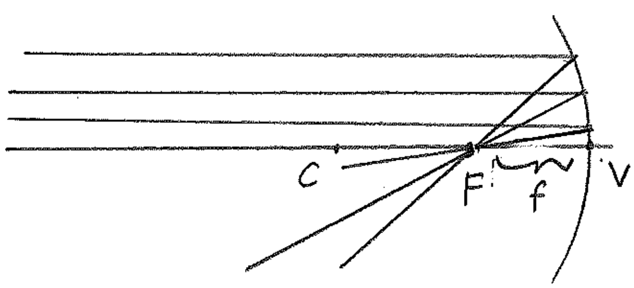


$r \approx 2s$

$s \approx \frac{1}{2} r$

$t \approx r - s \approx \frac{1}{2} r$

Takeaway: in a concave mirror, all paraxial rays are reflected to the same point F on the axis



F = focal point = focus

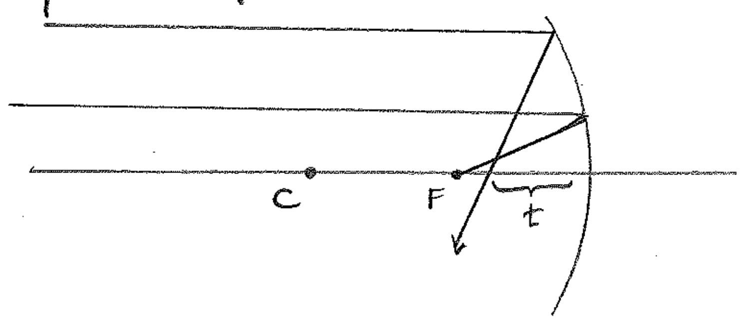
f = FV = focal length

$$\boxed{f = \tfrac{1}{2} r \text{ for a concave mirror}}$$

Non paraxial rays $\Rightarrow$ angles not small

$$r < 2s$$
$$s > \tfrac{1}{2}r$$
$$t = r - s < \tfrac{1}{2}r = f \Rightarrow t < f$$

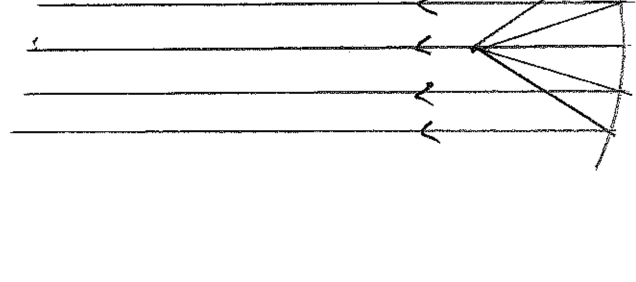
Nonparaxial rays are reflected to points between F and V



That not all rays are reflected to F called spherical aberration.

To get all rays to reflect to the same point use a parabolic mirror [TV satellite dish]

Principle of reversibility:
all rays coming <u>from</u> F reflect to give parallel rays



[auto headlights]

DEMO: candle and auto reflector $\Rightarrow$ ceiling

Image formation by a spherical mirror

DEMO: candle, concave mirror #38 ($r = 2.5\,m$, $f = 1.25\,m$)
large ground glass plate.

Have student hold candle far from mirror.
I locate focus ($\approx 1.25\,m$) on glass. Paraxial rays $\rightarrow$ F.

Student moves closer, I move away until I find image
Begin to see inverted image of flame.

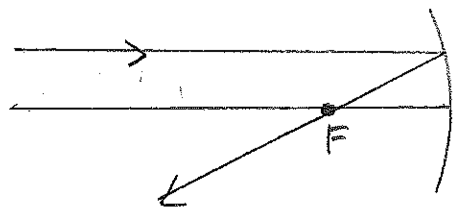
Image gets larger and forms on the wall.

Observations:

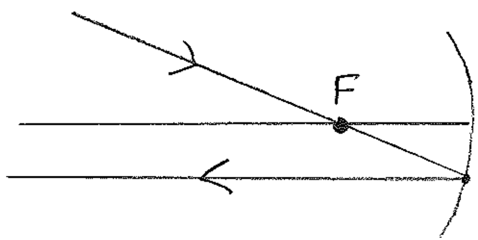
- image of flame is inverted
- as $d_o \downarrow$, $d_i \uparrow$
- as $d_i \uparrow$, size of image increases

DEMO: beginning of next class,
set out box and mirror w/ hidden bulb

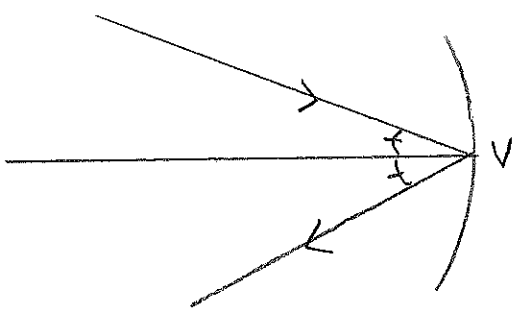
Four rules of ray tracing in a concave mirror



① a paraxial ray is reflected to pass through F

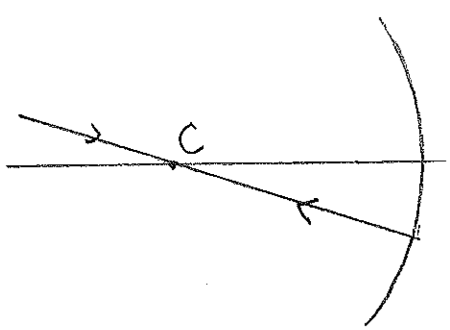


② a ray passing through F is reflected parallel to axis [reversibility]



③ a ray striking V is reflected at an equal angle across the axis

[mirror ⊥ to axis at V]

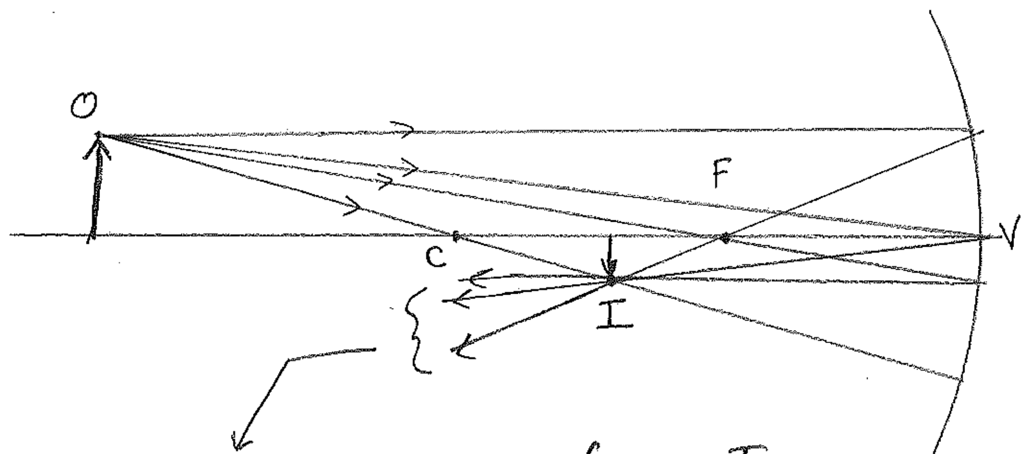


④ a ray passing through C is reflected to return through C

[mirror ⊥ to radius]

Real images

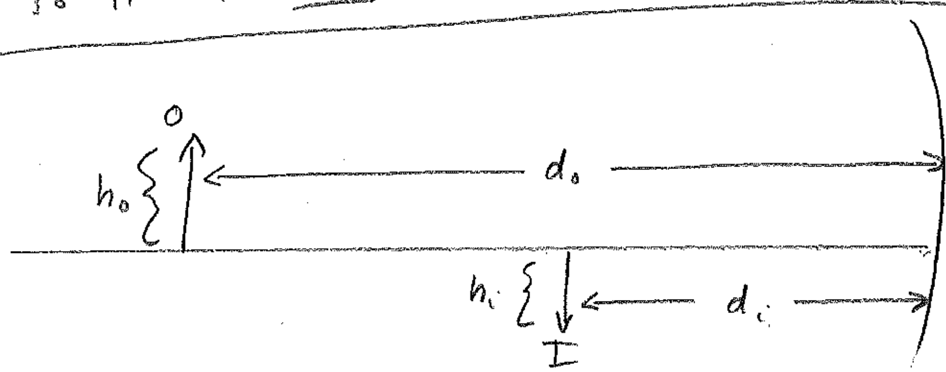
All rays diverging from a point O (object) reflected in a concave mirror reconverge to a point I (image)



These rays appear to come from I

and actually pass through I

so it's a <u>real</u> image



d_o = distance from object to mirror
d_i = distance from image to mirror } both positive since on R-side

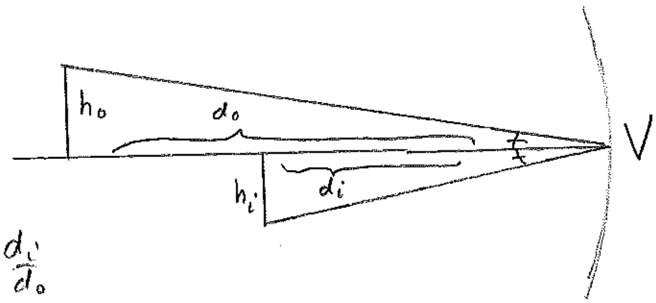
$h_o \doteq$ height (transverse size) of object (distance from axis)
h_i = height of image

We'll now show

① $\dfrac{h_i}{h_o} = \dfrac{d_i}{d_o}$

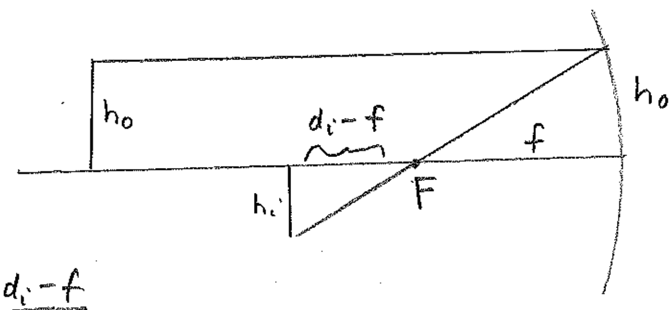
② $\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{1}{f}$

① follows from Rule 3:



similar triangles: $\dfrac{h_i}{h_o} = \dfrac{d_i}{d_o}$

② follows from Rule 1



Similar triangles: $\dfrac{h_i}{h_o} = \dfrac{d_i - f}{f}$

Combine equations $\dfrac{d_i}{d_o} = \dfrac{d_i - f}{f} = \dfrac{d_i}{f} - 1$

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

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

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

$\Rightarrow \boxed{\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{2}{r}}$ mirror equation

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Also valid for a plane mirror: $r = \infty$

$\Rightarrow \dfrac{1}{d_o} + \dfrac{1}{d_i} = 0 \Rightarrow d_i = -d_o$ ✓

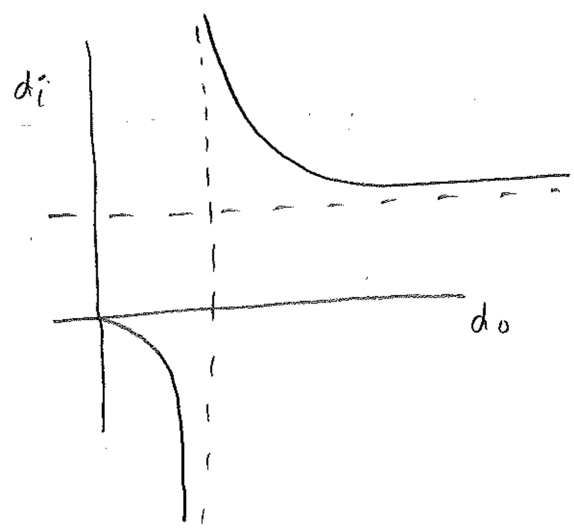
Solve $\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$ to find location of image

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

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

If $d_o = \infty$ (incoming rays are parallel), then $d_i = f$

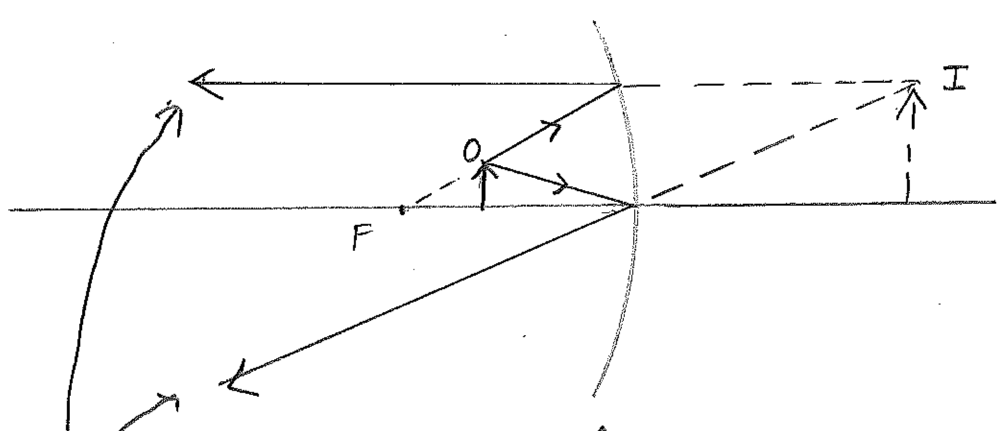
If $d_i = f$ (object is at focus, rays go out parallel), $d_i = \infty$



As $d_o \downarrow$, $d_i \uparrow$

[as we saw in demo]

If $0 < d_o < f$, then $d_i < 0$ $\Rightarrow$ image on V-side (virtual)



These rays appear to come from I but don't actually pass through I $\Rightarrow$ virtual image

[convex mirror done in problem set]

Magnification

m = (lateral) magnification

= ratio of transverse size of image to object

$= \pm \frac{h_i}{h_o}$

Choose + if image is upright (same as object)

− if image is inverted

For a real image in concave mirror, image is inverted

$m = -\frac{h_i}{h_o}$ but $\frac{h_i}{h_o} = \frac{d_i}{d_o}$ so

$\boxed{m = -\frac{d_i}{d_o}}$ magnification equation

For a virtual image, $d_i < 0$ so $m > 0$

image is upright

For a plane mirror, $d_i = -d_o$ so $m = 1$

image is same size as object