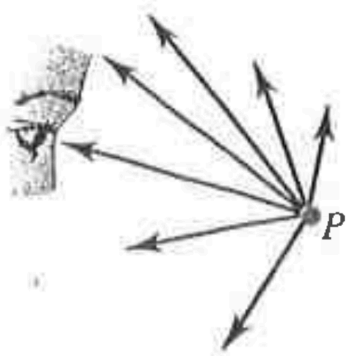
Geometric optics

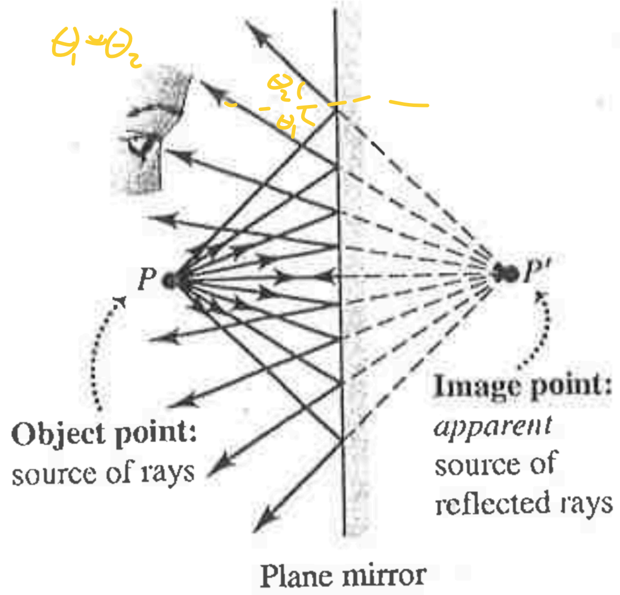
PHY117 HS2023

Week 10, Lecture 1
Dec. 19th, 2023
Prof. Ben Kilminster

34.1 Light rays radiate from a point object P in all directions. For an observer to see this object directly, there must be no obstruction between the object and the observer's eyes.

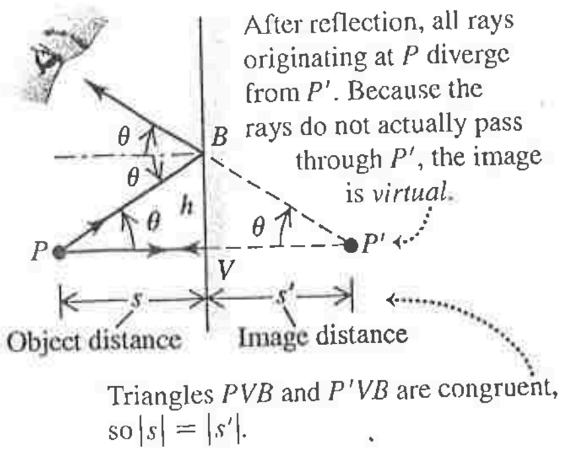


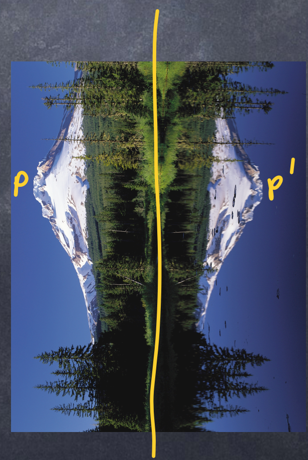
34.2 Light rays from the object at point P are reflected from a plane mirror. The reflected rays entering the eye look as though they had come from image point P'.



we can observe an object directly (P) or its image (P')

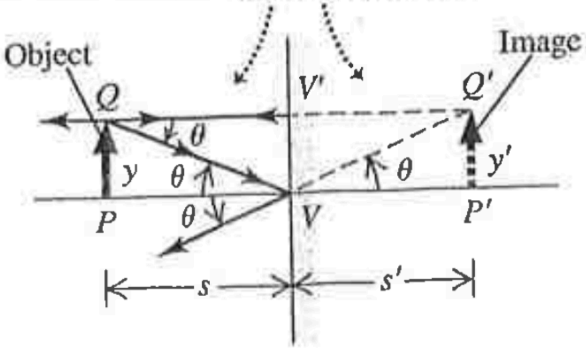
34.4 Construction for determining the location of the image formed by a plane mirror. The image point P' is as far behind the mirror as the object point P is in front of it.

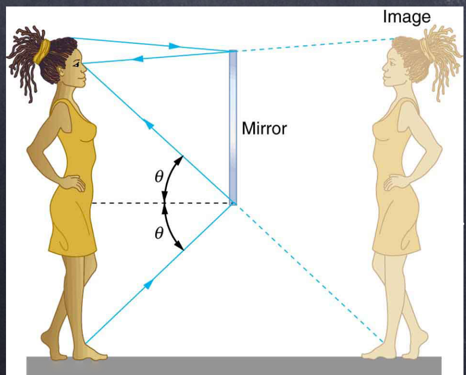




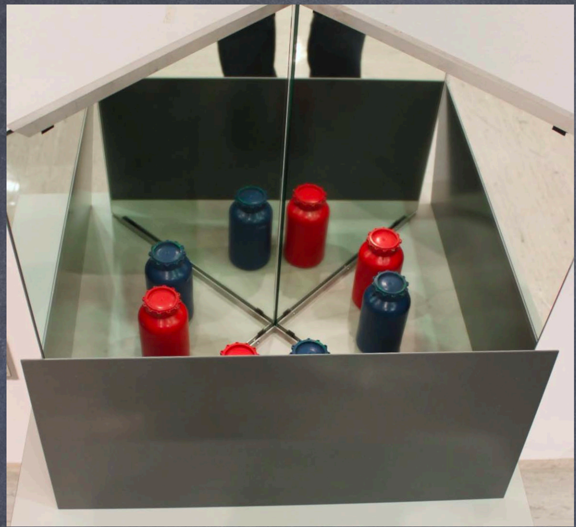
34.6 Construction for determining the height of an image formed by reflection at a plane reflecting surface.

For a plane mirror, PQV and $P'Q'V$ are congruent, so $y = y'$ and the object and image are the same size (the lateral magnification is 1).





Mirror size to see full body



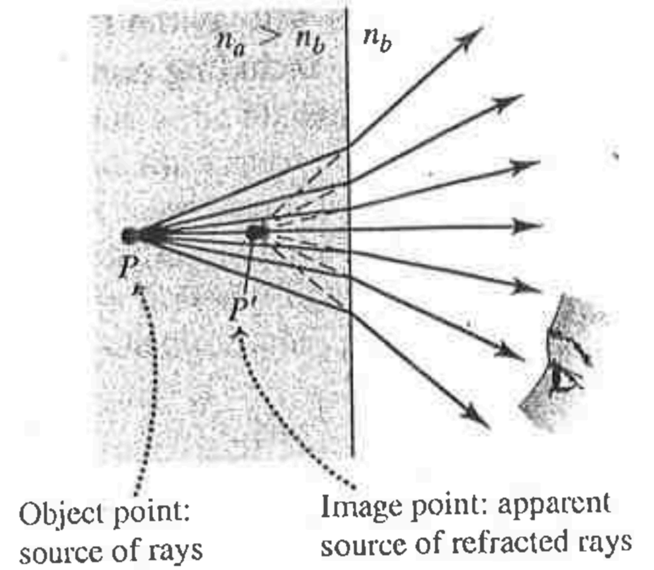
Mirror angle produces more images

90° : 3 images
60° : 5 images
30° : 11 images
⋮

(there is a formula, but not in this class)

34.3 Light rays from the object at point P are refracted at the plane interface. The refracted rays entering the eye look as though they had come from image point P'.

When $n_a > n_b$, P' is closer to the surface than P; for $n_a < n_b$, the reverse is true.

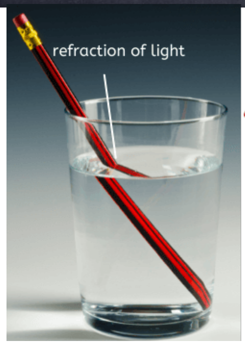


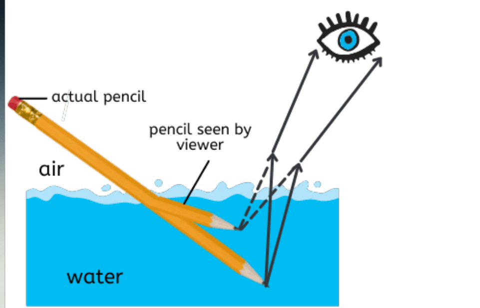
Instead, if we look through a transparent medium (water, glass) at an object p.

Refraction causes the distance to change, to a distance p'.

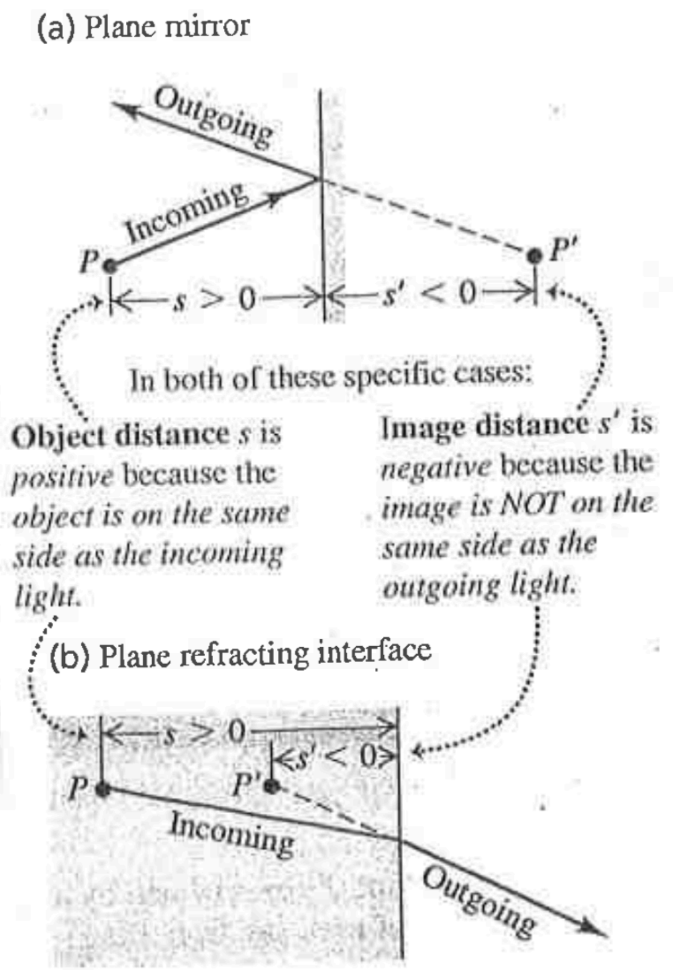
This is a "virtual" image because outgoing light rays do not pass through p'.

Figures 34.2 & 34.3 show "virtual images" because outgoing light rays do not pass through p'





34.5 For both of these situations, the object distance s is positive (rule 1) and the image distance s' is negative (rule 2).



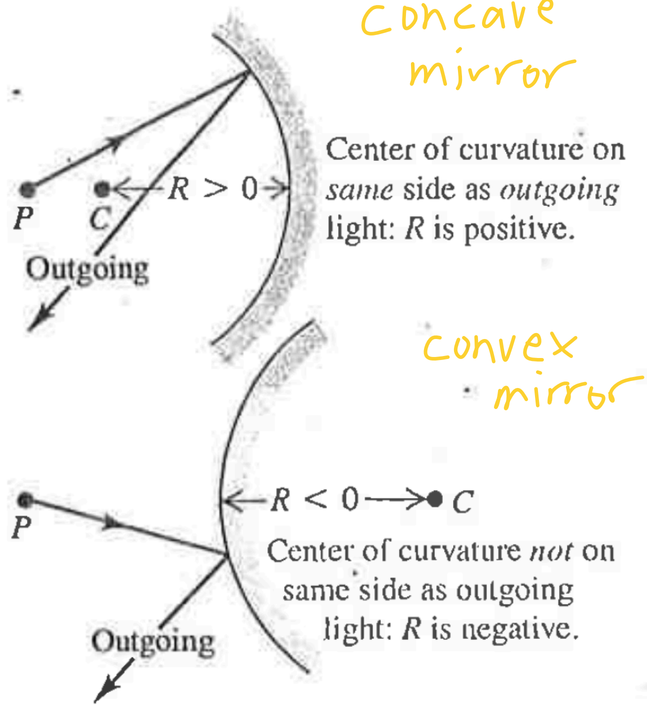
we refer to s as the distance from the object to the surface.

s': distance to the image.

objects: $s>0$ if object is on the same side as the incoming light to the surface

images: $s'>0$ if image is on the same side as the outgoing light from the surface.

34.11 The sign rule for the radius of a spherical mirror.



spherical mirrors cause light rays to

converge (concave mirrors)

or

diverge (convex mirrors)

Some terms:

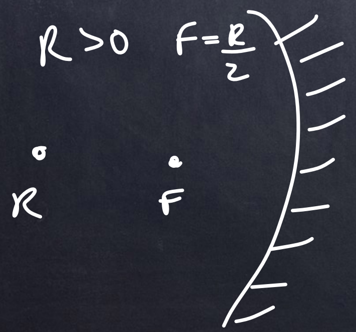
C: center of mirror if it was extended into a sphere.

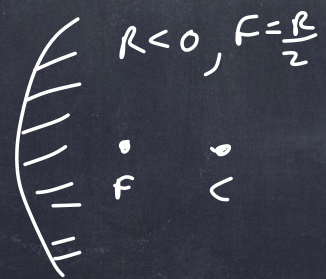
R: radius of the sphere

R can be + or −

F: focal point

$$F = \frac{R}{2}$$

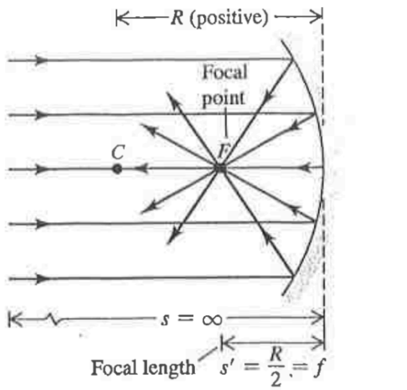




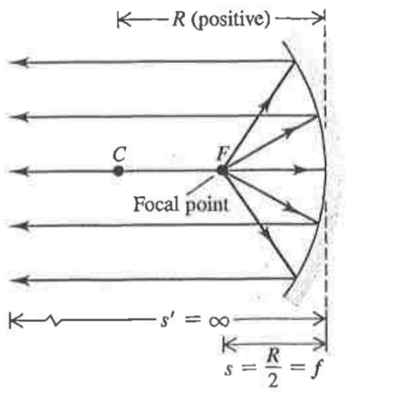
concave mirror

34.13 The focal point and focal length of a concave mirror.

(a) All parallel rays incident on a spherical mirror reflect through the focal point.



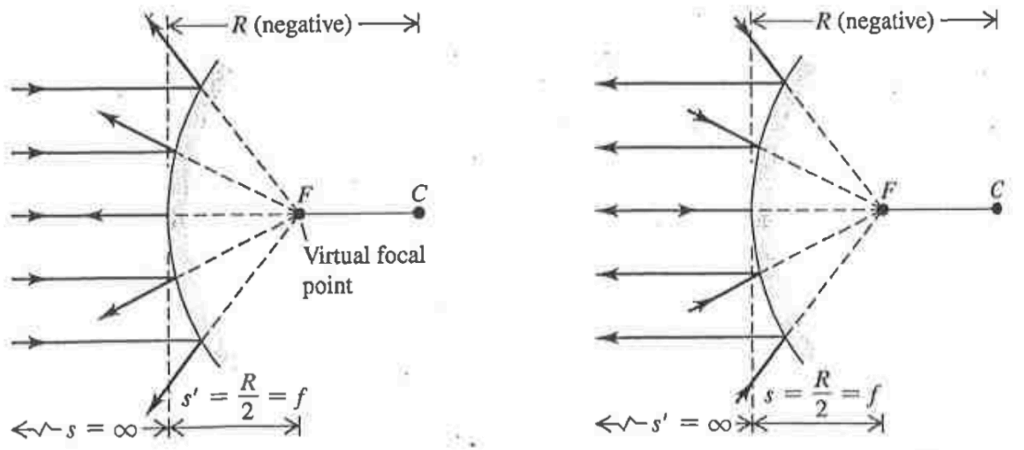
(b) Rays diverging from the focal point reflect to form parallel outgoing rays.



convex mirror

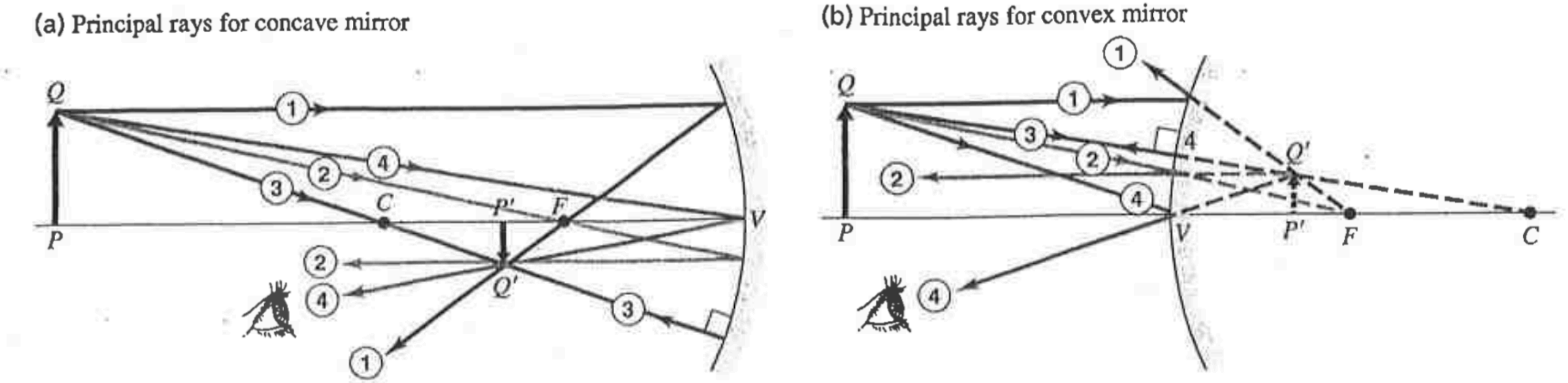
(a) Paraxial rays incident on a convex spherical mirror diverge from a virtual focal point.

(b) Rays aimed at the virtual focal point are parallel to the axis after reflection.



Rules for mirrors

34.19 The graphical method of locating an image formed by a spherical mirror. The colors of the rays are for identification only; they do not refer to specific colors of light.



(a)
1. Ray parallel to axis reflects through focal point.
2. Ray through focal point reflects parallel to axis.
3. Ray through center of curvature intersects the surface normally and reflects along its original path.
4. Ray to vertex reflects symmetrically around optic axis.

(b)
1. Reflected parallel ray appears to come from focal point.
2. Ray toward focal point reflects parallel to axis.
3. As with concave mirror: Ray radial to center of curvature intersects the surface normally and reflects along its original path.
4. As with concave mirror: Ray to vertex reflects symmetrically around optic axis.

Any 2 rays are enough to find the image, (position, & the height)

but more will check your answer.

Mirrors

An object has an image that is in general a different size + different distance from the center of the mirror surface

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

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

y': height of the image
y: height of the object

A negative m means the image is "inverted".

The rules for s (+ or −) are the same for mirrors + lenses.

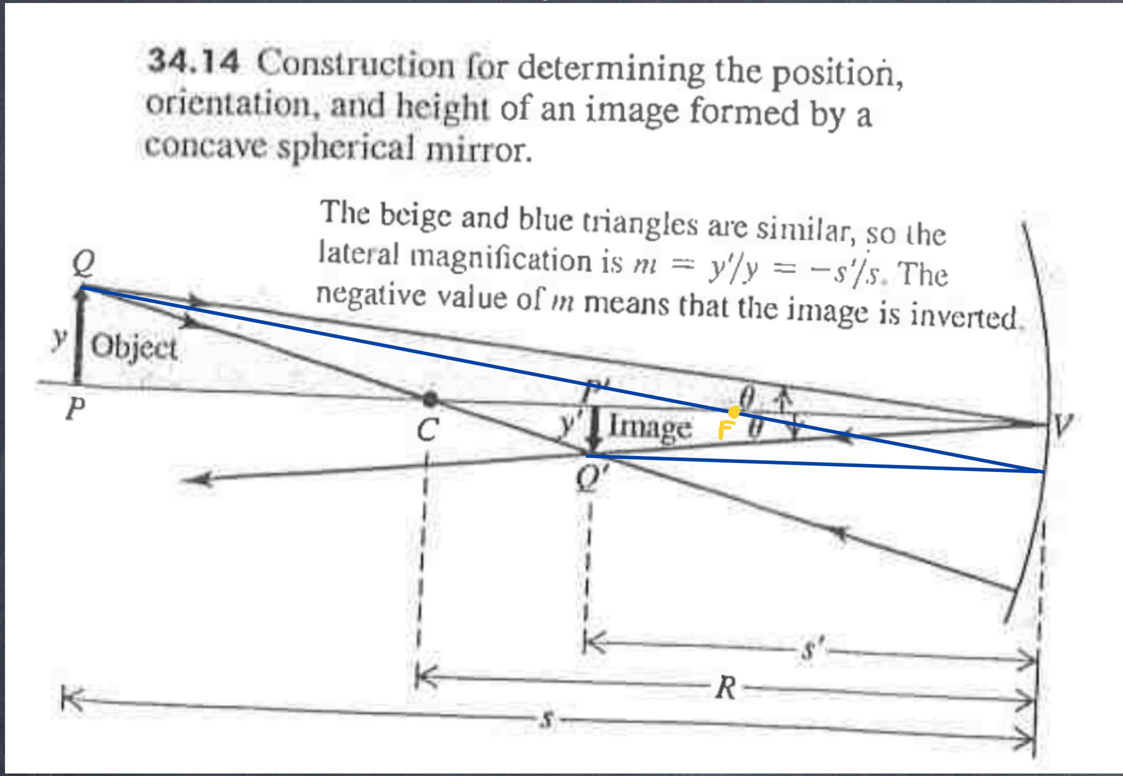
For mirrors

s + if the object is in front of the mirror (real object)
− if the object is behind the mirror (virtual object)*

s' + if the image is in front of the mirror (real image)
− if the image is behind the mirror (virtual image)

r, f + if the center of curvature is in front of the mirror (concave mirror)
− if the center of curvature is behind the mirror (convex mirror)

Example where object has +s > R



1: ray through the center reflected through the center

2: ray to vertex (v) reflected at same angle as incoming

3: ray through focal point is reflected parallel to CV

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

Example: An object 2cm tall is 3cm from a concave mirror with radius of curvature of 10 cm.
Where is the image? What is the image height?
Is it inverted? Is it real or virtual?

we know: $R = 10\text{ cm} \Rightarrow f = \frac{1}{2}R = 5\text{cm}$

$s = 3\text{cm}, \; y = 2\text{cm}$

we need: $s' + y'$

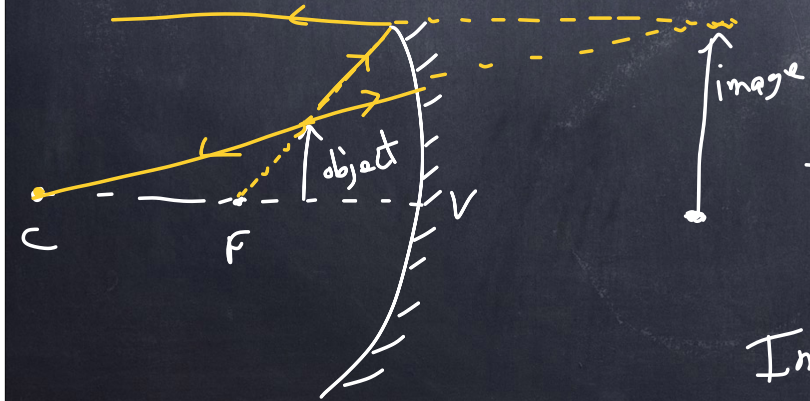
solve for s': $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \Rightarrow \frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{5\text{cm}} - \frac{1}{3\text{cm}}$

$$\frac{1}{s'} = \frac{3-5}{15\text{cm}} = \frac{-2}{15\text{cm}}$$

$$s' = -7.5\text{ cm}$$

(7.5 cm behind mirror.

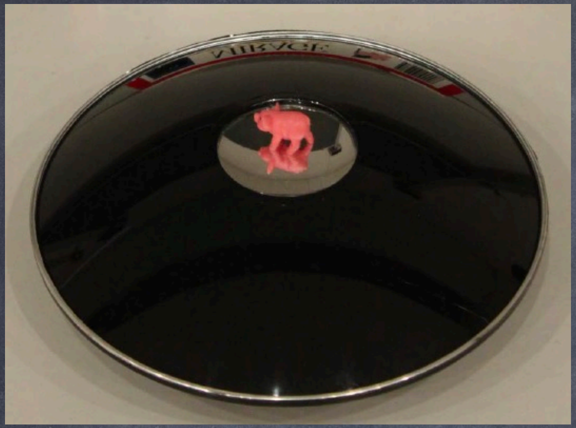
check



$$\frac{y'}{y} = m = \frac{-s'}{s} = -\left(\frac{-7.5\text{cm}}{3\text{ cm}}\right) = +2.5$$

$y' = my = (2.5)(2\text{cm}) = 5\text{cm}$ new height

Image is not inverted. Image is virtual.



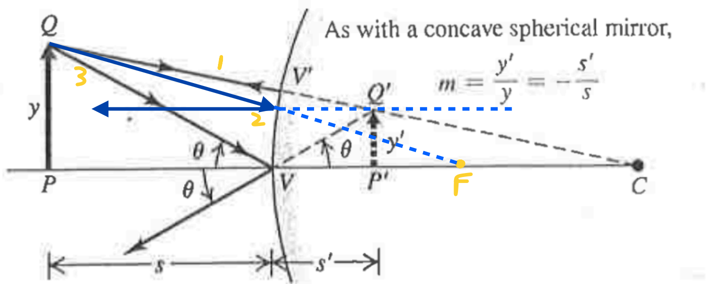
Convex mirror

ray 1: ray through the center

ray 2: ray through focal point

ray 3: ray to vertex

(b) Construction for finding the magnification of an image formed by a convex mirror



s is +
s' is −

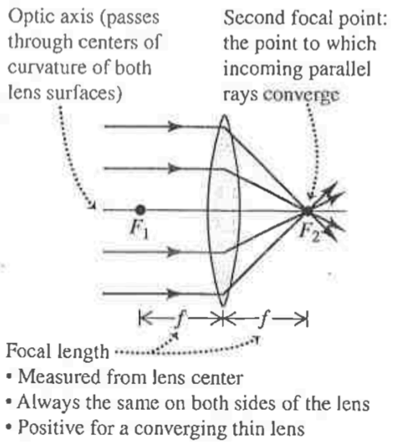
$m = \frac{-s'}{s} = +$ (not inverted)

Lenses refract light : rays either converge through focal point or diverge from focal point

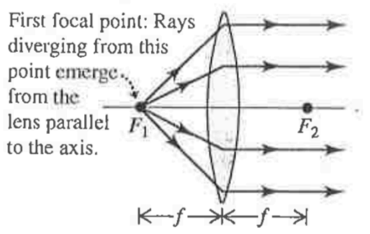
converging lens

34.28 F_1 and F_2 are the first and second focal points of a converging thin lens. The numerical value of f is positive.

(a)



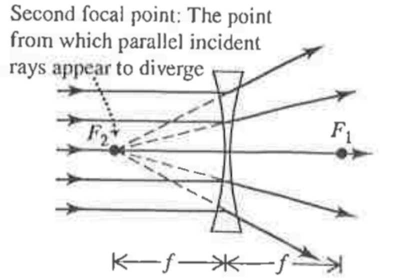
(b)



diverging lens

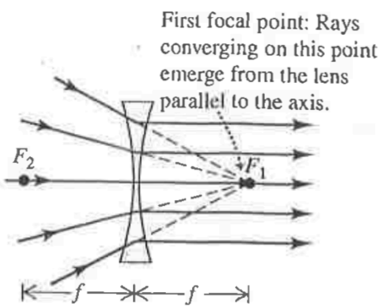
34.31 F_2 and F_1 are the second and first focal points of a diverging thin lens, respectively. The numerical value of f is negative.

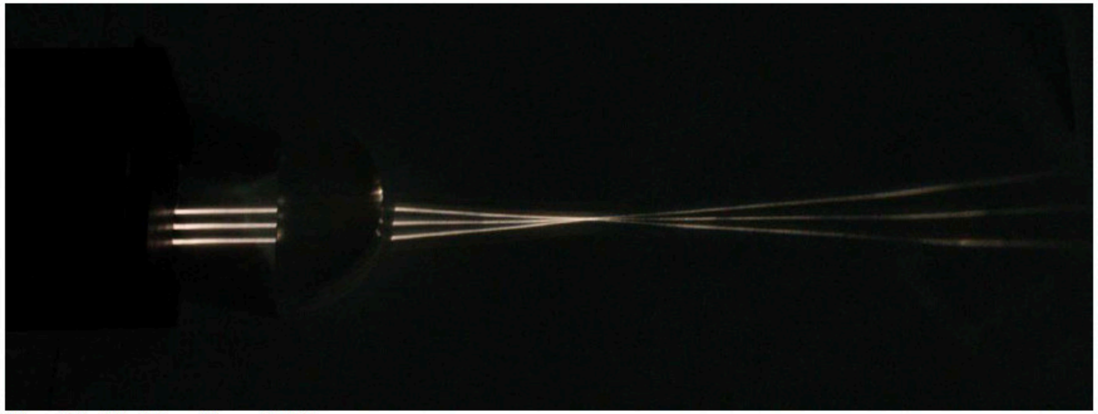
(a)



For a diverging thin lens, f is negative.

(b)



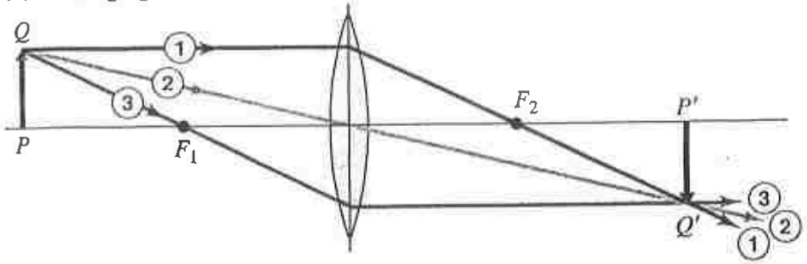


Paraxiale Strahlen; Gauss Optik

Rules for lenses

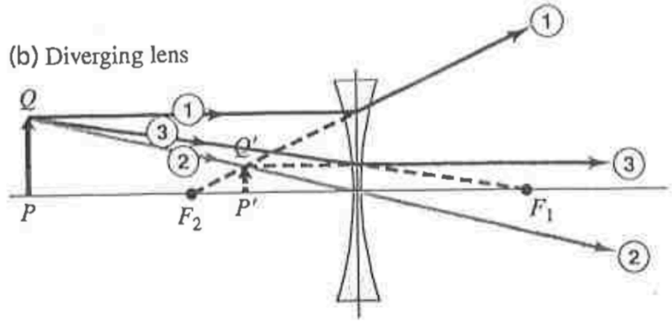
34.36 The graphical method of locating an image formed by a thin lens. The colors of the rays are for identification only; they do not refer to specific colors of light. (Compare Fig. 34.19 for spherical mirrors.)

(a) Converging lens



① Parallel incident ray refracts to pass through second focal point F_2.
② Ray through center of lens does not deviate appreciably.
③ Ray through the first focal point F_1 emerges parallel to the axis.

(b) Diverging lens



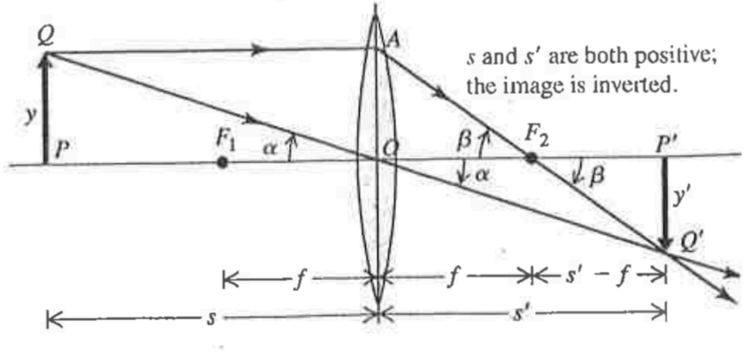
① Parallel incident ray appears after refraction to have come from the second focal point F_2.
② Ray through center of lens does not deviate appreciably.
③ Ray aimed at the first focal point F_1 emerges parallel to the axis.

s	+ (real object) for objects in front of the surface (incident side)
	− (virtual object) for objects in back of the surface (transmission side)
s'	+ (real image) for images in back of the surface (transmission side)
	− (virtual image) for images in front of the surface (incident side)
r, f	+ if the center of curvature is on the transmission side
	− if the center of curvature is on the incident side

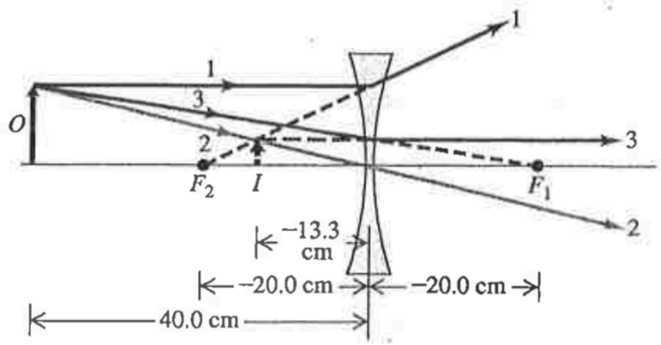
As with mirrors,
$f > 0$, converging lens
$f < 0$, diverging lens

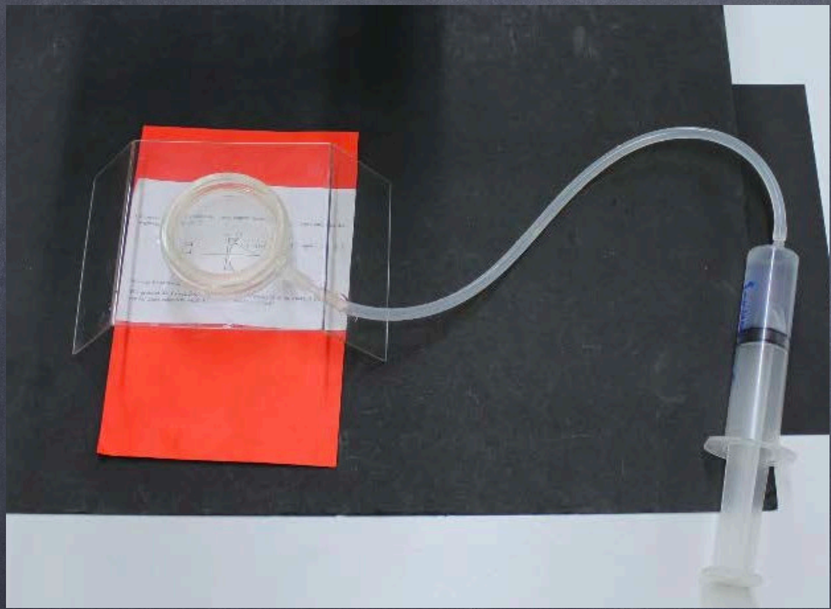
Also, $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ $\quad m = \frac{y'}{y} = -\frac{s'}{s}$

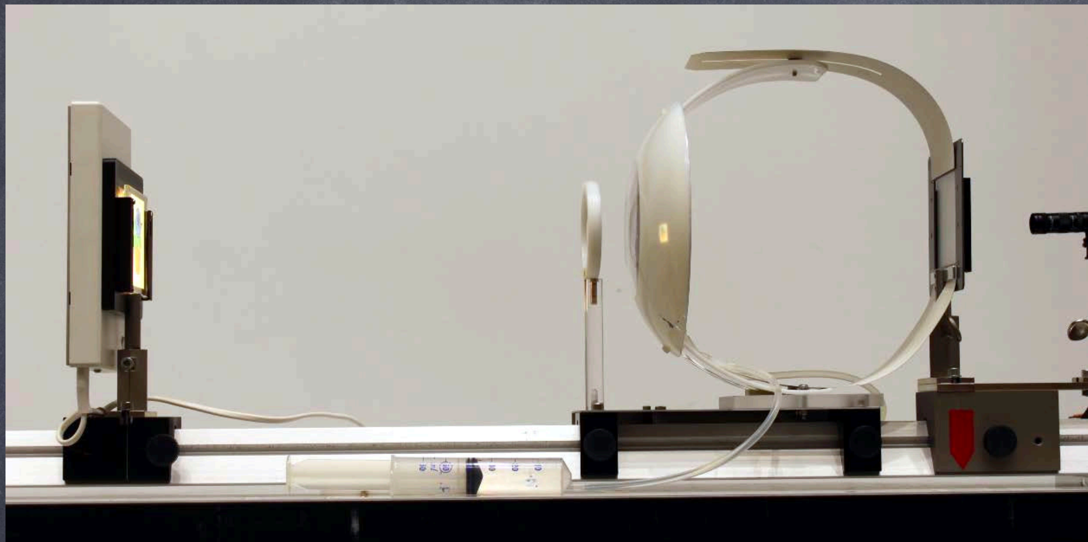
34.29 Construction used to find image position for a thin lens. To emphasize that the lens is assumed to be very thin, the ray QAQ' is shown as bent at the midplane of the lens rather than at the two surfaces and ray QOQ' is shown as a straight line.



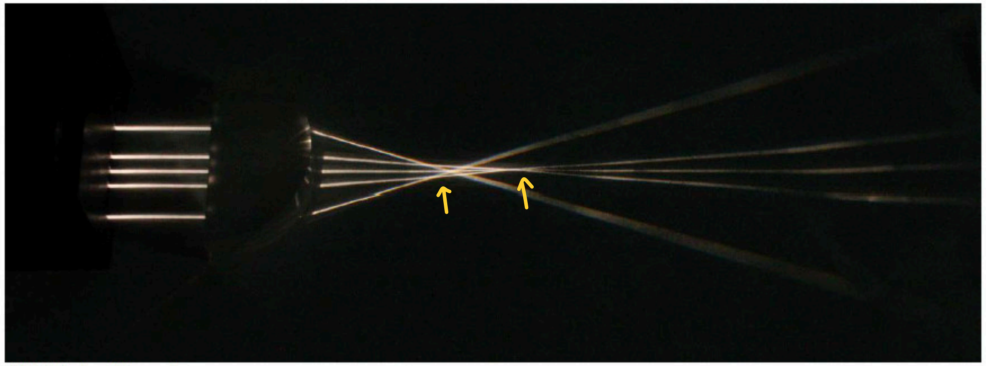
34.38 Principal-ray diagram for an image formed by a thin diverging lens.







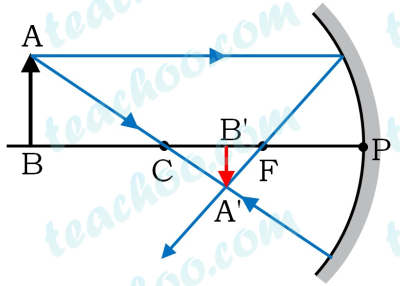
Spherical aberration

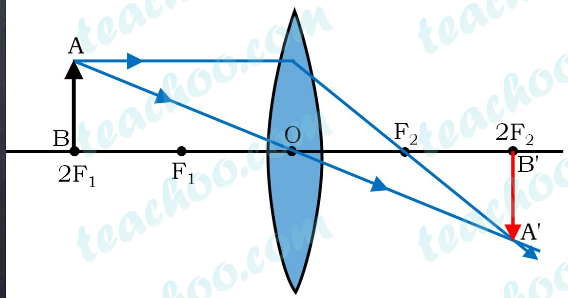

Sphärische Aberration

teachoo.com

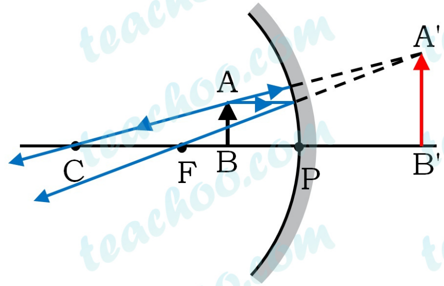
Real Image Vs Virtual Image

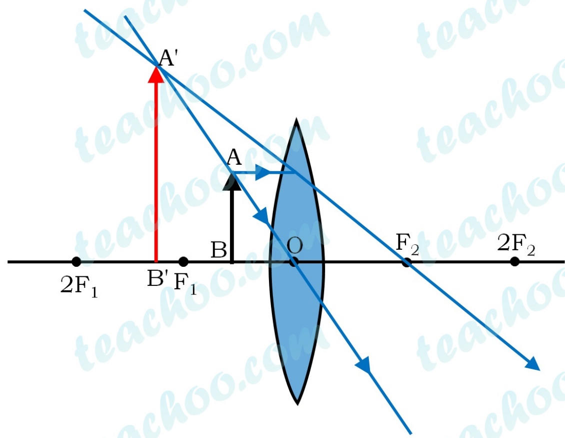
Real Image





Virtual Image

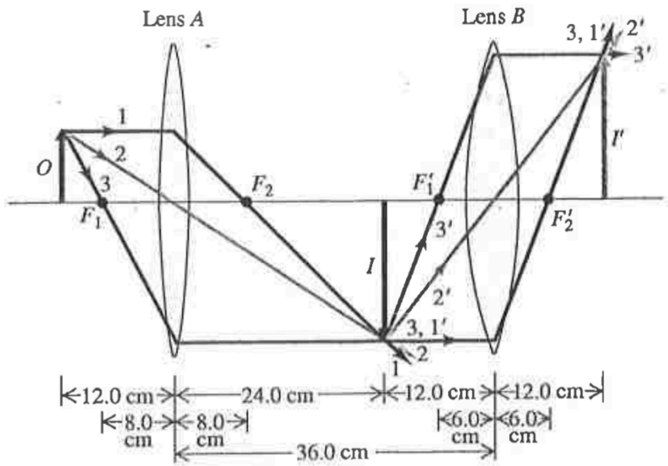


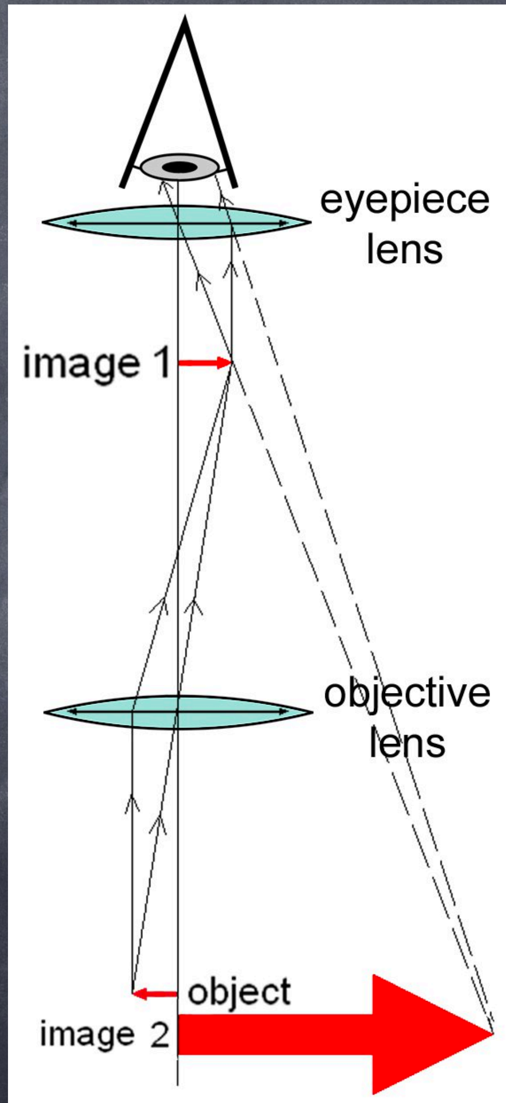


combination of lenses:

microscope uses 2 lenses to magnify objects.

34.39 Principal-ray diagram for a combination of two converging lenses. The first lens (*A*) makes a real image of the object. This real image acts as an object for the second lens (*B*).

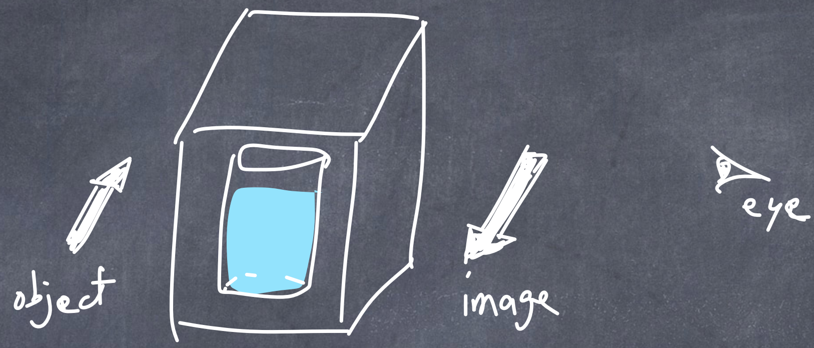




First, find image 1.

Second, ignore lens 1, + calculate image 2 using image 1 as object + lens 2.

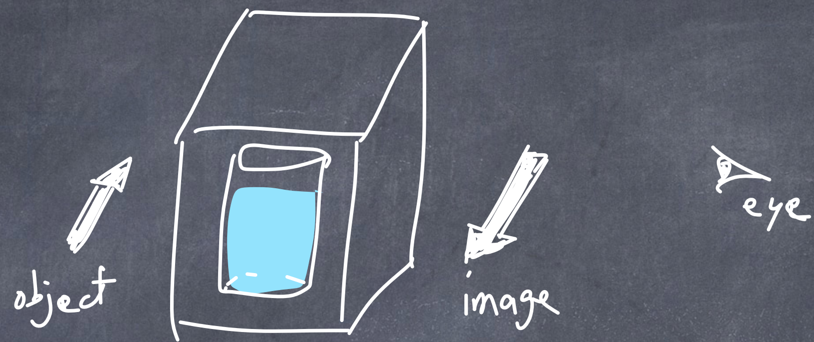
water glass



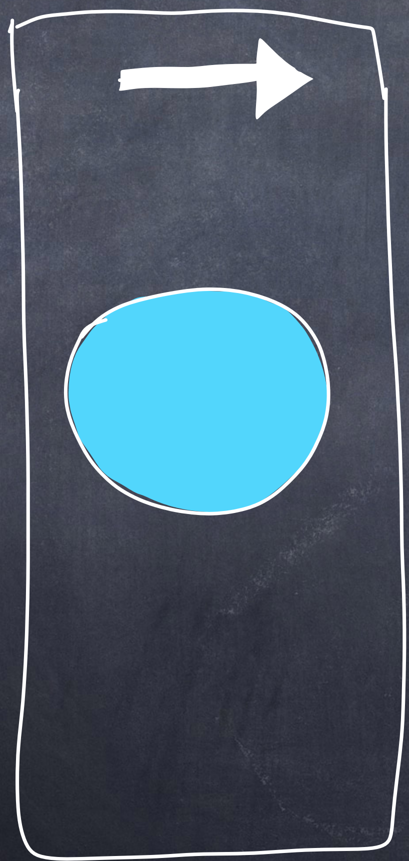
How?

water glass

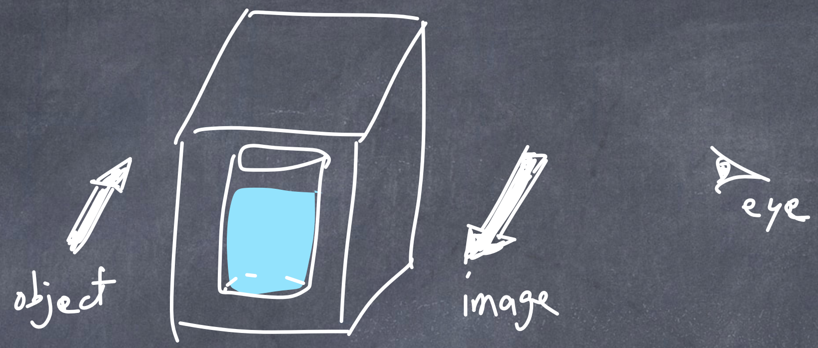
How?



from above:



water glass



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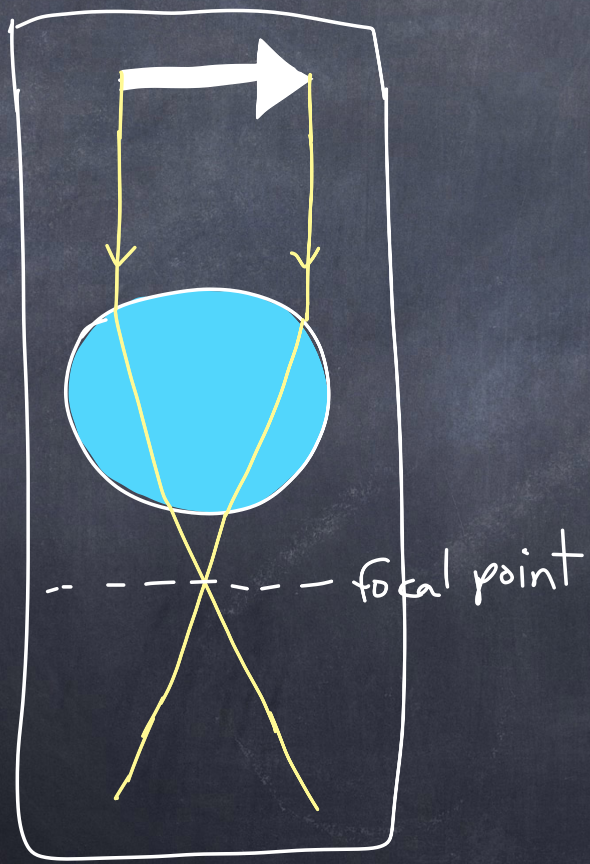
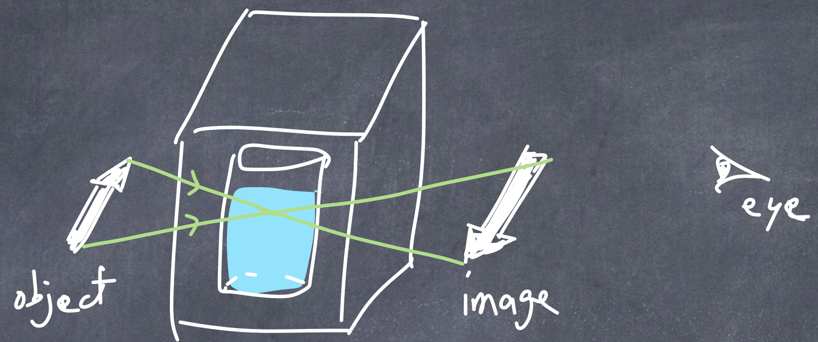


water glass



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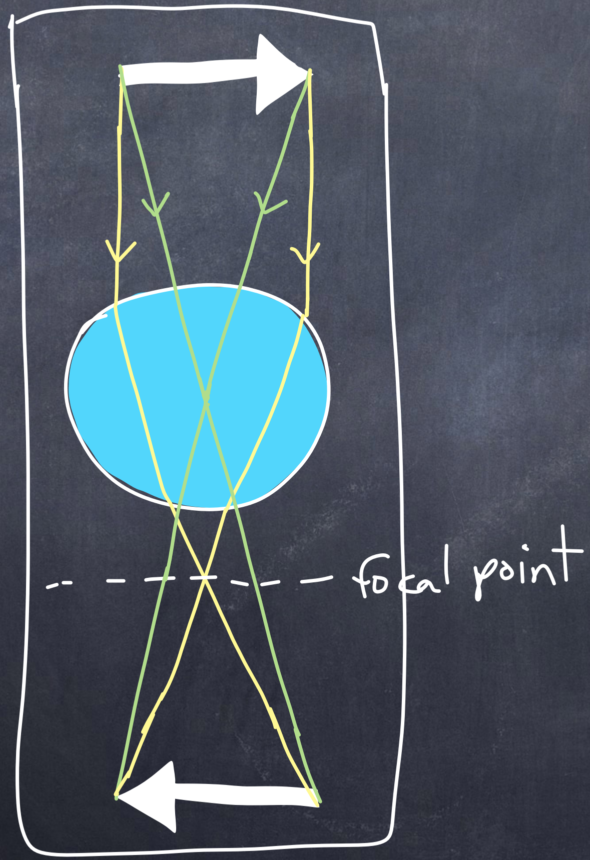
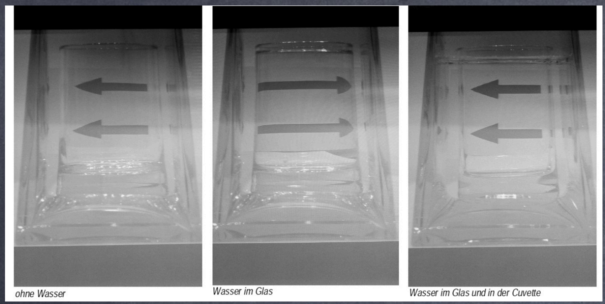
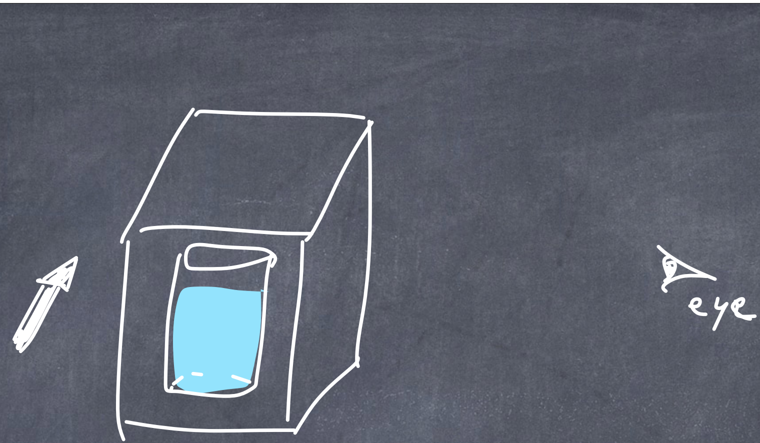


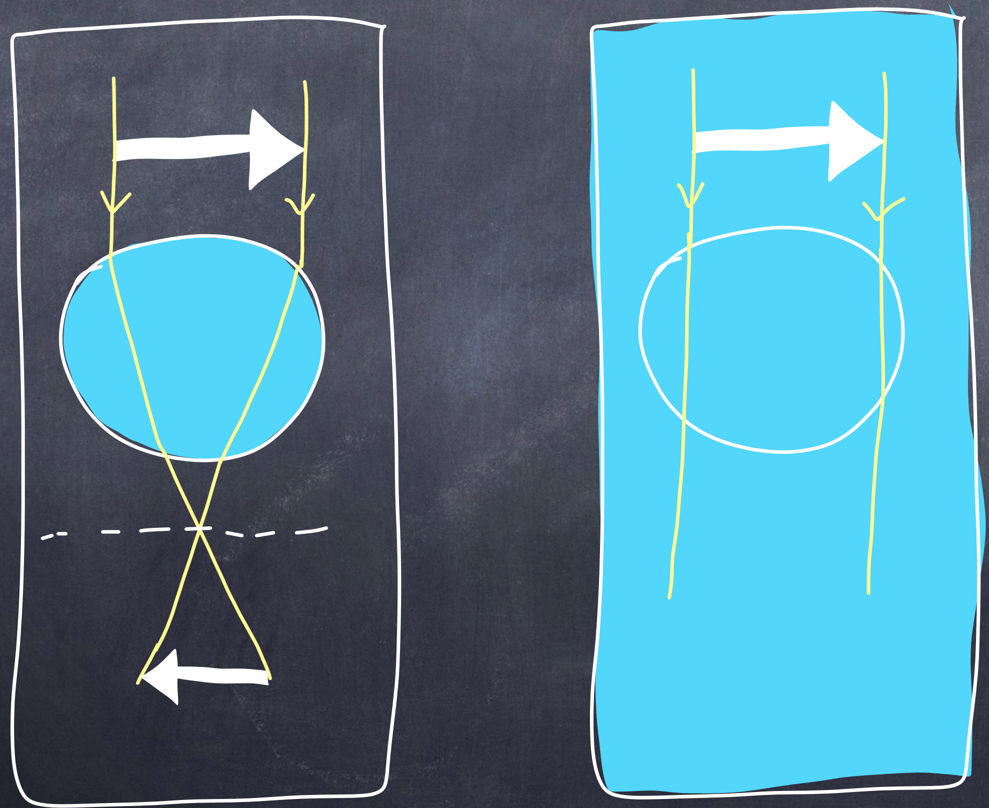
ohne Wasser

Wasser im Glas

water glass


ohne Wasser
Wasser im Glas
Wasser im Glas und in der Cuvette


eye



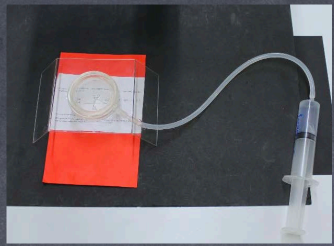
- Wednesday lecture will review last exercise sheet

- Learn to do weekly exercise sheets + online quizzes
  - → Questions like these will be on the exam
  - → will soon put remaining lecture quizzes online

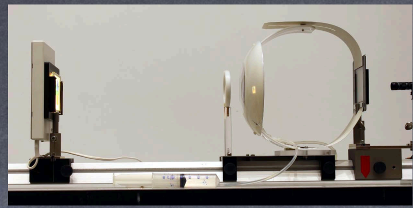
- Some of you, I'll see in PHY 127 next semester: modern physics + scientific instruments (NMR, CT scans, etc.)

- Good luck on the exam + thanks!

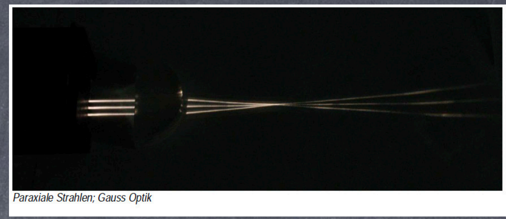
W71



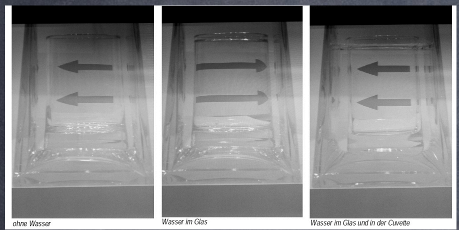
W81



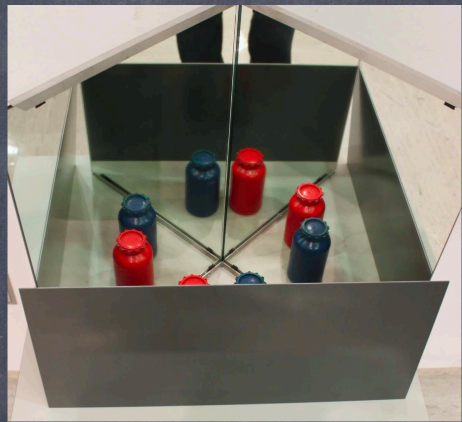
W82



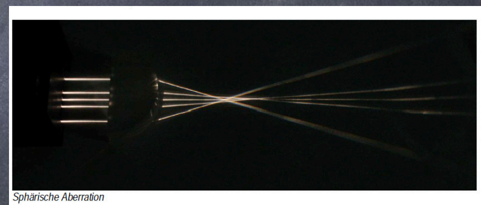
W83



W88



W69



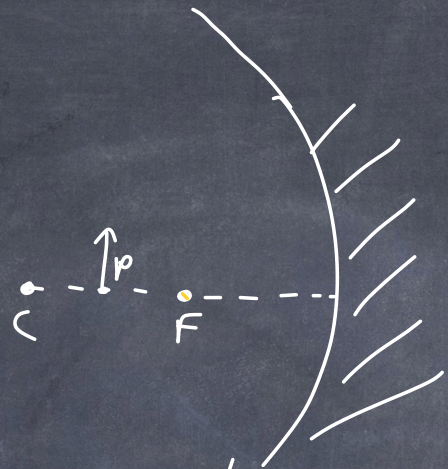
W84

W70

W72

W121

Other example:



where is p' ?

where is p' ?

s is +

s' is +

m is − (inverted)

y' > y (image is larger)

⇒ image is real & inverted & larger