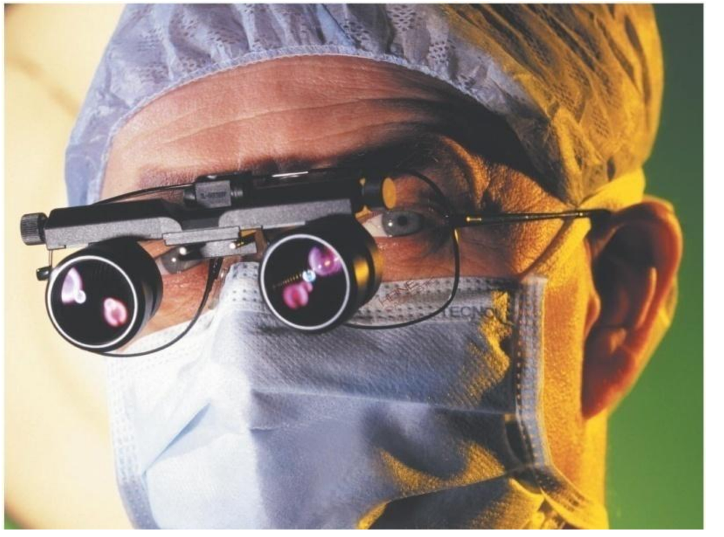
Geometric Optics
Limit when $\lambda \rightarrow 0$
Diffraction is Irrelevant in this Case
Light Behaves like e Particle

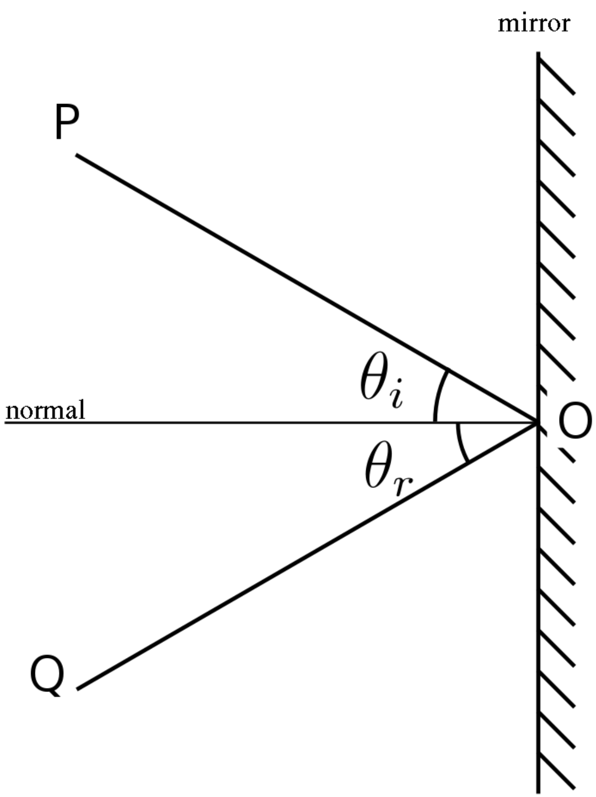
Your eyes, microscopes, cameras, telescopes are all good examples of geometric optical systems. Geometric optics is the limit when the wavelength is zero.

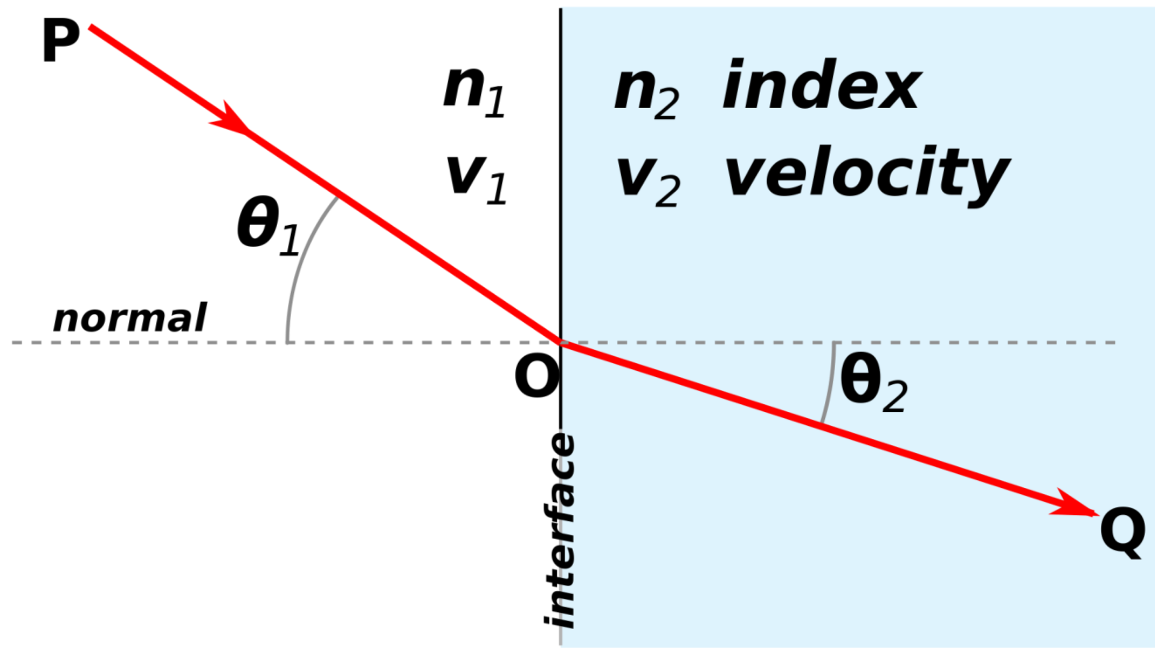
Introduction

- Lenses can correct vision problems. For someone wearing glasses or contacts, light entering the eye through the glasses or contacts is forced to focus on the retina instead of in front of it.
- The surgeon in our photo is using combinations of optical elements to magnify a small surgical site.

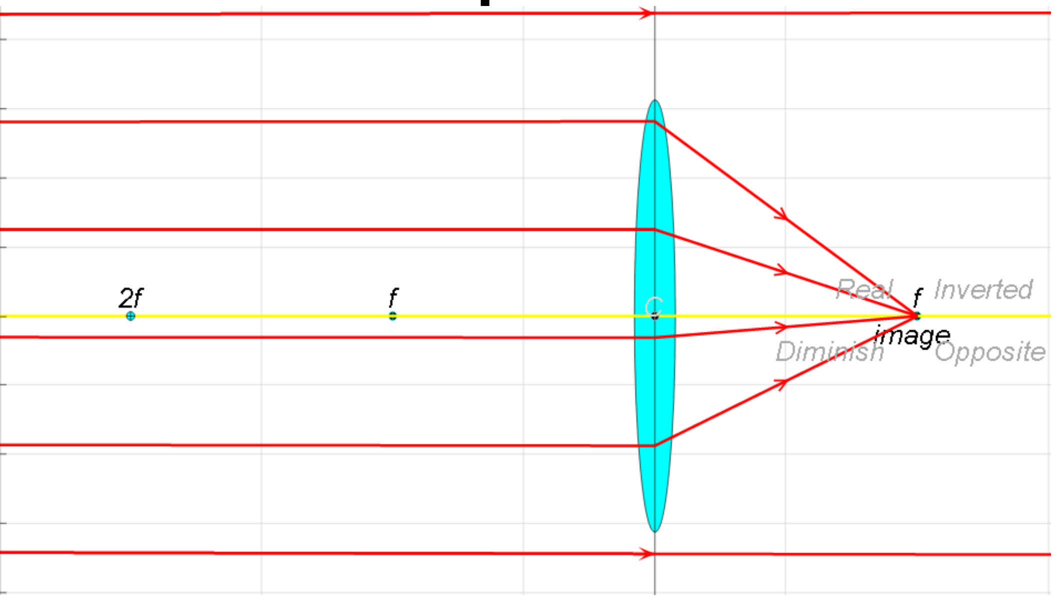


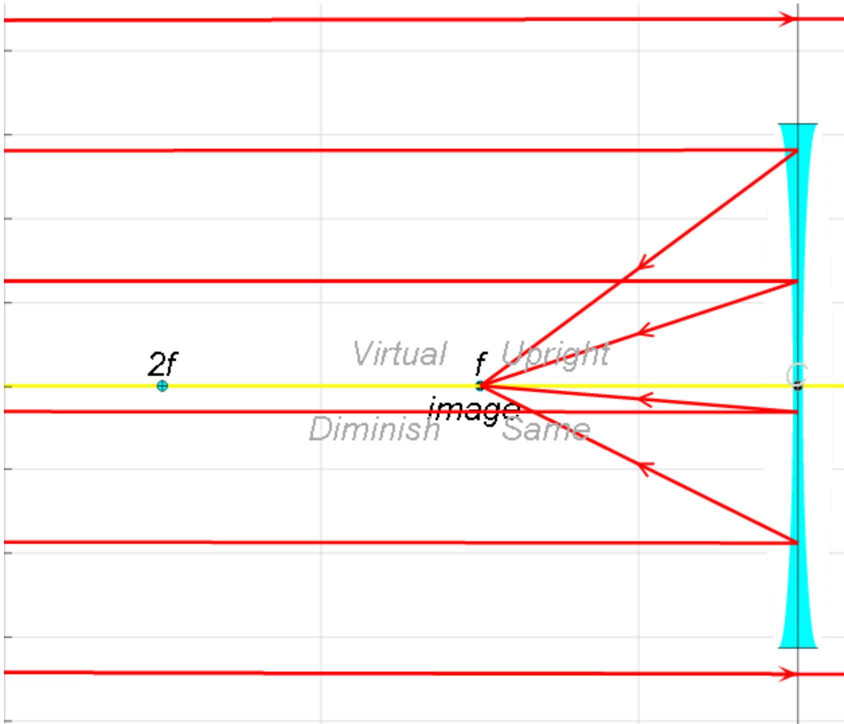
Reflection and Refraction
Principle of Least Time or Least Action





A simple Convex and Concave lens

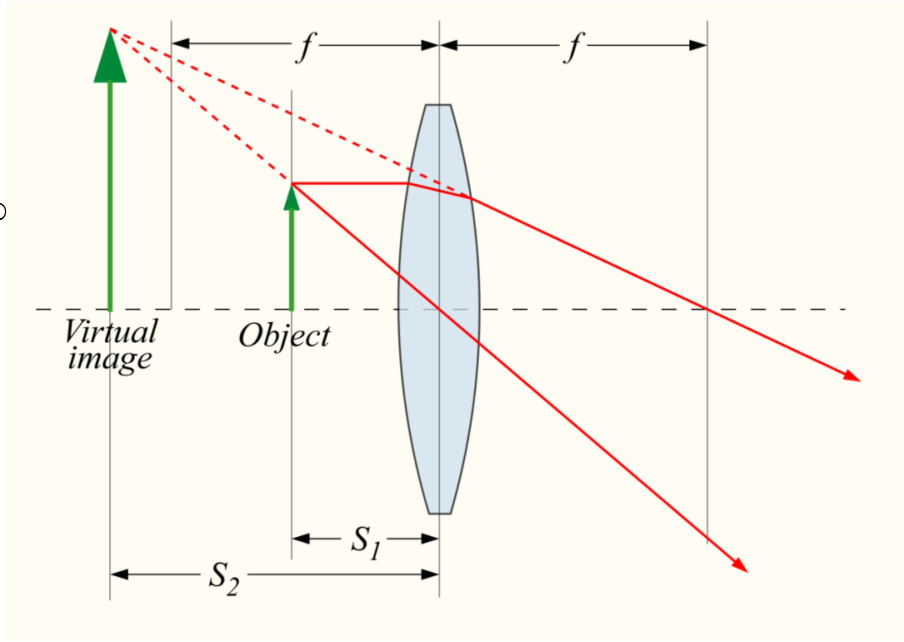




Thin Lens Approximation

Based on Spherical Approximation

Note that ray through center of lens is not deflected



$1/S_1 + 1/S_2 = 1/f$

Often writen as: 1/o +1/i=1/f

f=focal length - distance of image from lens for object at ∞

$S_1 = o =$ object distance from lens "center"

$S_2 = i =$ image distance from lens "center"

$S_1, o > 0$ for objects on "object side" of lens

$S_2, i > 0$ for "real" image on "image side" of lens

$S_2, i < 0$ for "imaginary" image on "object side" of lens

Magnification: $\mathrm{m} \equiv \dfrac{\text{size of image}}{\text{size of object}}$

Size of Image $\propto S_2 = i$

Size of Object $\propto S_1 = o$

$$\rightarrow m = -\frac{S_2}{S_1} = -\frac{i}{o} = \frac{f}{f - S_1} = \frac{f}{f - o} = \frac{f - i}{f}$$

(minus sign to take into account inverted image ($S_2, i > 0 -$ image inverted on "image side")

Newton Notation for Thin Lenses

See also online Calculator: hyperphysics.phy-astr.gsu.edu/hbase/geoopt/lenseq.html

1/o +1/i=1/f

$$m = -\frac{i}{o} = -i\frac{1}{o} = -i\left[\frac{1}{f} - \frac{1}{i}\right] = -i\frac{i-f}{fi} = \frac{f-i}{f}$$

We can also write this as:

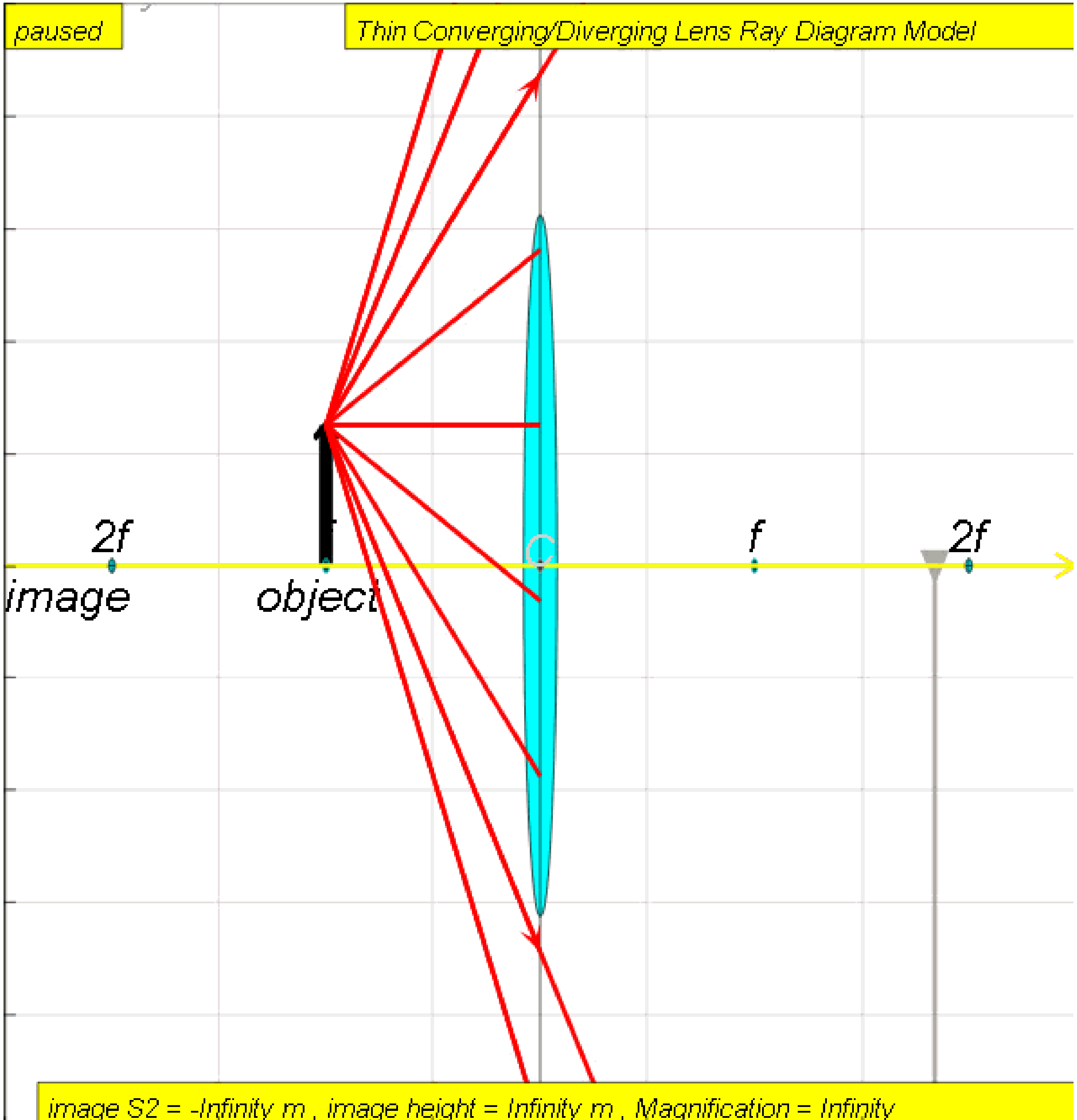
$$m = -\frac{i}{o} = -\frac{1}{o}i = -\frac{1}{o}\left[\frac{1}{\frac{1}{f} - \frac{1}{o}}\right] = -\frac{1}{o}\frac{fo}{o-f} = \frac{f}{f-o}$$

$$\rightarrow m^2 = \frac{f-i}{f}\frac{f}{f-o} = \frac{f-i}{f-o}$$

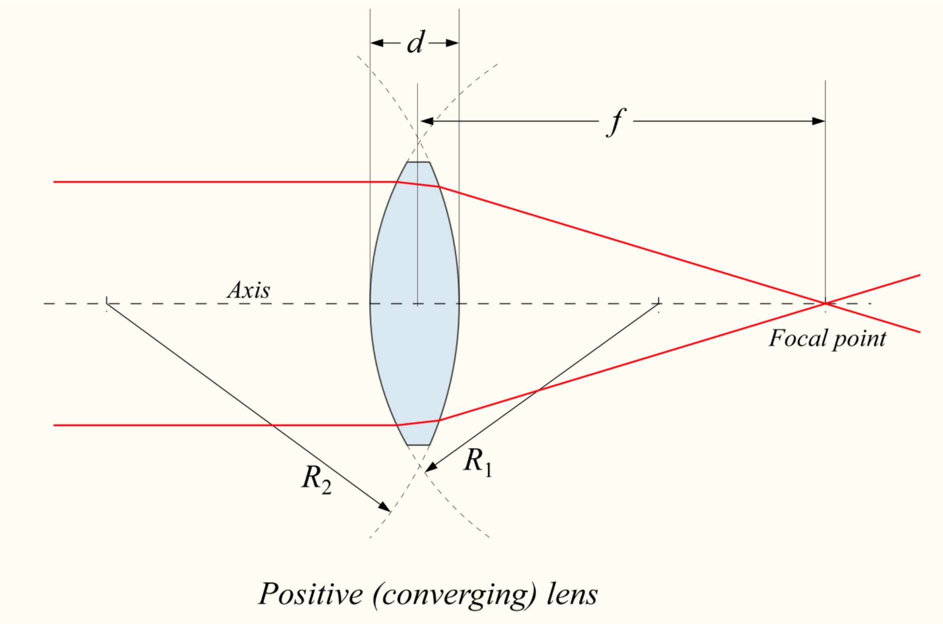
Also: $m = \dfrac{f}{f-o} = \dfrac{f-i}{f} \rightarrow f^2 = (f-i)(f-o)$

$\rightarrow$ Product of differences of object and image from focus is f ^{2}

Object and Image in Convex Lens



Lensmaker Equation



Thick Lens (general but assume lens of material index of refraction n in vacuum):

$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}+\frac{(n-1)d}{nR_1R_2}\right]$$

R_1, R_2 are radii of curvature of front and back surface

d=thickness of lens

Thin Lens Limit (d<< R_1, R_2)

$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

R_1 is positive is front surface is convex and negative is front surface is concave

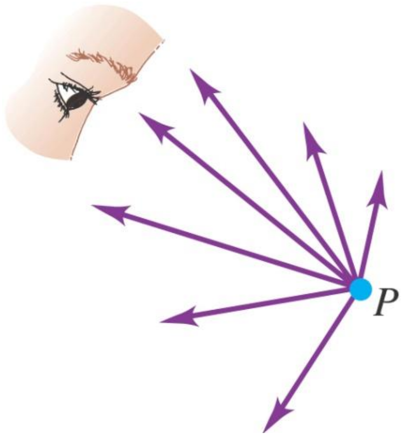
R_2 is positive is back surface is concave and negative is back surface is convex

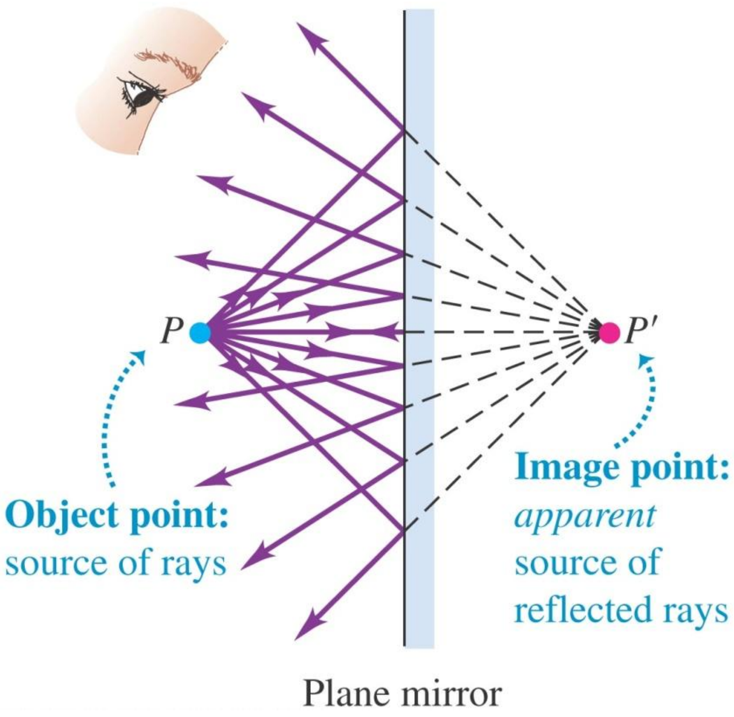
Note that this sign convention can be different in different books

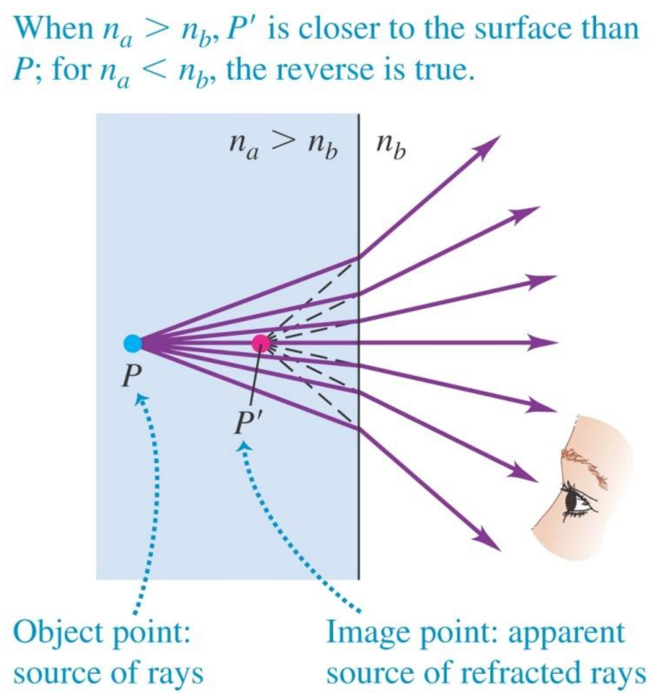
In lens shown (front convex and back convex) that R_1 is positive and R_2 is negative

Objects, images, and light rays

- Light rays from a source will radiate in all directions, reflect from mirrored surfaces, and bend if the pass from a material of one index to another.

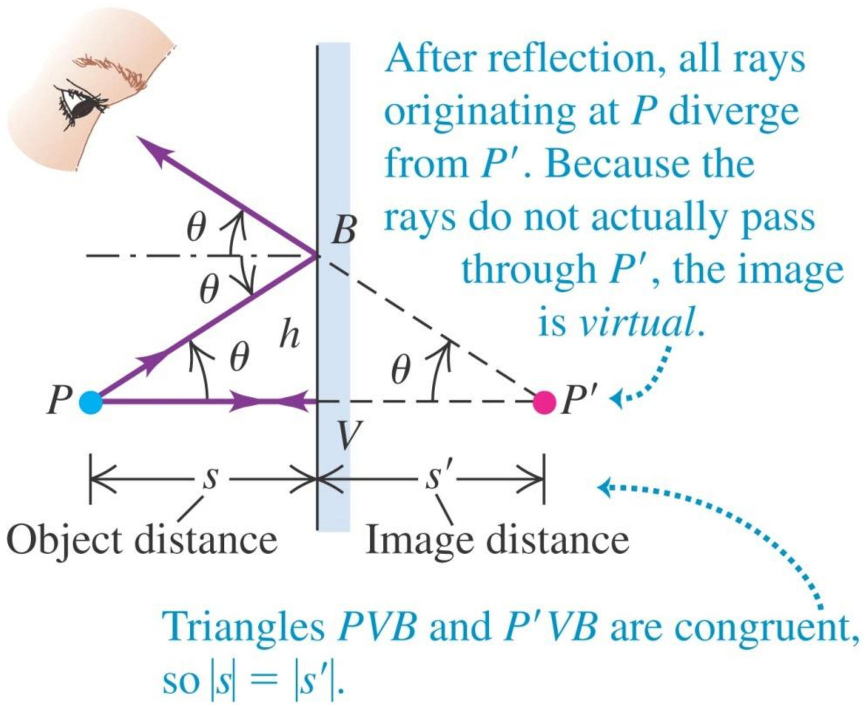


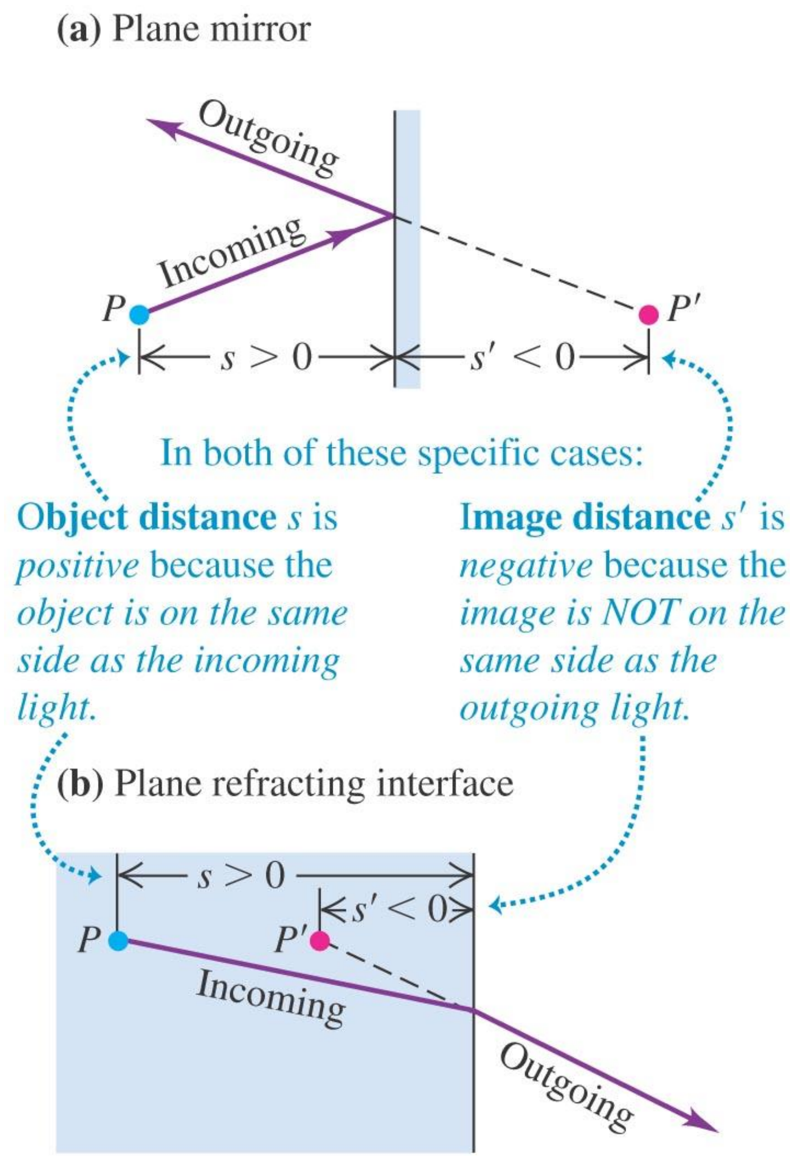




Constructing the image from a plane mirror I

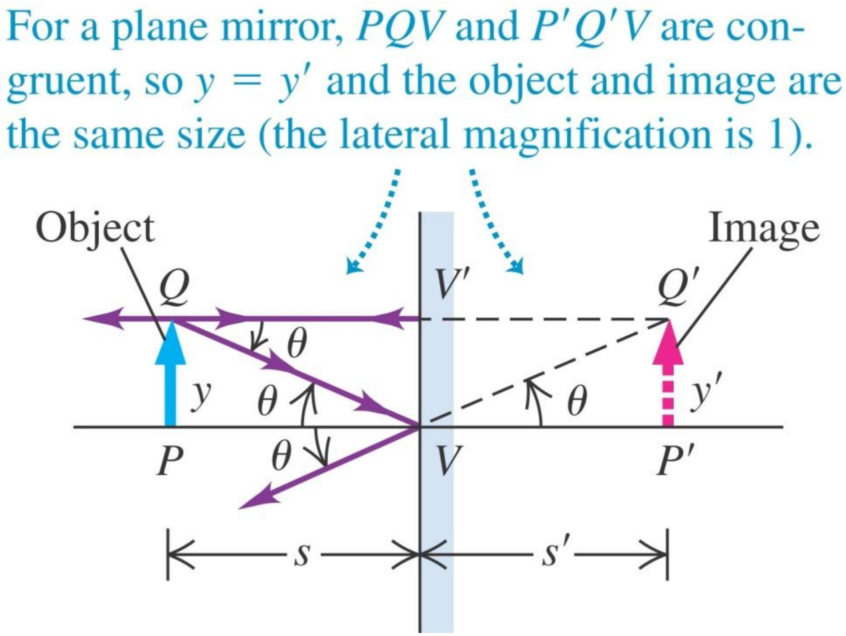
– Following the light rays to form an image of an object.

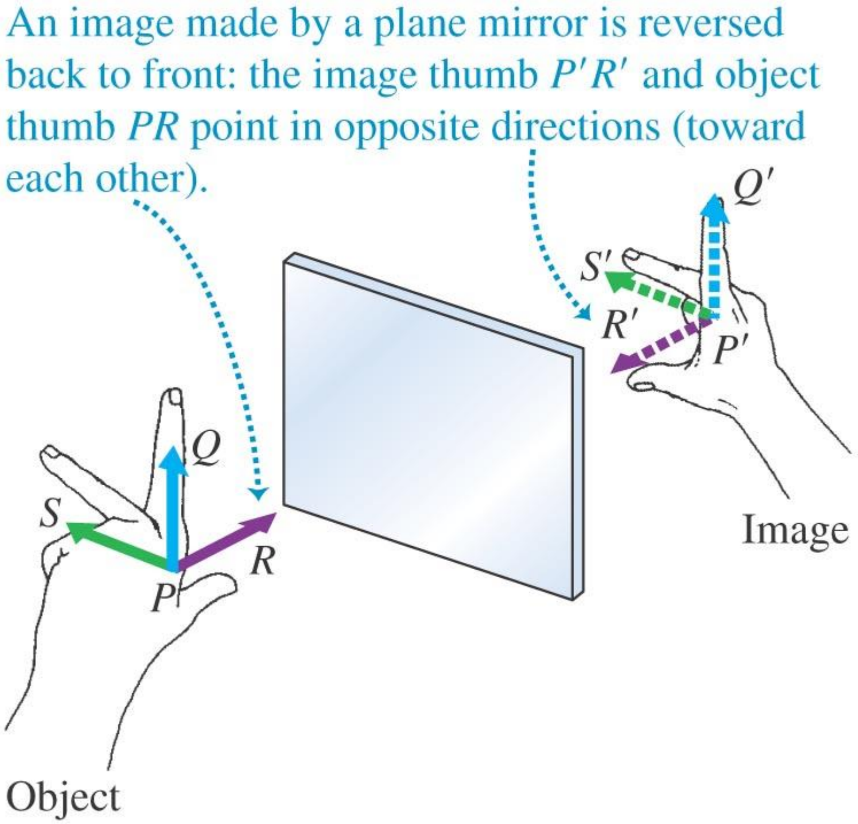




Constructing the image from a plane mirror II

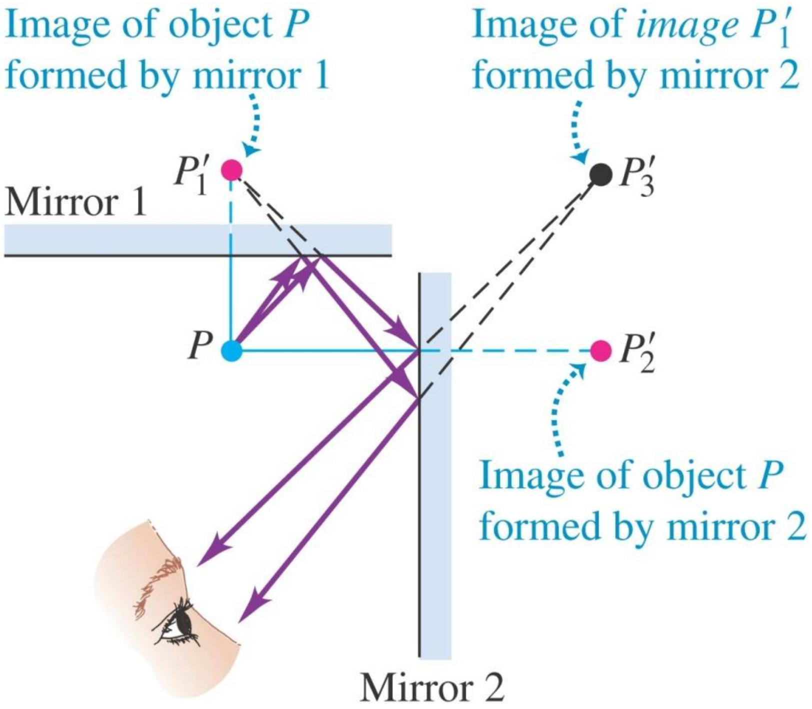
- Images from a plane mirror show left/right reversal.





Constructing the image from plane mirror(s)

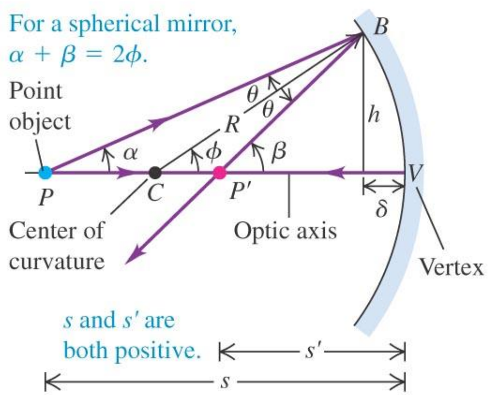
- Which image is reversed?
- Multiple mirrors can create a host of virtual image possibilities.



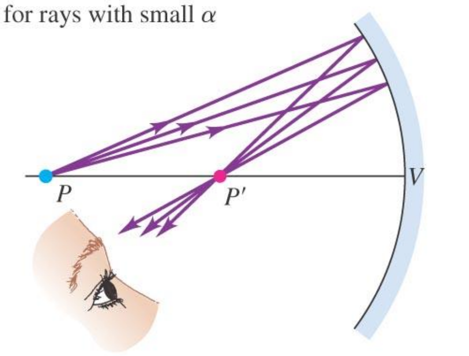
Reflections from a spherical mirror

- Images from a concave mirror change depending on the object position.
- Concave and convex mirror sign convention.

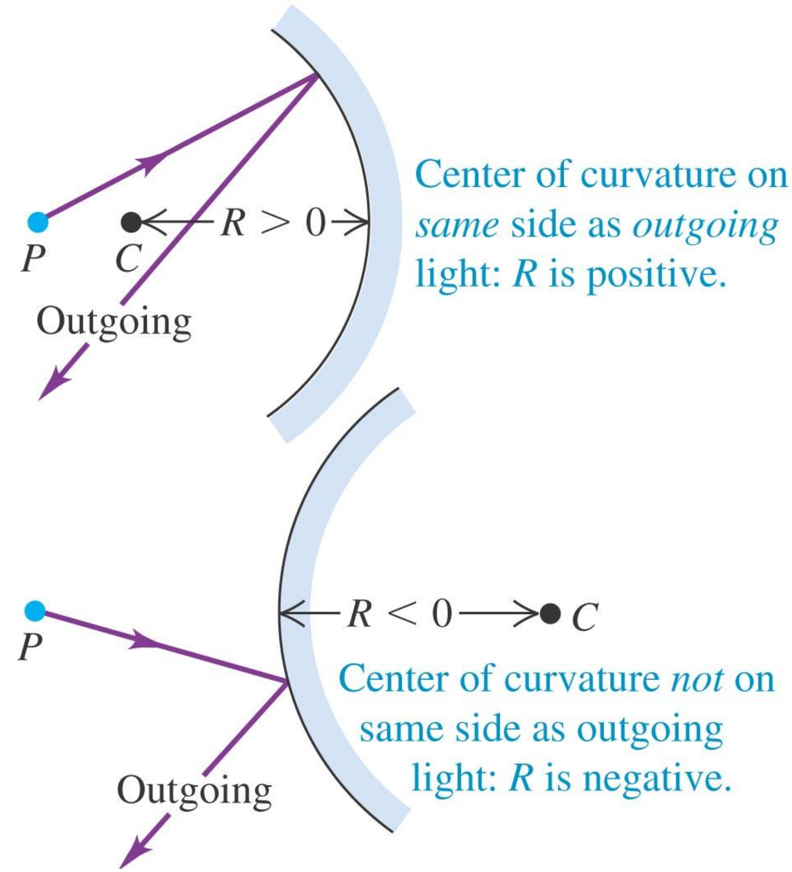
(a) Construction for finding the position P' of an image formed by a concave spherical mirror



(b) The paraxial approximation, which holds for rays with small α



All rays from P that have a small angle α pass through P', forming a real image.

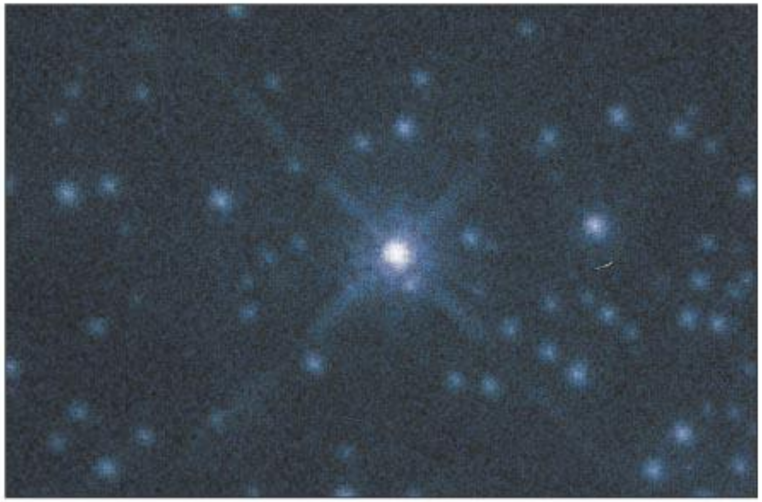


The Hubble Space Telescope

- The HST has a spherical mirror. Unfortunately, it was ground to the wrong dimensions by 1/50 the width of a human hair over a mirror as large as a person.
- Replacing the mirror was unthinkable. The final solution was an electronic adjustment to the photodiode array which converts the optical image to digital data.
- Consider Figure at right to see the dramatic “before” and “after” images.

A star seen with the original mirror

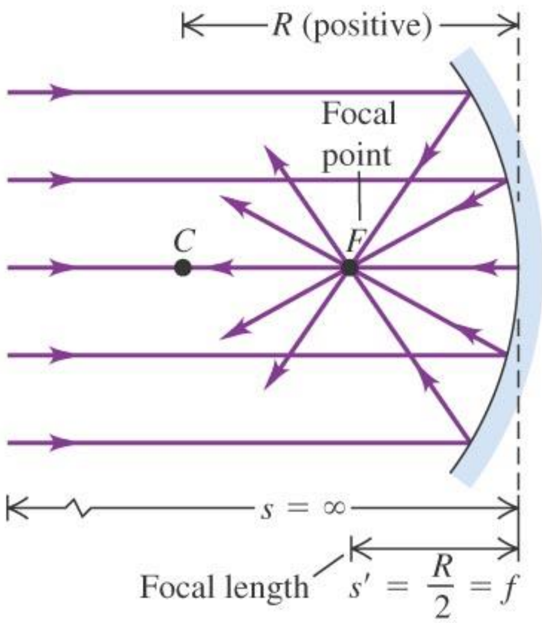
The same star with corrective optics



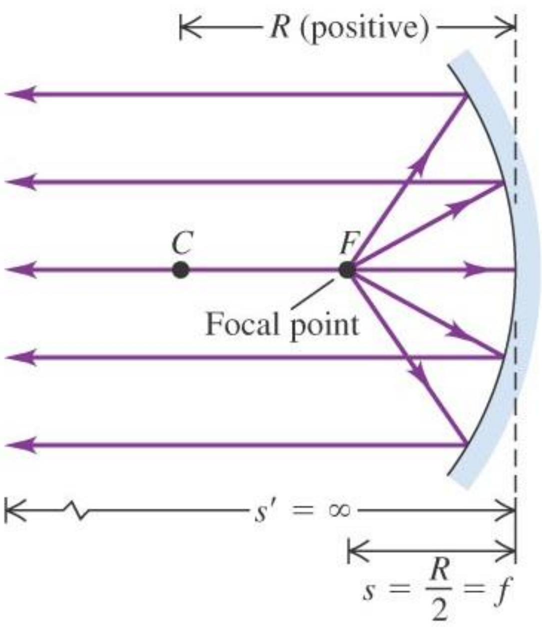
The focal point and focal length of a spherical mirror

- The focal point is at half of the mirror's radius of curvature.
- All incoming rays will converge at the focal point.

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

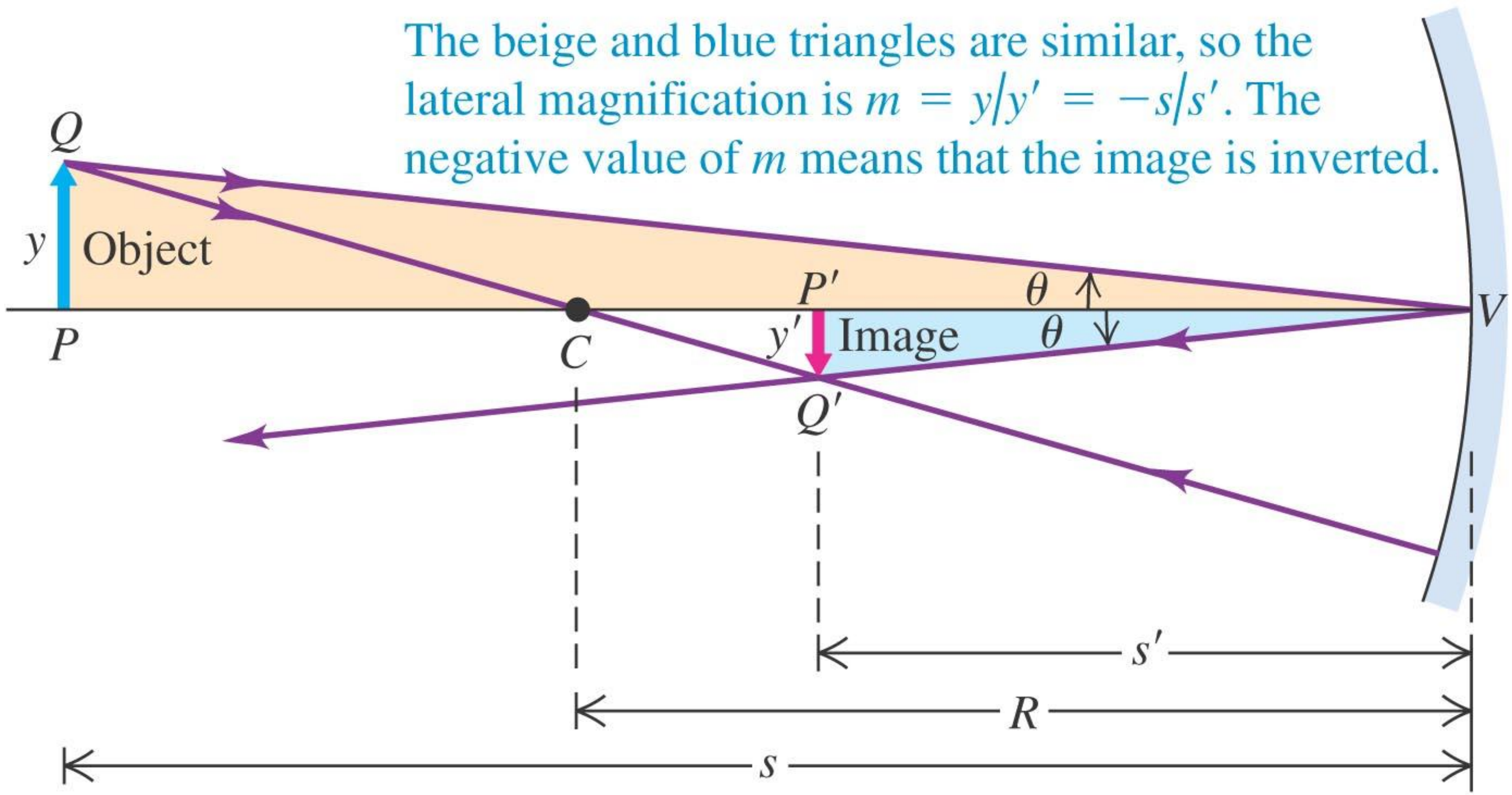


(b) Rays diverging from the focal point reflect to form parallel outgoing rays.

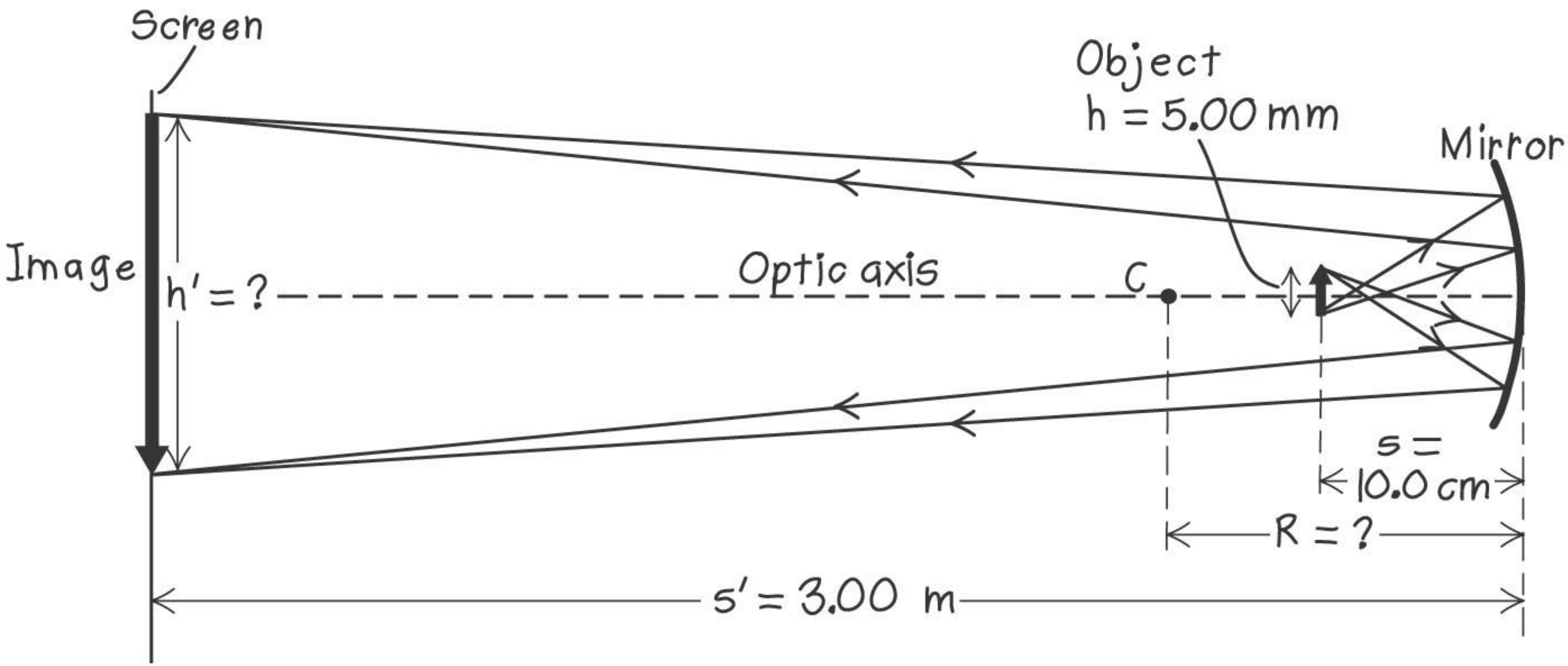


A system of rays may be constructed to reveal the image

- Rays are drawn with regard to the object, the optical axis, the focal point, and the center of curvature to locate the image.



Images formed from concave mirrors

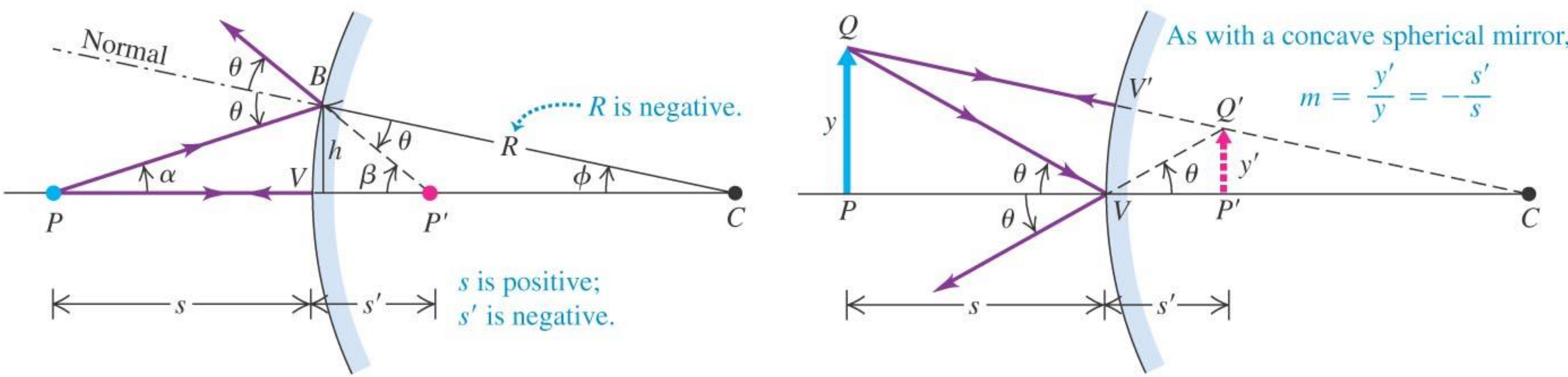


The convex spherical mirror I

- If you imagine standing inside a shiny metal ball to visualize the concave spherical mirror, imagine standing on the outside to visualize the concave spherical mirror.

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

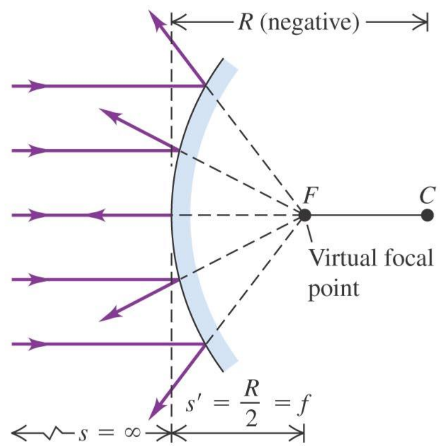
(b) Construction for finding the magnification of an image formed by a convex mirror



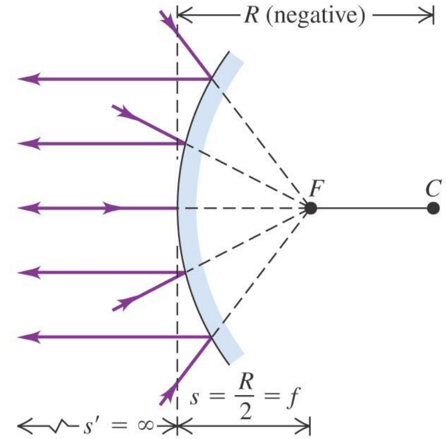
The convex spherical mirror II

- The convex spherical mirror cannot produce a real image regardless of the position of the object.
- Consider Santa's problem

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

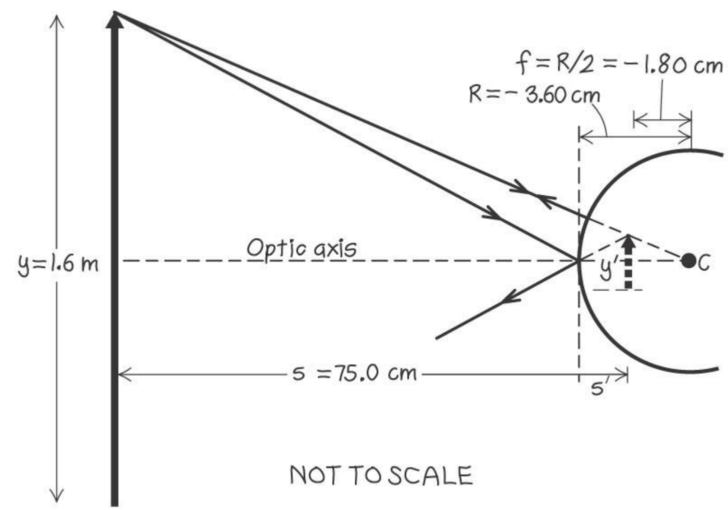


(b) Rays aimed at the virtual focal point are parallel to the axis after reflection.



(a)

(b)

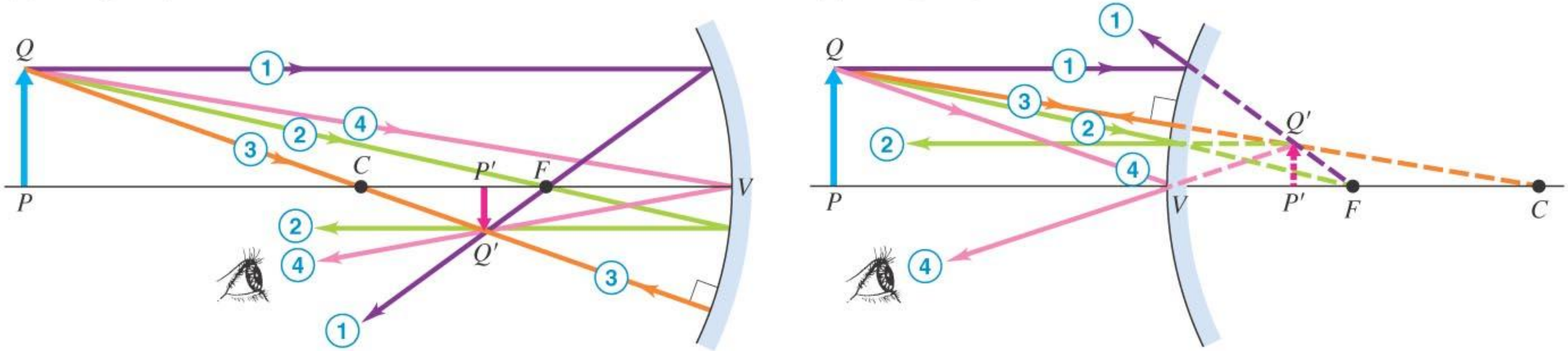


A graphical method for mirrors

- Graphical formalism using the object, the center of curvature, the focal point, and the mirror plane.

(a) Principal rays for concave mirror

(b) Principal rays for convex mirror



(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.

The graphical method for mirrors II

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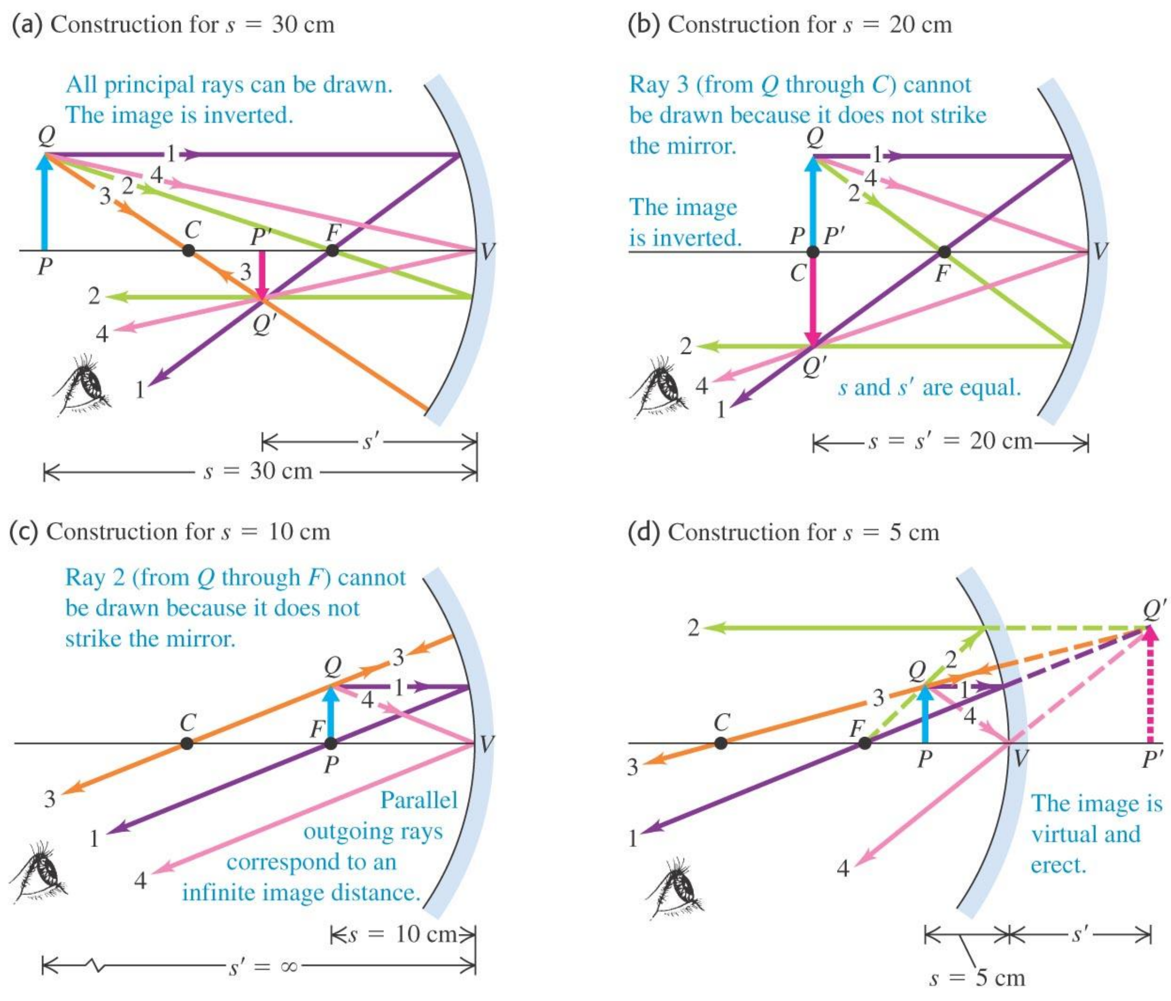
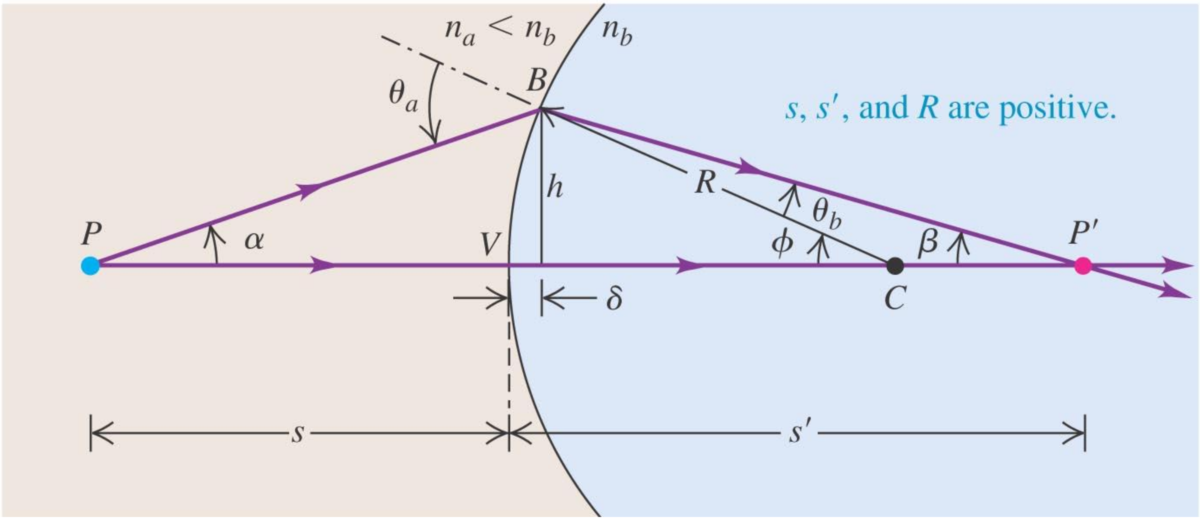
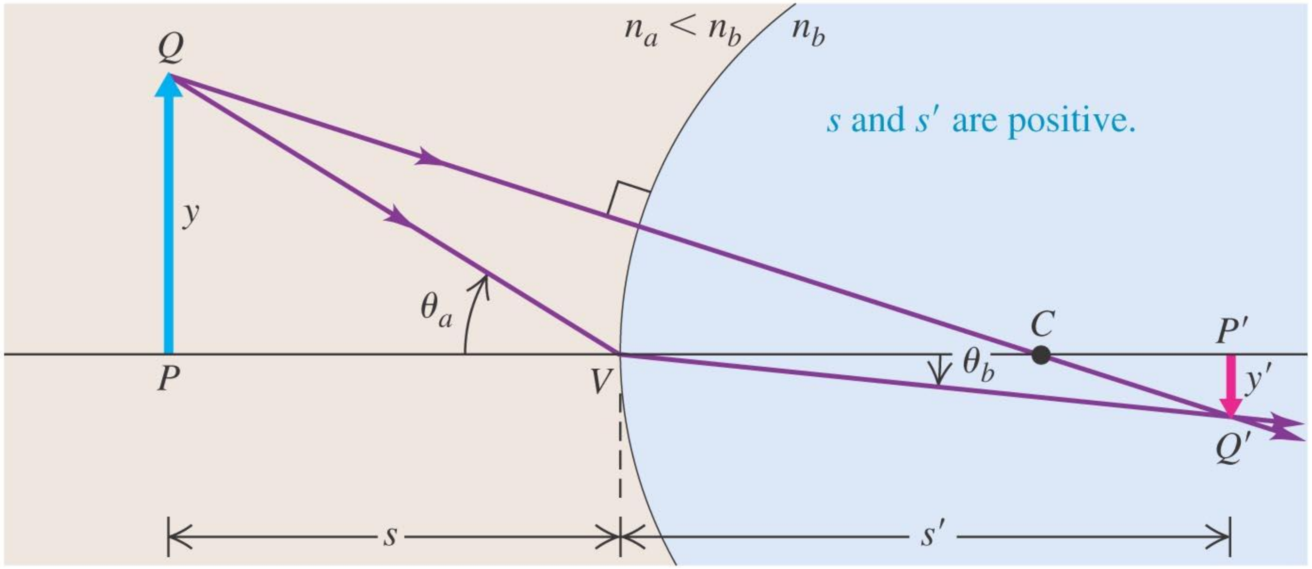


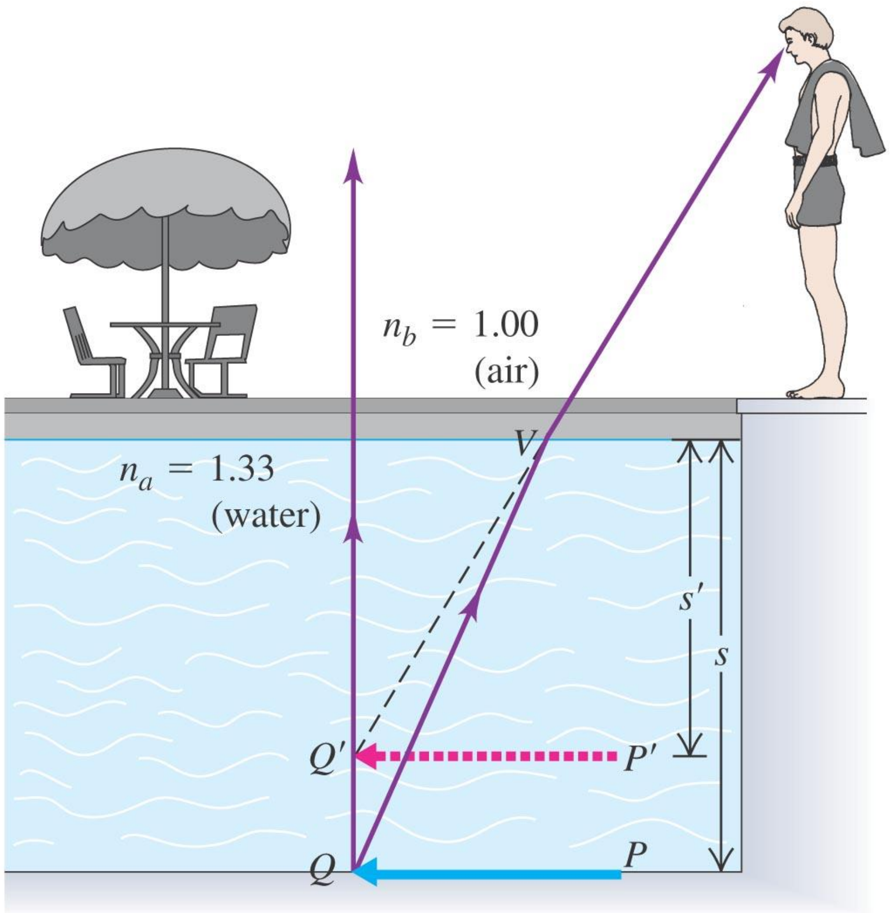
Refraction within a sphere

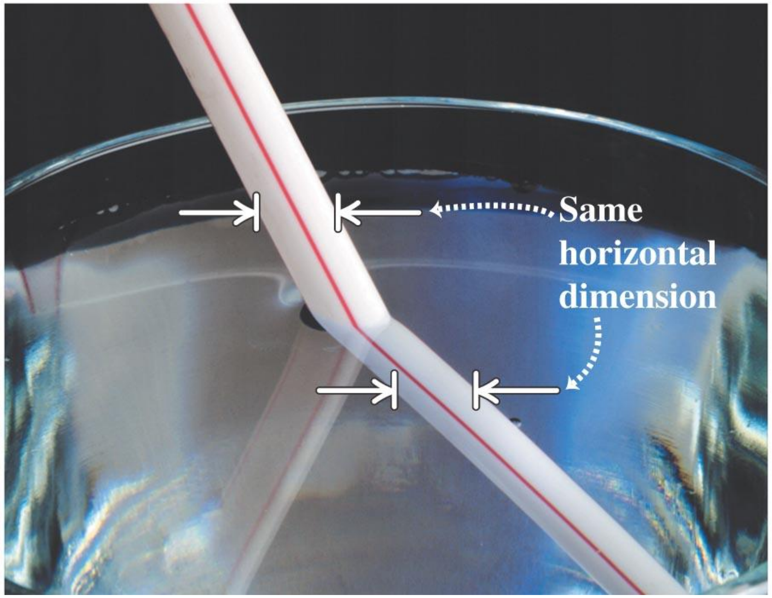
- Light traveling through a raindrop.





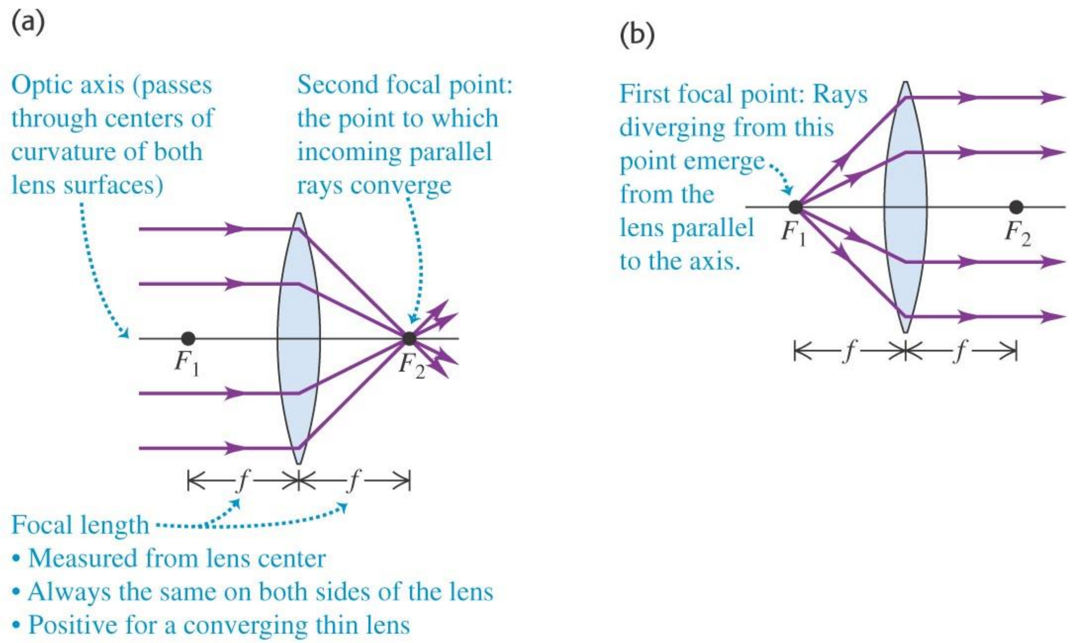
Images formed by refraction

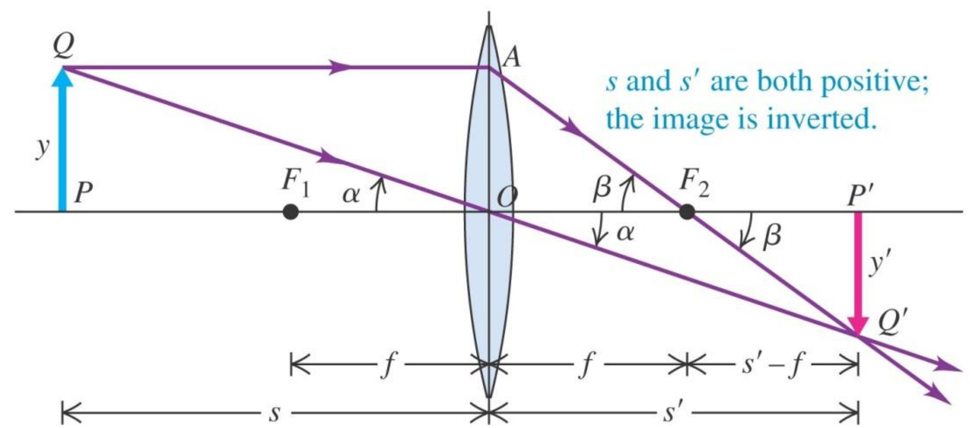




Thin lenses I

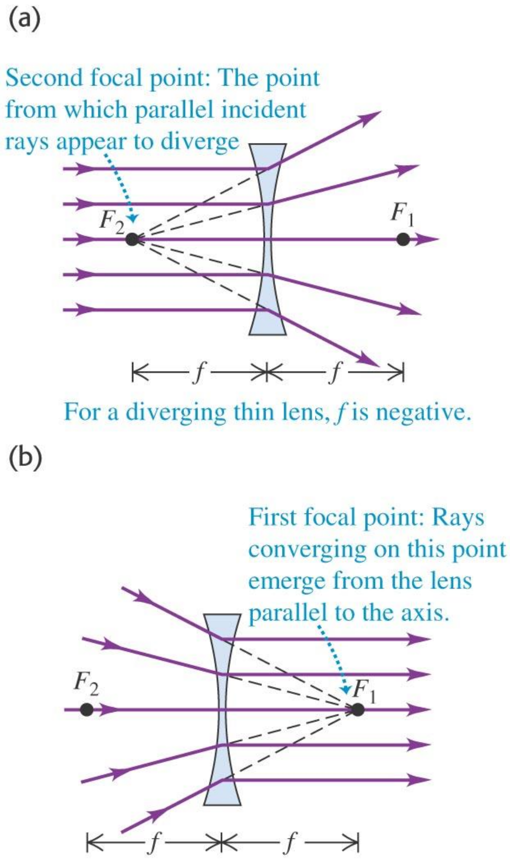
- The converging lens is shown in Note symmetrical focal points on either side of the lens.
- Using the same ray formalism as we used with mirrors to find the image.

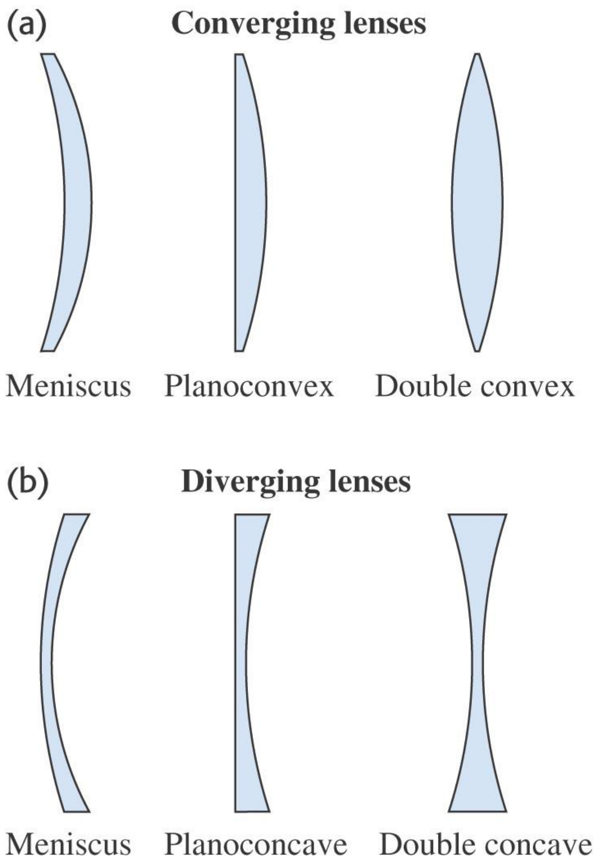




Thin lenses II

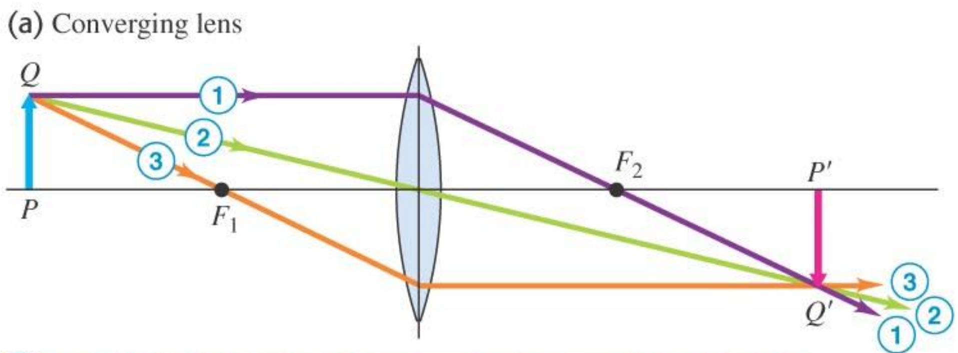
- Bottom left illustrates a diverging lens scattering light rays and the position of its second (virtual) focal point.



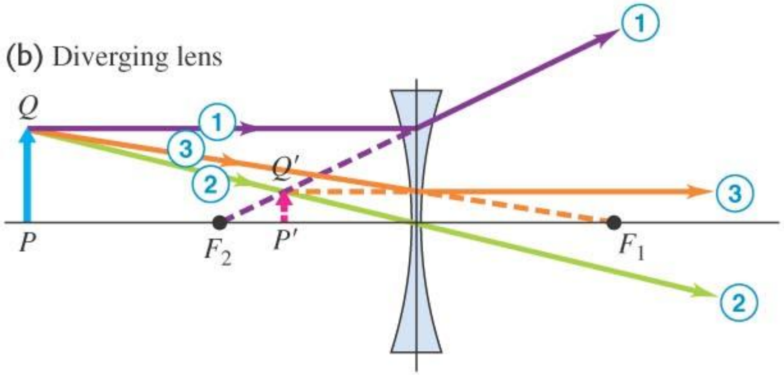


Graphical methods for lenses

- Ray-tracing method we used for mirrors.



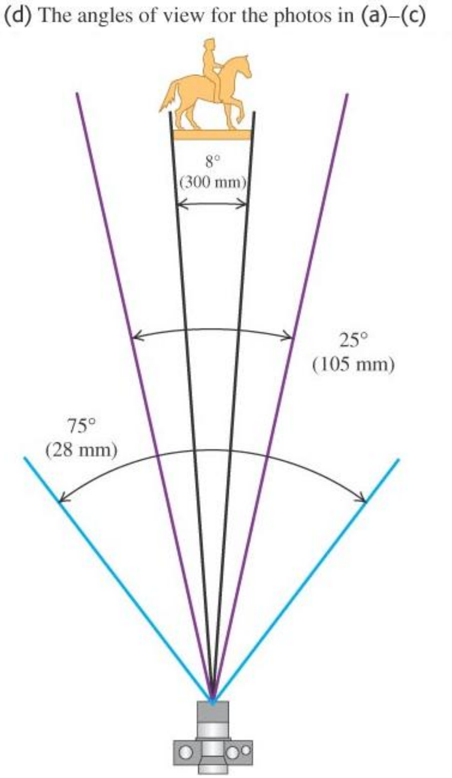
(1) Parallel incident ray refracts to pass through second focal point F_2.
(2) Ray through center of lens does not deviate appreciably.
(3) Ray through the first focal point F_1 emerges parallel to the axis.

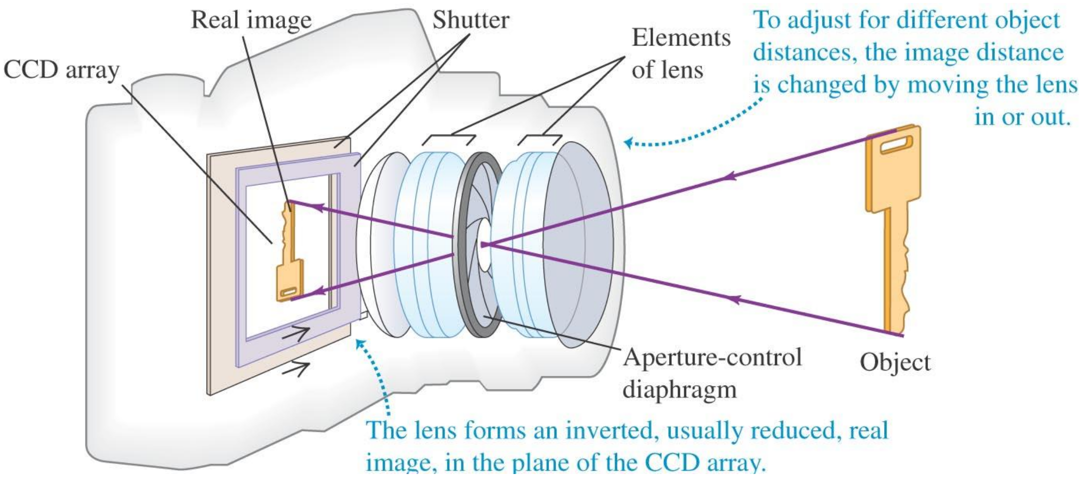


(1) Parallel incident ray appears after refraction to have come from the second focal point F_2.
(2) Ray through center of lens does not deviate appreciably.
(3) Ray aimed at the first focal point F_1 emerges parallel to the axis.

The camera

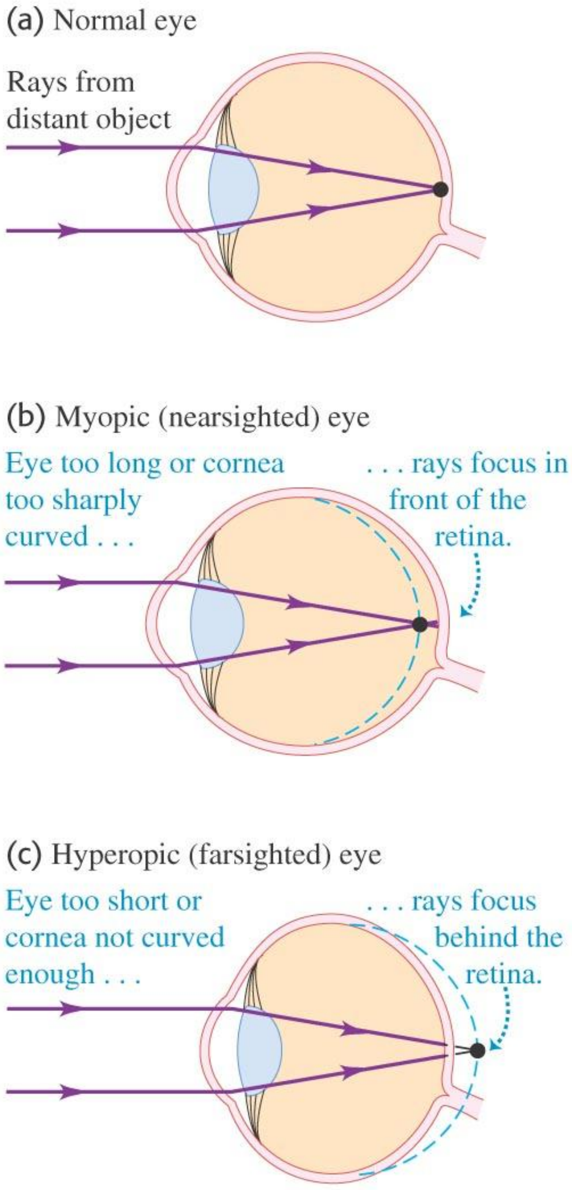
- A clever arrangement of optics with a method to record the inverted image on its focal plane (sometimes film, sometimes an electronic array, it depends on your camera).



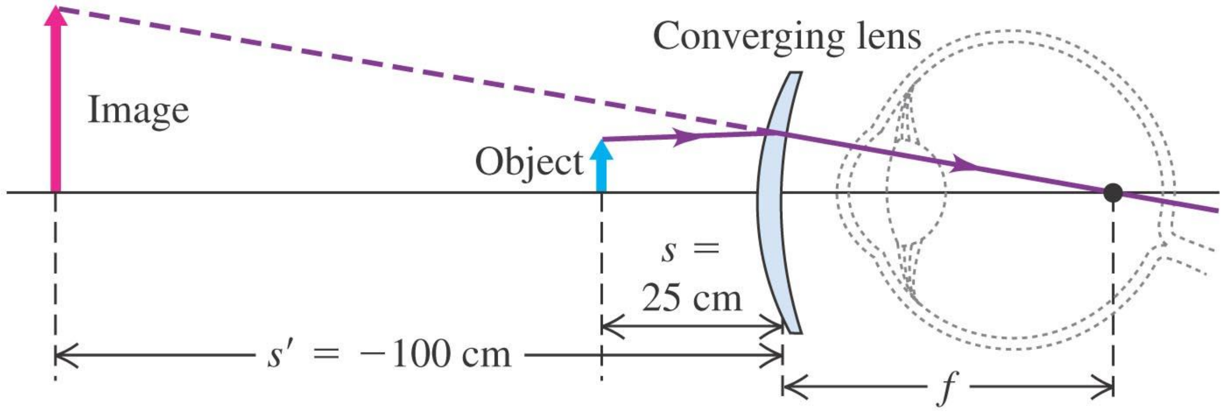


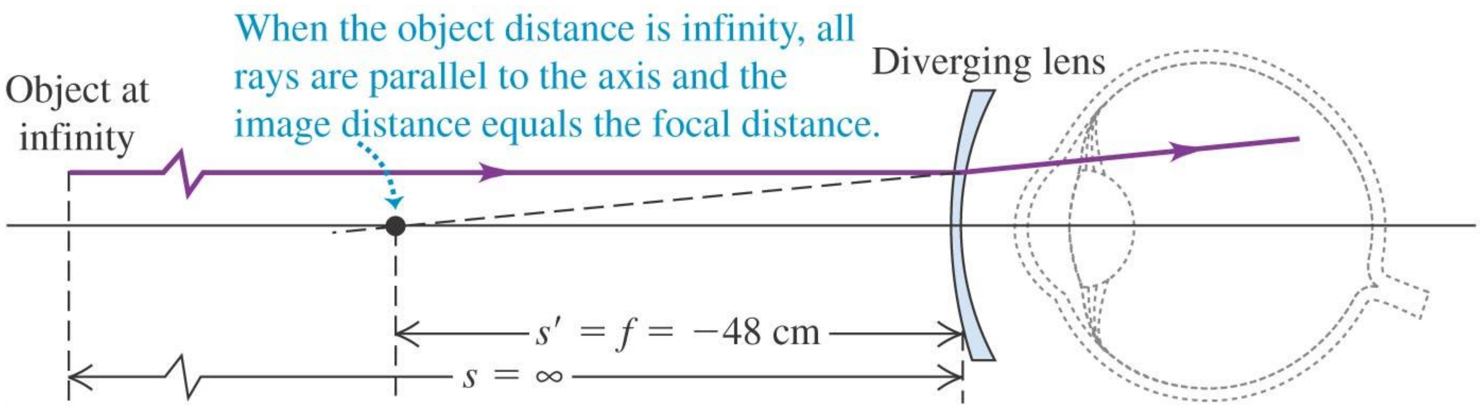
The eye—vision problems

- When the lens of the eye allows incoming light to focus in front of or behind the plane of the retina, a person’s vision will not be sharp.
- Figure shows normal, myopic, and hyperopic eyesight.



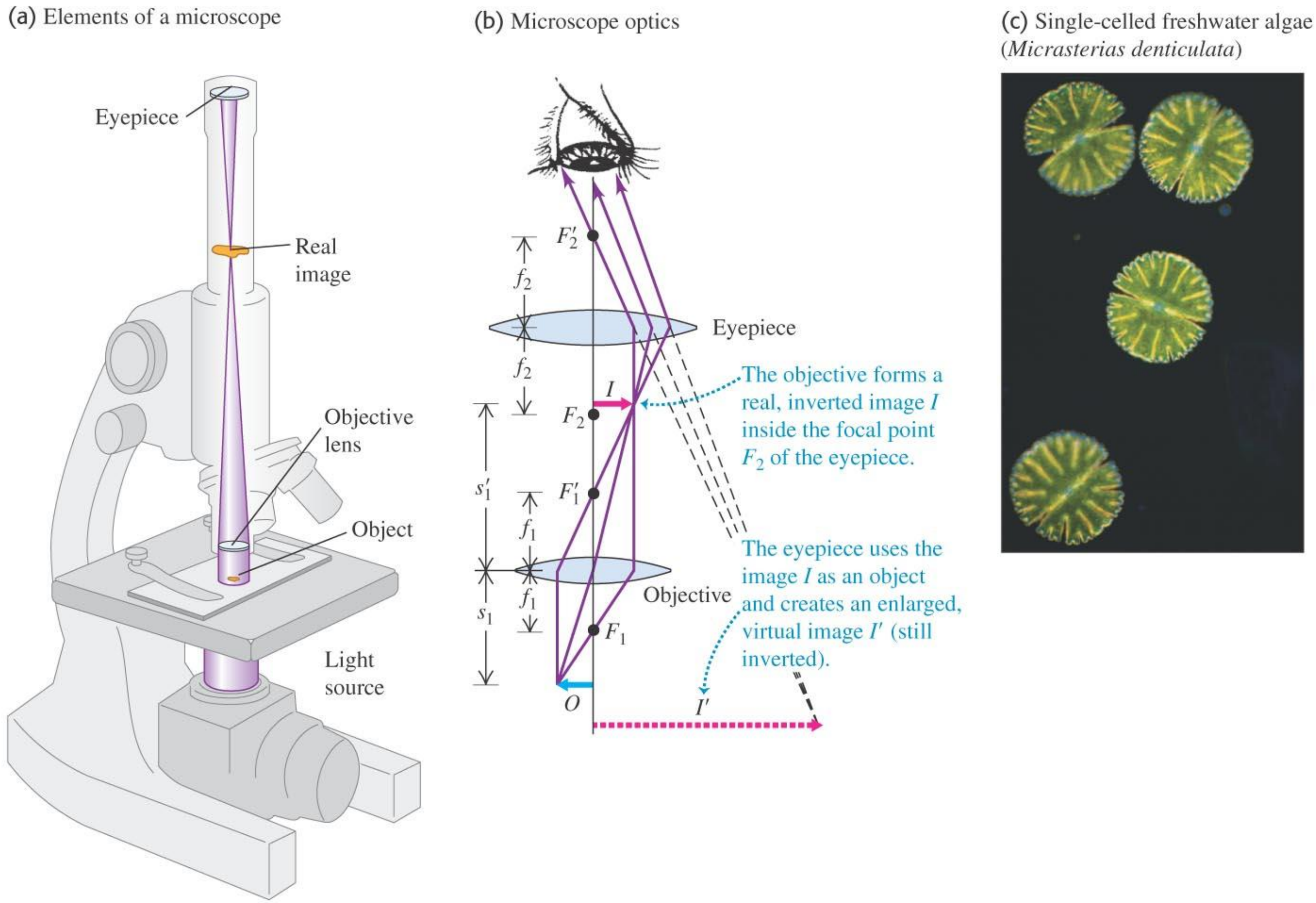
Vision correction—examples





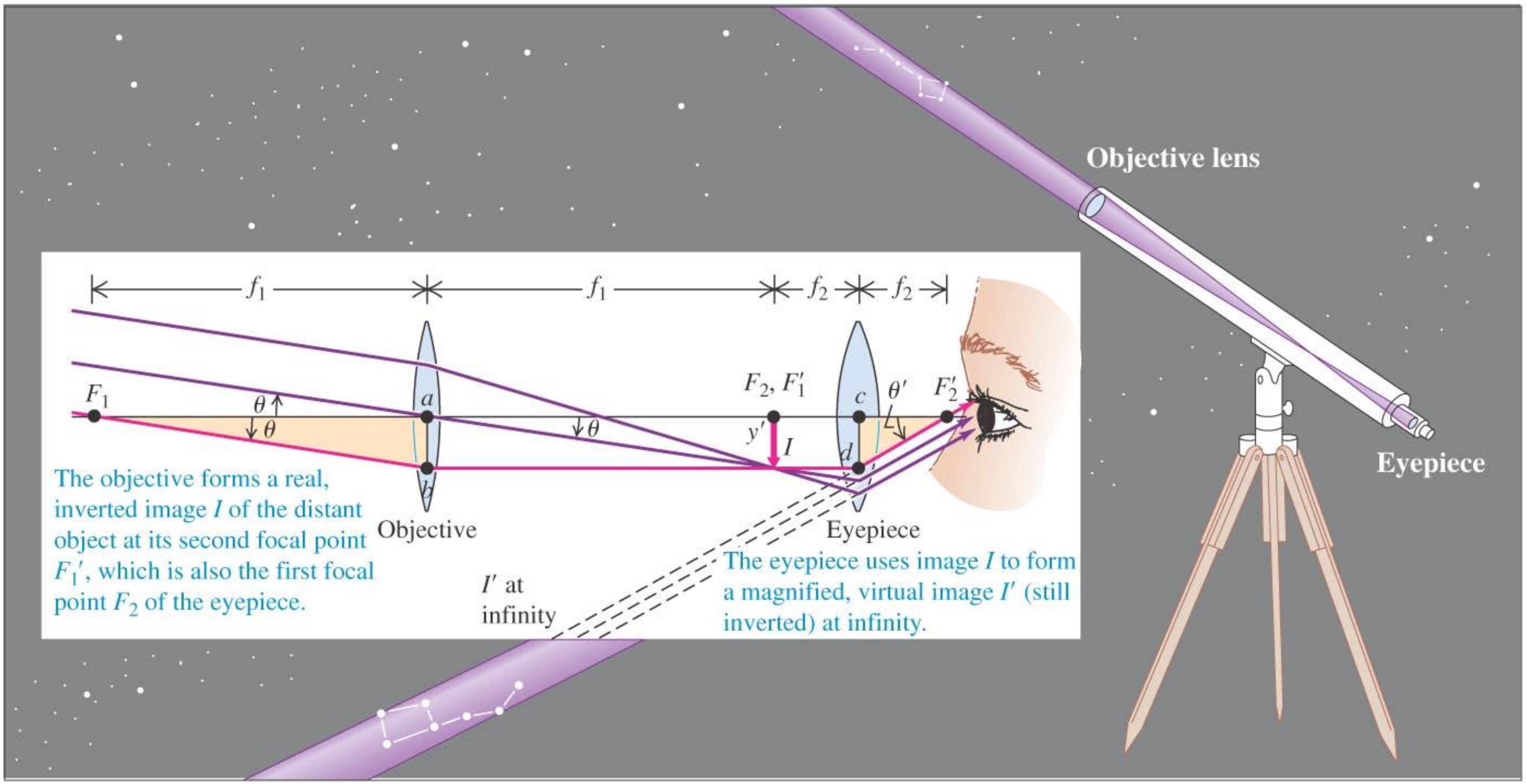
The microscope

- Optical elements are arranged to magnify tiny images for visual inspection. Figure presents the elements of an optical microscope.



The astronomical telescope

- Optical elements are arranged to magnify distant objects for visual inspection. Figure presents the elements of an astronomical telescope.



The reflecting telescope

- Optical elements are arranged to reflect collected light back to an eyepiece or detector. This design eliminates aberrations more likely when using lenses. It also allows for greater magnification. The reflective telescope is shown in Figure