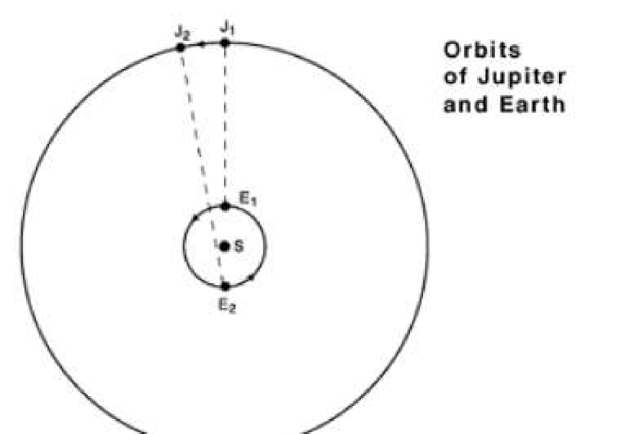
Chapter 11 Light: Geometric Optics

(Giancoli CH 23)

Contents of Chapter 23

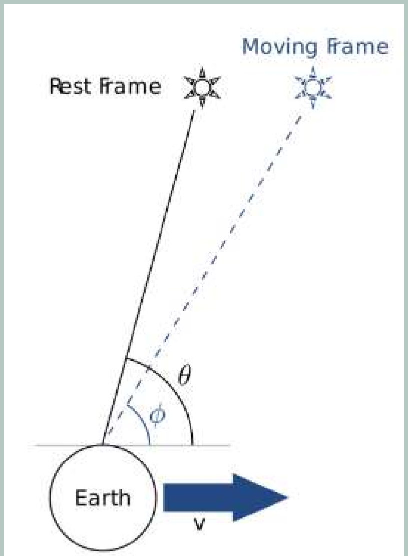
How fast is light? a history

- Galileo 1667
  - Descartes thought light had an infinite speed, Galileo though otherwise. He devised an experiment where person A and B would be several miles away on two hills. Person A would uncover a lantern, and person B would uncover his lantern as soon as he sees light from A. Time would then be measured between when A uncovers his lantern until A sees B’s light, then divide by twice the distance between them. Very inconclusive.
- Ole Rømer 1676
  - He studied the eclipses of Io, Jupiter’s largest moon, by Jupiter to find Io’s orbital period. He accidentally found a pattern that the eclipse happened about 11 minutes earlier than expect at E1 and about 11 minutes later than expected at E2. He took this total time difference of 22 minutes and gave this info to Huygens, who divided it by Earth’s orbital diameter to find the speed of light to be 214km/s.

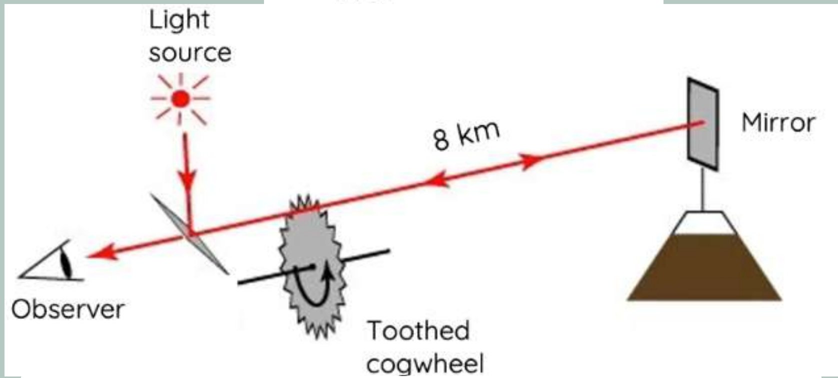


How fast is light? a history

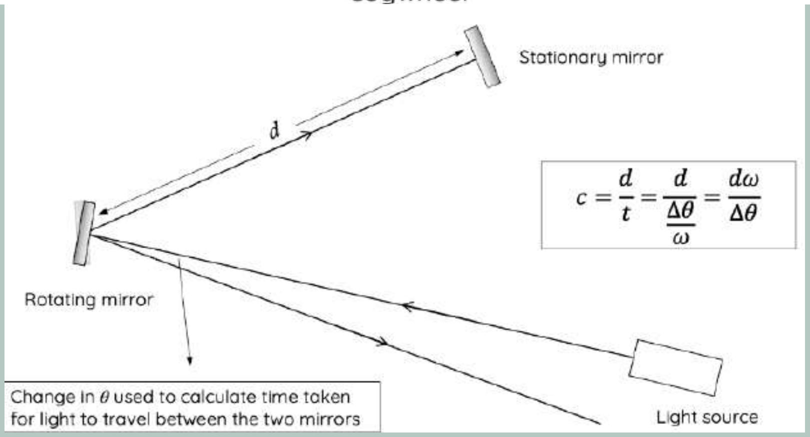
- James Bradley 1728
  - He discovered stellar aberration, which is when stars appear to be moving about their true position due to the motion of Earth. Using this phenomenon, and with knowing the relative speed of earth, he found the speed of light with vector addition and found it to be 301km/s



- Armand Fizeau 1849
  - He used a beam of light reflected from a mirror 8km away. The reflection was aimed at the teeth of a rapidly spinning wheel. Depending on the angular speed of the wheel, the reflected light may or may not pass through the same gap between the teeth of the wheel



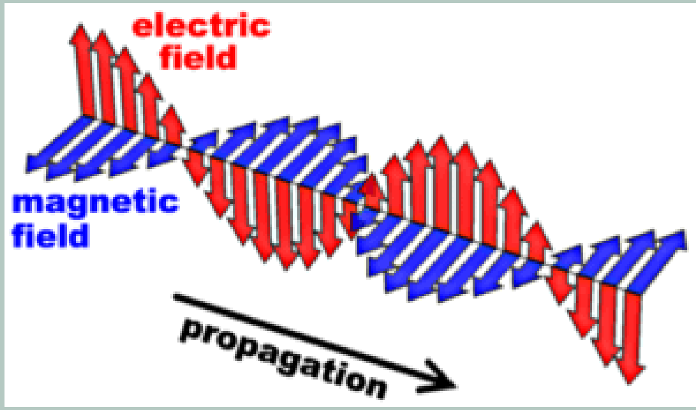
- Leon Foucault 1862
  - Same idea as Fizeau but with rotating mirror in place of the toothed wheel. The returning light hits the rotating mirror at 2 different angles



Date	Author	Method	Result (km/s)	Error
1676	Olaus Roemer	Jupiter's satellites	214,000	
1726	James Bradley	Stellar Aberration	301,000	
1849	Armand Fizeau	Toothed Wheel	315,000	
1862	Leon Foucault	Rotating Mirror	298,000	+-500
1879	Albert Michelson	Rotating Mirror	299,910	+-50
1907	Rosa, Dorsay	Electromagnetic constants	299,788	+-30
1926	Albert Michelson	Rotating Mirror	299,796	+-4
1947	Essen, Gorden-Smith	Cavity Resonator	299,792	+-3
1958	K. D. Froome	Radio Interferometer	299,792.5	+-0.1
1972	Evenson et al.	Lasers	299,792.4574	+-0.001
1983		Adopted Value	299,792.458	

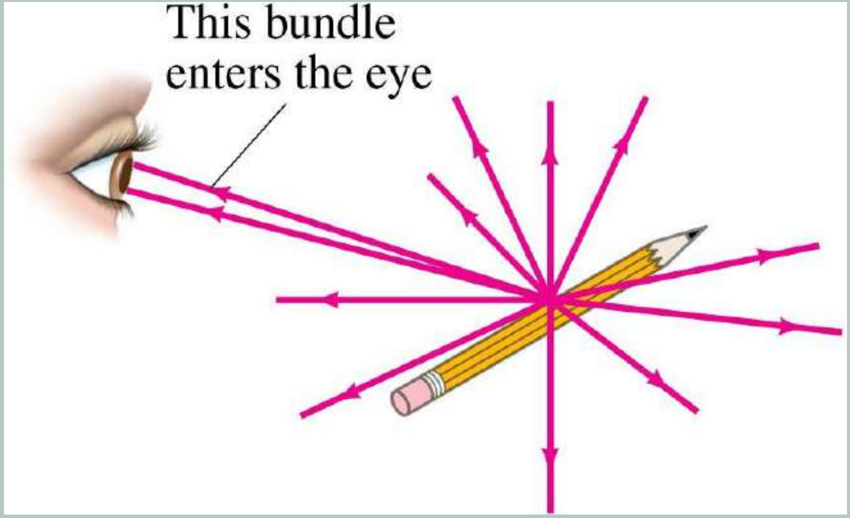
23-1 The Ray Model of Light

- Light is a transverse wave that travels at 299,792,458 m/s in a vacuum. (3x10^8 m/s)



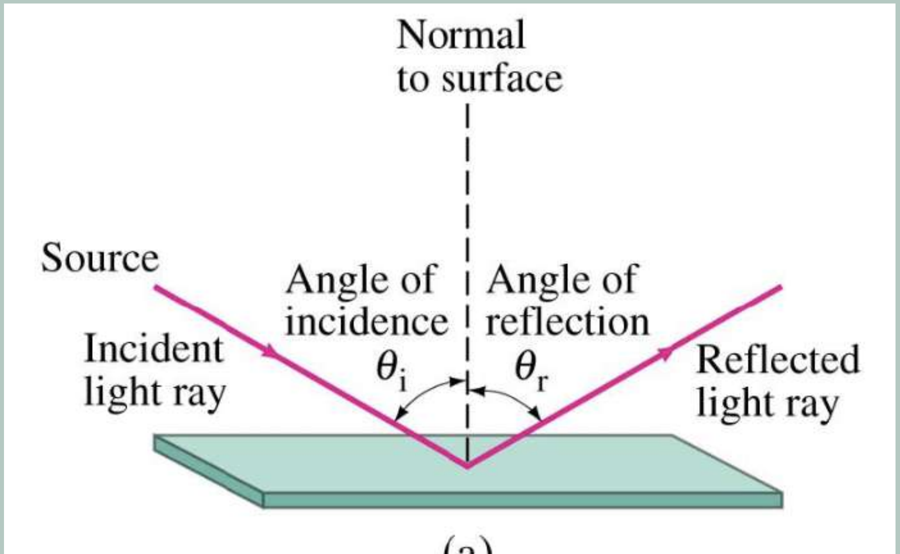
- Does not need a medium to travel through

- Light in geometric optics is represented as a ray, which are straight lines emanating from an object. Light as a wave is next chapter

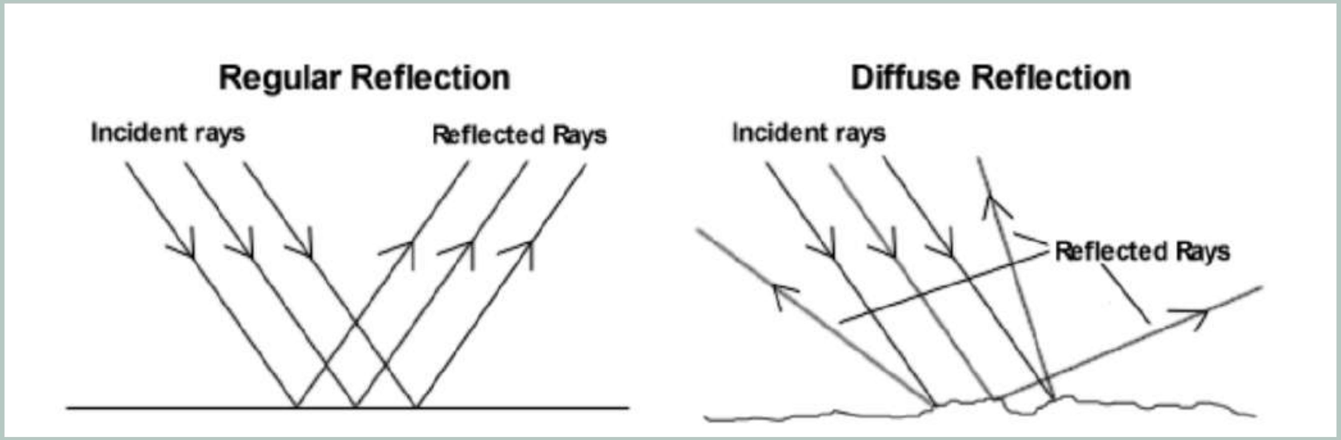


23-2 Reflection; Image Formation by a Plane Mirror

- Law of Reflection: angle of incidence equals the angle of reflection $\theta_i = \theta_r$
- Diffuse reflection occurs from rough surfaces and incident rays are reflected at many angles



(a)



23-2 Reflection; Image Formation by a Plane Mirror

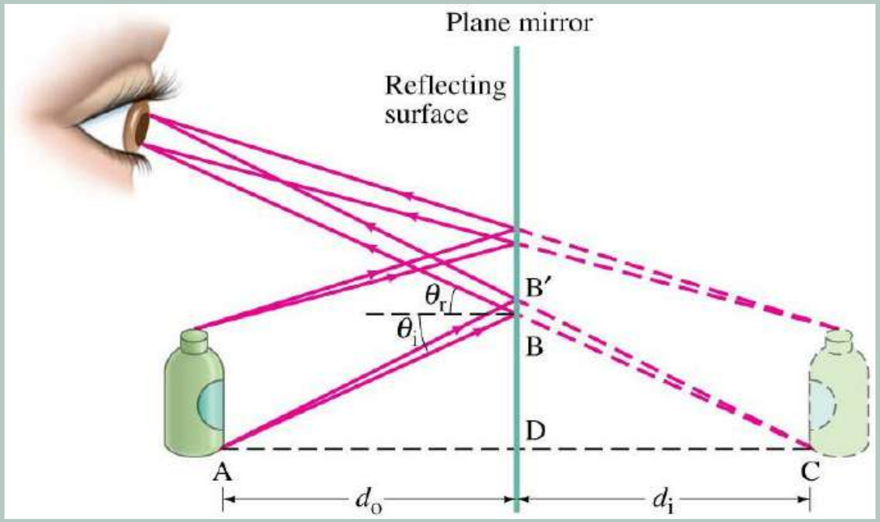
- In a plane (flat) mirror, images appear to be behind (or in) the mirror

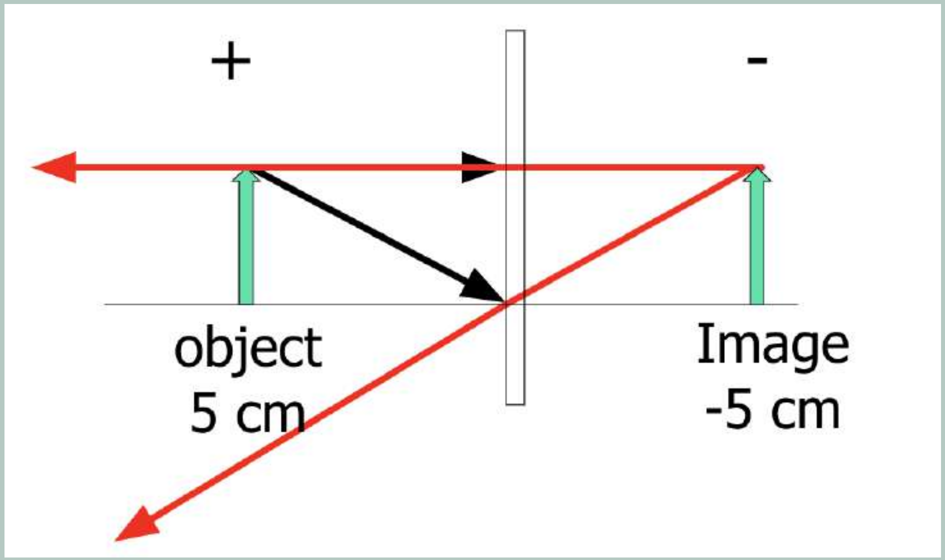
- This is called a virtual image, as the light does not go through it.

$$d_i = d_o$$

distance of the image from the mirror

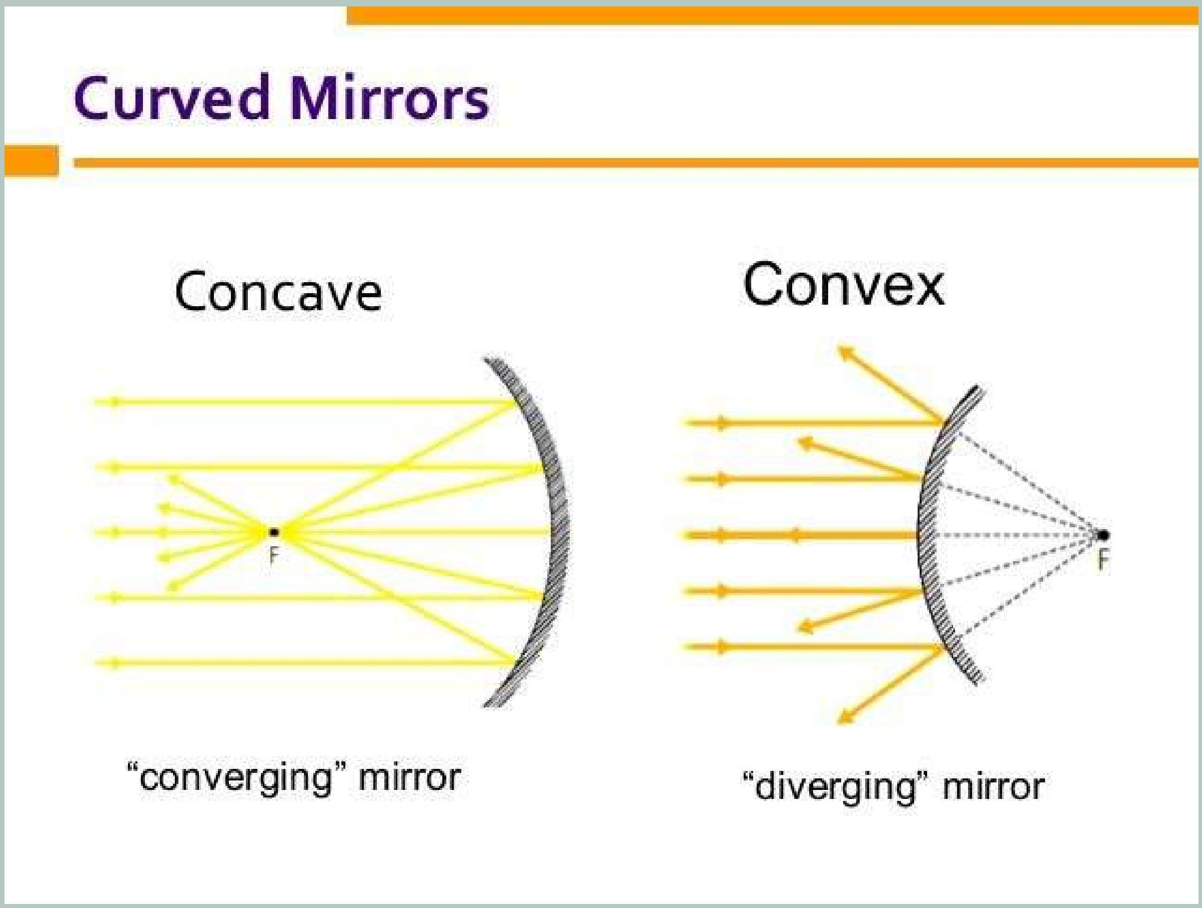
The distance of the object from the mirror





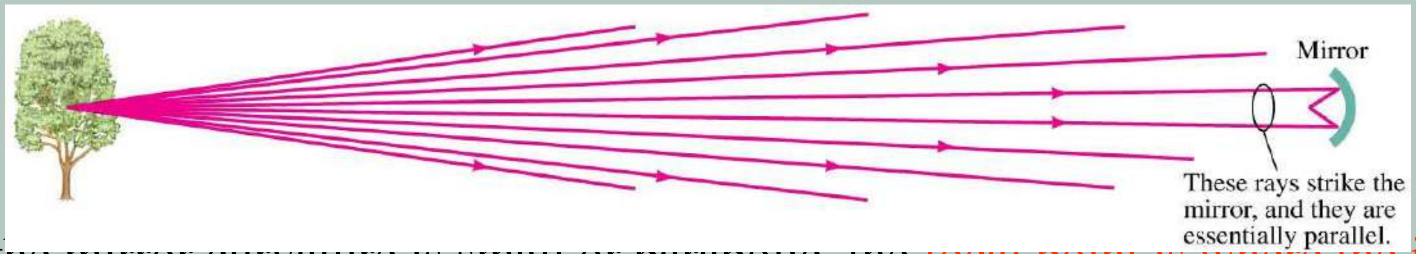
23-3 Formation of Images by Spherical Mirrors

Spherical mirrors may be reflective on the inside (concave) or outside (convex)



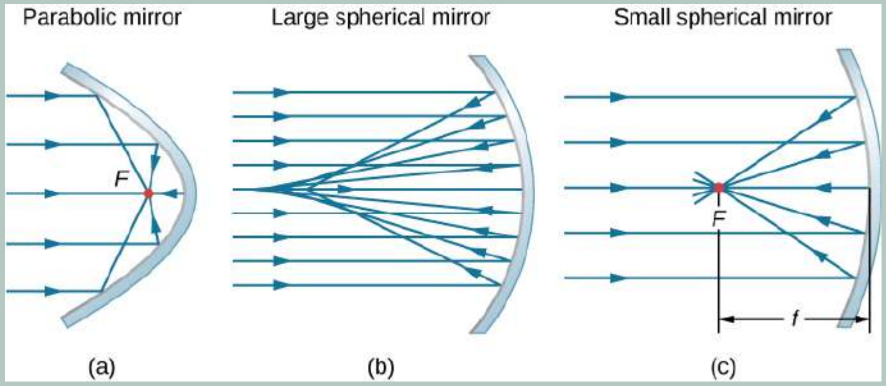
23-3 Formation of Images by Spherical Mirrors

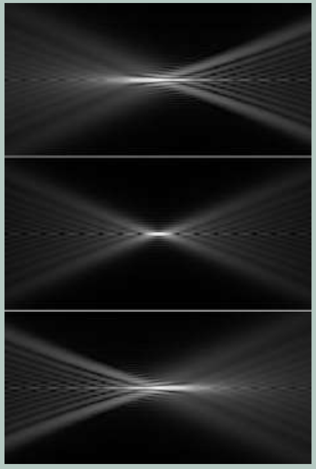
- Rays coming from a faraway object are effectively parallel and are able to be focused

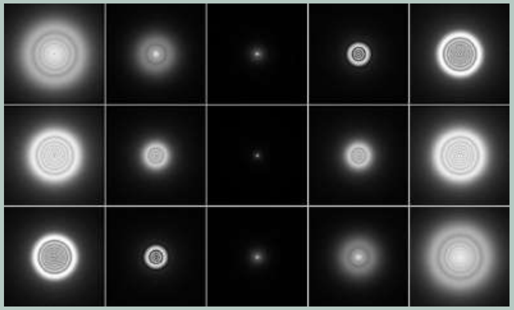


- If the mirror curvature is small or parabolic, the focal point is where the incident parallel rays converge. Located at half the radius of curvature f = r/2

- If the mirror curvature is large, the rays do not all converge at exactly the same place. This is called spherical aberration.



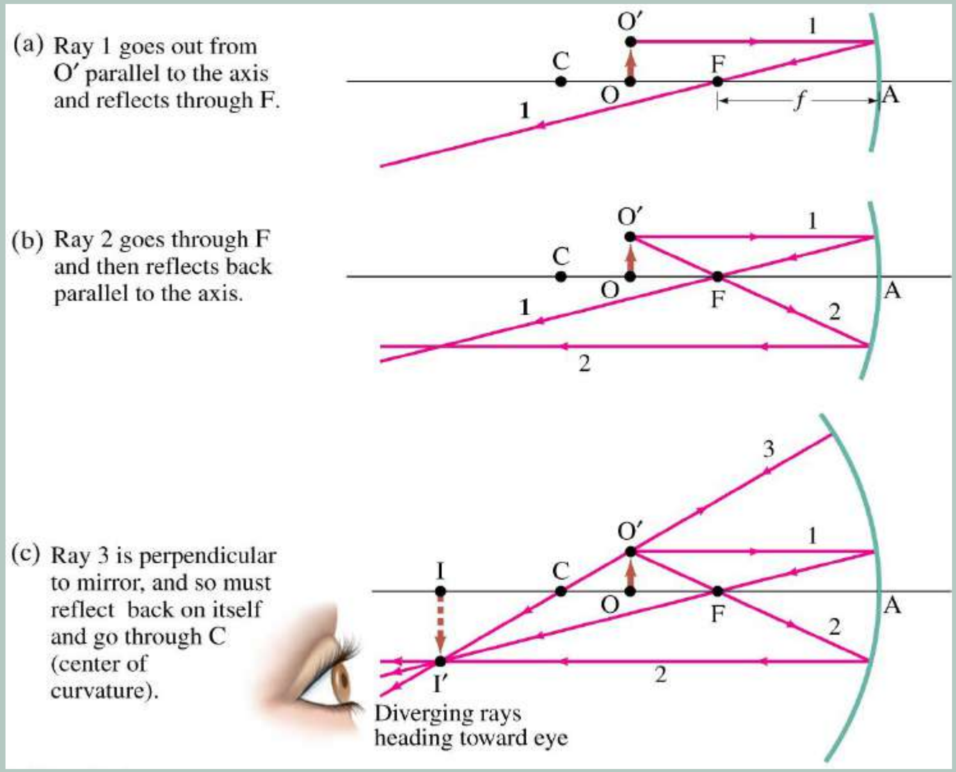




23-3 Formation of Images by Spherical Mirrors

Ray diagrams are used to determine where an image will form or converge.
The diagrams are formed from 3 principle rays

- 1st- Ray parallel to principle axis reflects through focal point.
- 2nd- Ray through focal point reflects parallel to principle axis.
- 3rd- Ray through the center of the lens reflects about the principle axis
- **4th (If you want to be bougie)- Ray through center of curvature reflects back upon itself.



23-3 Formation of Images by Spherical Mirrors

- The Thin Lens Equation relates the object distance, image distance, and focal length of the mirror

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

- Magnification

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

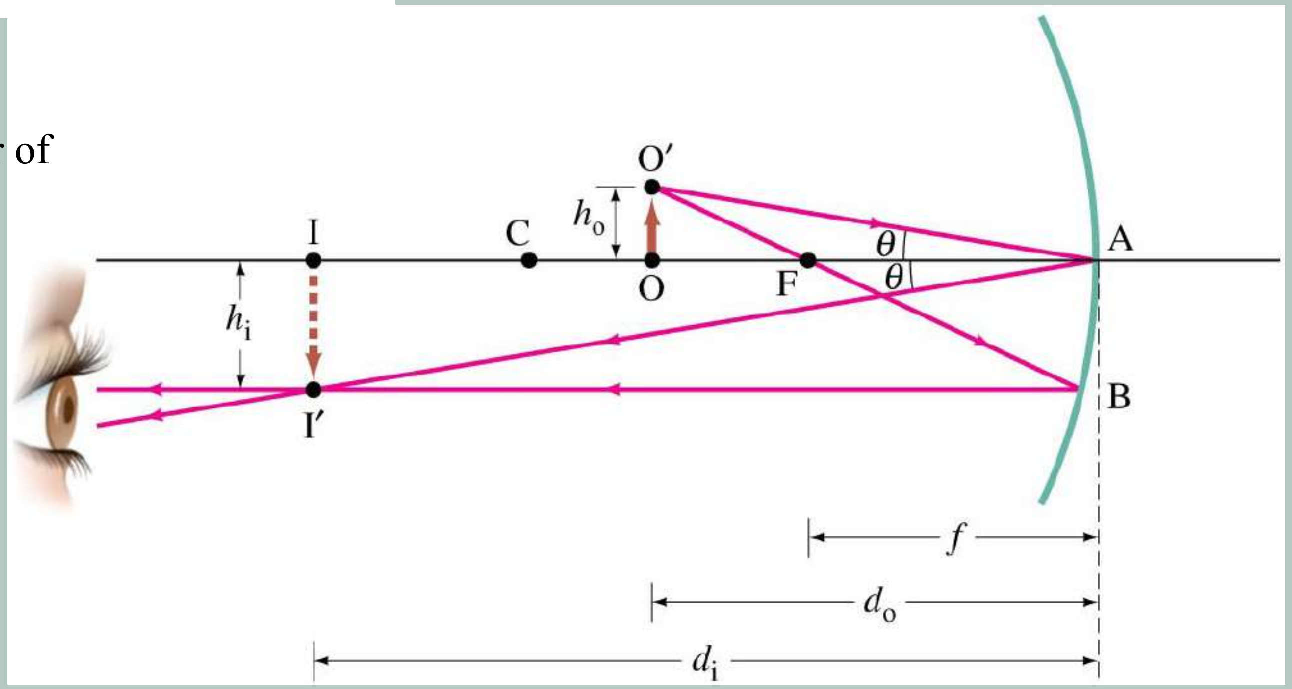
m < 0 image is inverted, else it is upright
m < |1| image is smaller, else it is larger

This object is between the center of curvature and focal point

-> is image larger or smaller?
-> inverted or upright?
-> virtual or real?

it is larger, inverted, and real

[for examples on image formation]

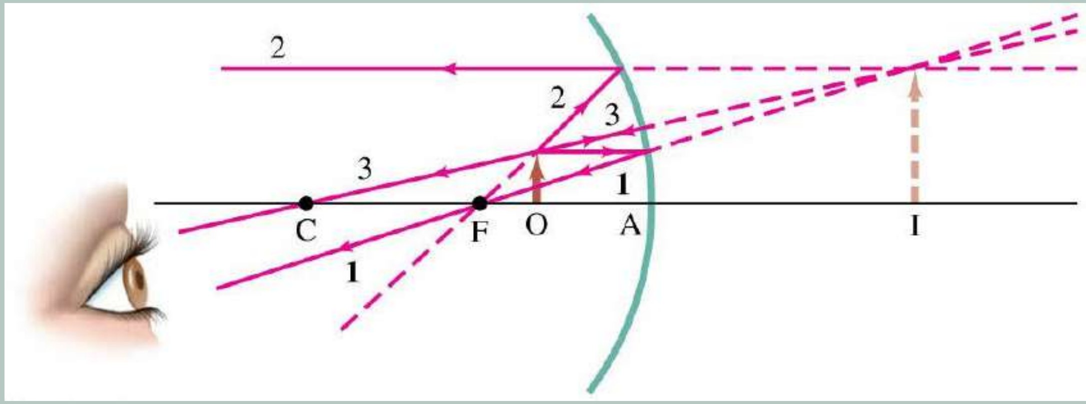


23-3 Formation of Images by Spherical Mirrors

you practice….

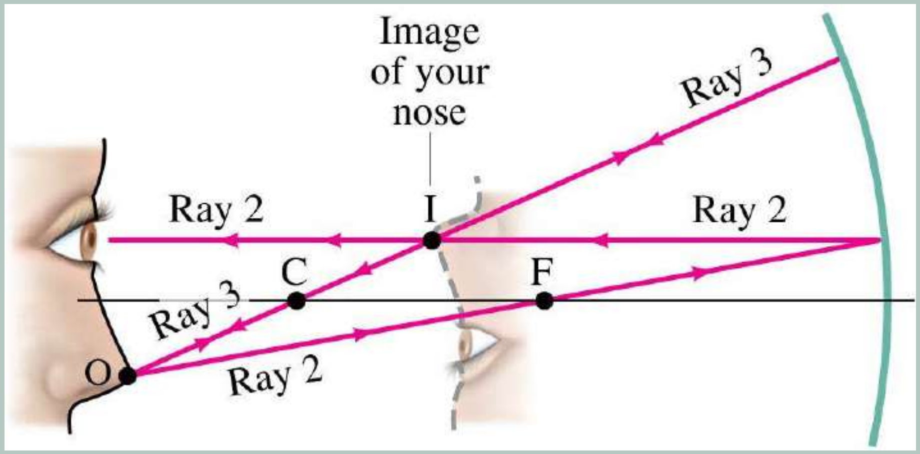
1) If an object is inside the focal point:

its image will be upright, larger, and virtual.



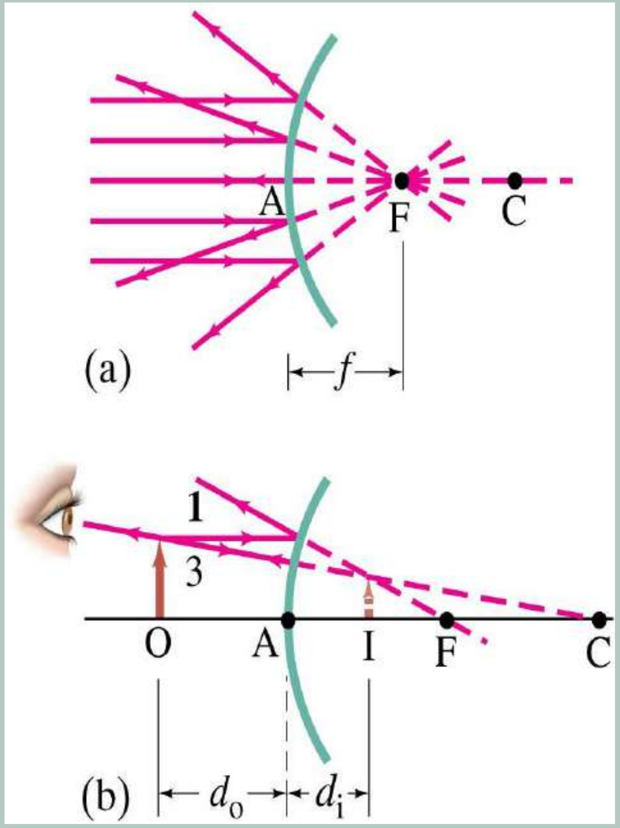
2) object is outside the center of curvature:

its image will be inverted, smaller, and real



23-3 Formation of Images by Spherical Mirrors

3) For a convex "diverging" mirror: the image is always virtual, upright, and smaller.



Example 1

The radius of curvature of a spherical, convex, mirror is 20cm. What is its focal length?

Example 2

An object is placed 12 cm to the left of a convex mirror. The image has a magnification of ¼.

a) is the image upright or inverted?
b) Is the image real or virtual?
c) image distance?
d) focal length of mirror?

17. What type of mirror is shown in Fig. 23–50? Explain.

FIGURE 23–50 Question 17 and Problem 15.

23-4 Index of Refraction

- Light slows when traveling through a denser medium (λ changes f remains the same)
- Light bends at the interface between media, or refracts. Each medium is characterized by a unitless index of refraction

the speed of light in vacuum

$$n = \frac{c}{v}$$

the speed of light in the medium

TABLE 23–1 Indices of Refraction†

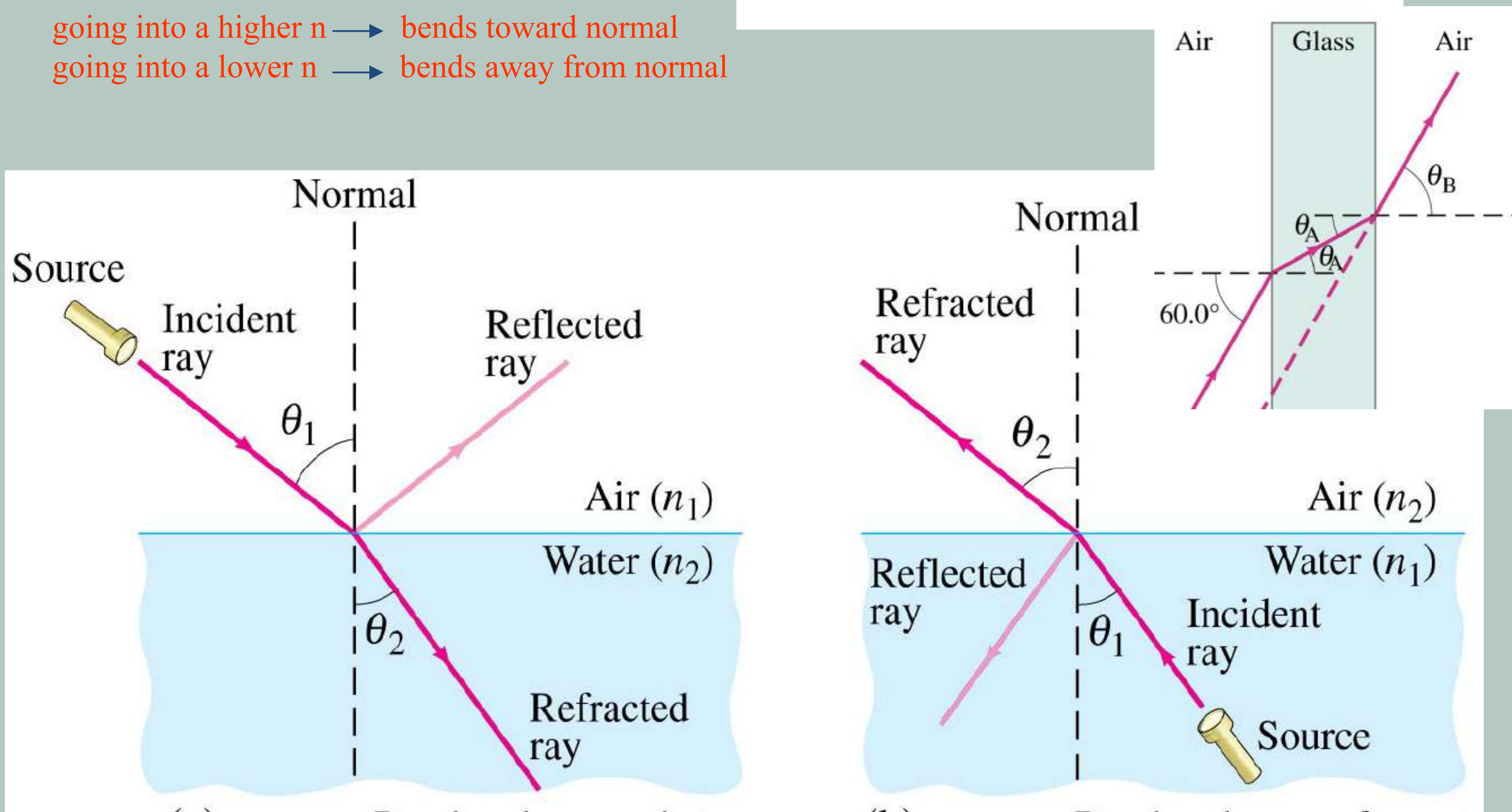
Material	$n = \dfrac{c}{v}$
Vacuum	1.0000
Air (at STP)	1.0003
Water	1.33
Ethyl alcohol	1.36
Glass	
Fused quartz	1.46
Crown glass	1.52
Light flint	1.58
Plastic	
Acrylic, Lucite, CR-39	1.50
Polycarbonate	1.59
"High-index"	1.6–1.7
Sodium chloride	1.53
Diamond	2.42

† $\lambda = 589$ nm.

23-5 Refraction: Snell's Law

Law of Refraction (Snell's Law): $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

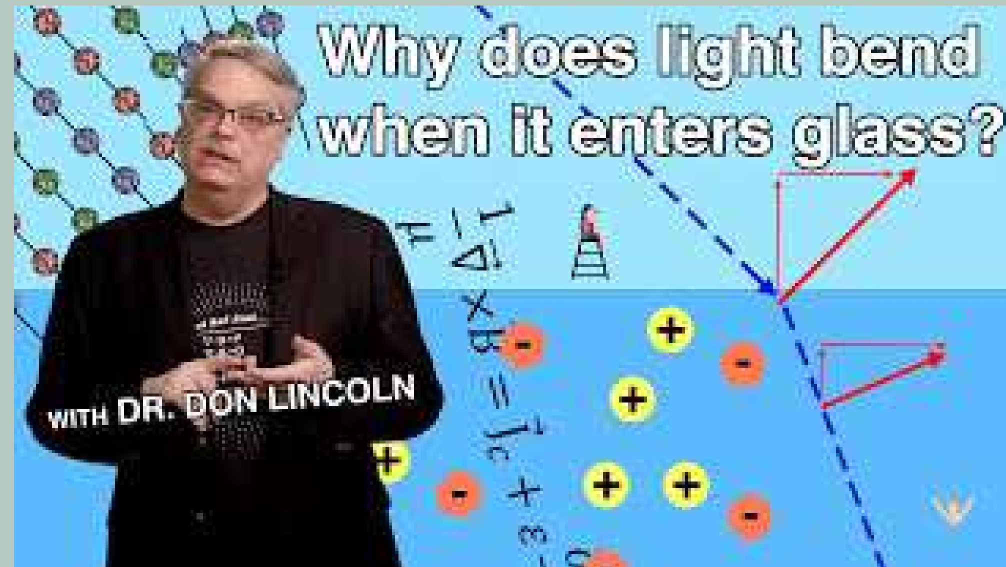
going into a higher n ⟶ bends toward normal
going into a lower n ⟶ bends away from normal



(a) $n_2 > n_1$: Ray bends toward ⊥ (b) $n_1 > n_2$: Ray bends away from ⊥

23-5 Refraction: Fermet’s Principle

Fermet’s Principle:
“Principle of least time”
the actual path taken by a beam of light is the one which is traversed in least time



5. Parallel light rays cross interfaces from medium 1 into medium 2 and then into medium 3 as shown in Fig. 23–51. What can we say about the relative sizes of the indices of refraction of these media?

(*a*) $n_1 > n_2 > n_3$.
(*b*) $n_3 > n_2 > n_1$.
(*c*) $n_2 > n_3 > n_1$.
(*d*) $n_1 > n_3 > n_2$.
(*e*) $n_2 > n_1 > n_3$.
(*f*) None of the above.

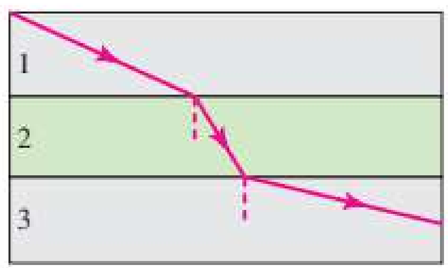
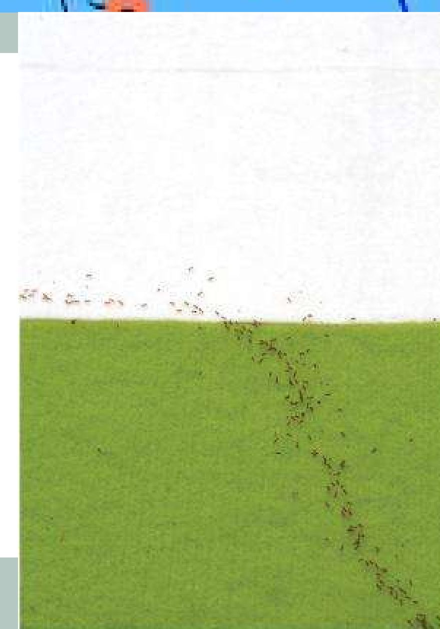


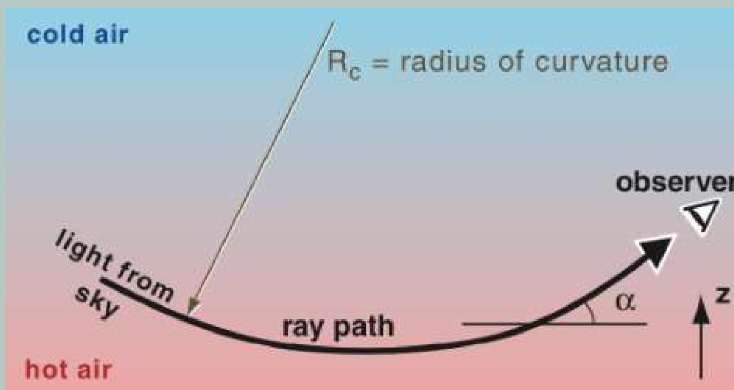
FIGURE 23–51 MisConceptual Question 5.



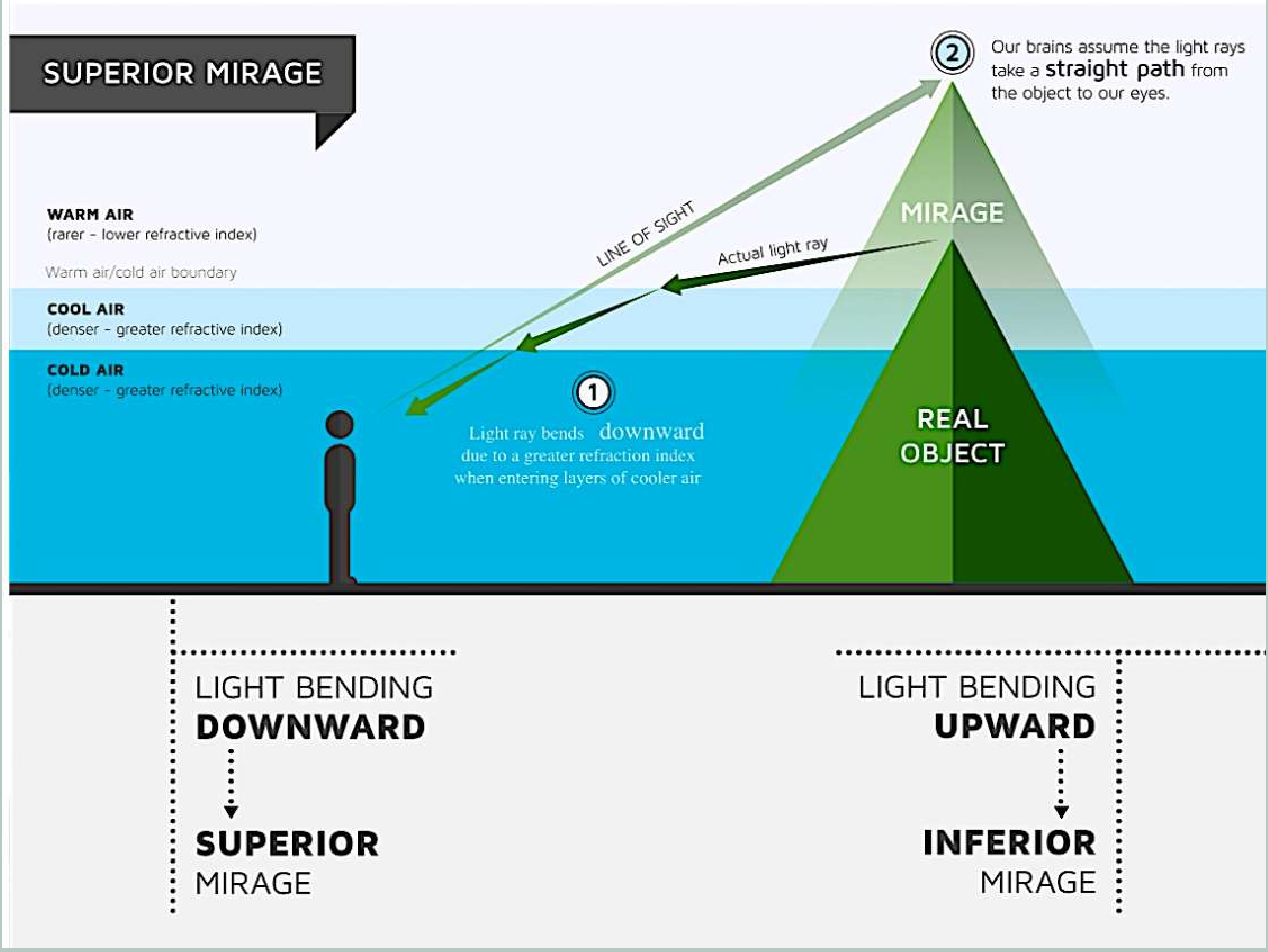
Refraction

Mirages are created when light passes through air of different temperatures

- **Inferior mirages:** air is heated (less dense -> lower *n*) closer to surface, making light from the sun bend away from the normal/ back up to our eyes making you see the sky in the ground (like a mirror)



- s (mo o surface, making light bend toward the normal/ bend down


SUPERIOR MIRAGE
Our brains assume the light rays take a straight path from the object to our eyes.
WARM AIR
(rarer - lower refractive index)
Warm air/cold air boundary
COOL AIR
(denser - greater refractive index)
COLD AIR
(denser - greater refractive index)
LINE OF SIGHT
Actual light ray
MIRAGE
REAL OBJECT
1
Light ray bends downward due to a greater refraction index when entering layers of cooler air
2
LIGHT BENDING DOWNWARD
SUPERIOR MIRAGE
LIGHT BENDING UPWARD
INFERIOR MIRAGE

23-6 Total Internal Reflection

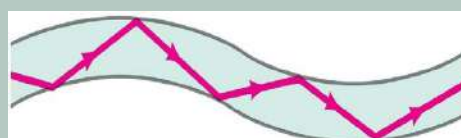
If light passes into a medium with a smaller index of refraction $n_2 < n_1$,there is a θ_1 for which no transmission will occur ($\theta_2 = 90^o$), this is called the critical angle $\theta_1 = \theta_c$

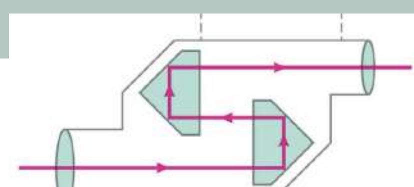
$$\sin(\theta_c) = \frac{n_2}{n_1}$$

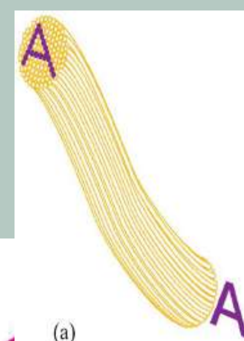
When $\theta_1 \geq \theta_c$, there is total in **has no loss of intensity, works better rors!!!**

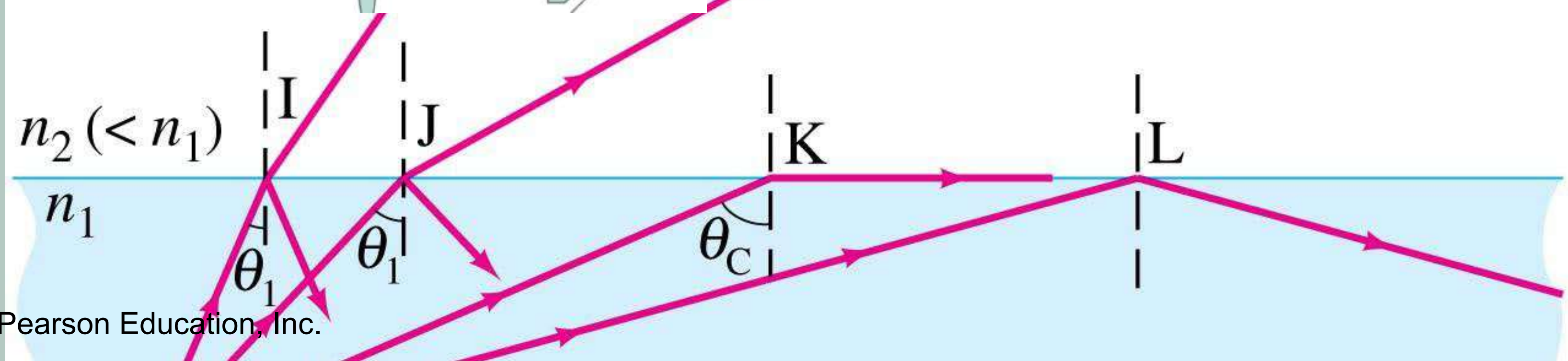
examples:

- fiber optics
- binoculars









Example 3

(II) In searching the bottom of a pool at night, a watchman shines a narrow beam of light from his flashlight, 1.3 m above the water level, onto the surface of the water at a point 2.5 m from his foot at the edge of the pool (Fig. 23–57). Where does the spot of light hit the bottom of the 2.1-m-deep pool? Measure from the bottom of the wall beneath his foot.

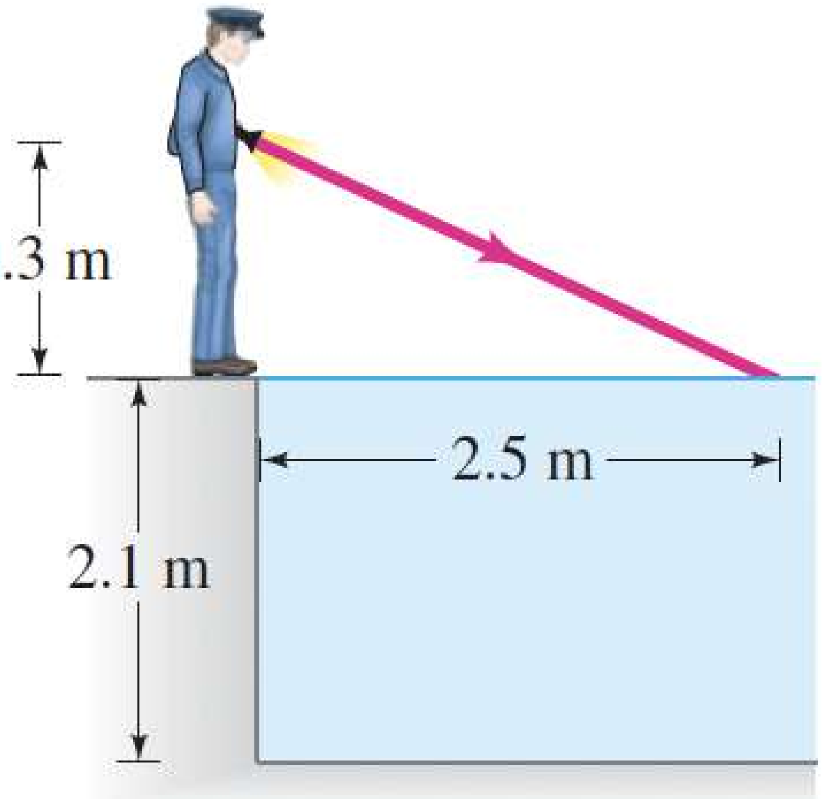


FIGURE 23–57
Problem 34.

Example 4

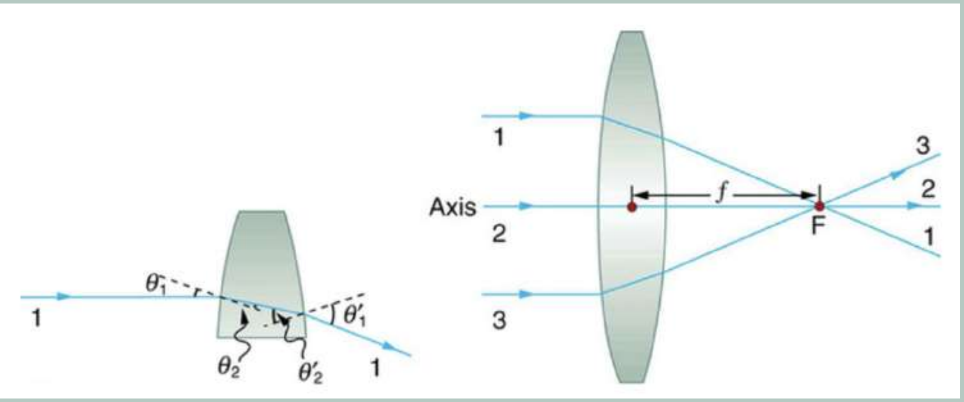
The index of refraction of diamond is 2.4

a) White light,in air, shines into a diamond. What minimum angle of incidence in the diamond is required to obtain total internal reflection?
b) The wavelength of red light is 700nm, what is the wavelength of this light in the diamond?

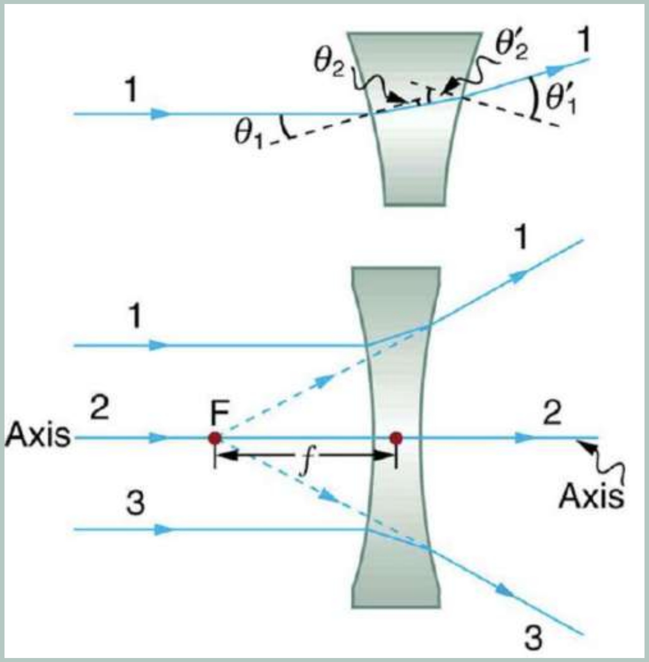
cool note: The low angle of incidence required to trap light in the diamond allows the light to disperse

23-7 Thin Lenses; Ray Tracing

Convex/Converging lens: thicker in center than at edge



Concave/diverging lens: thicker at edge than in center



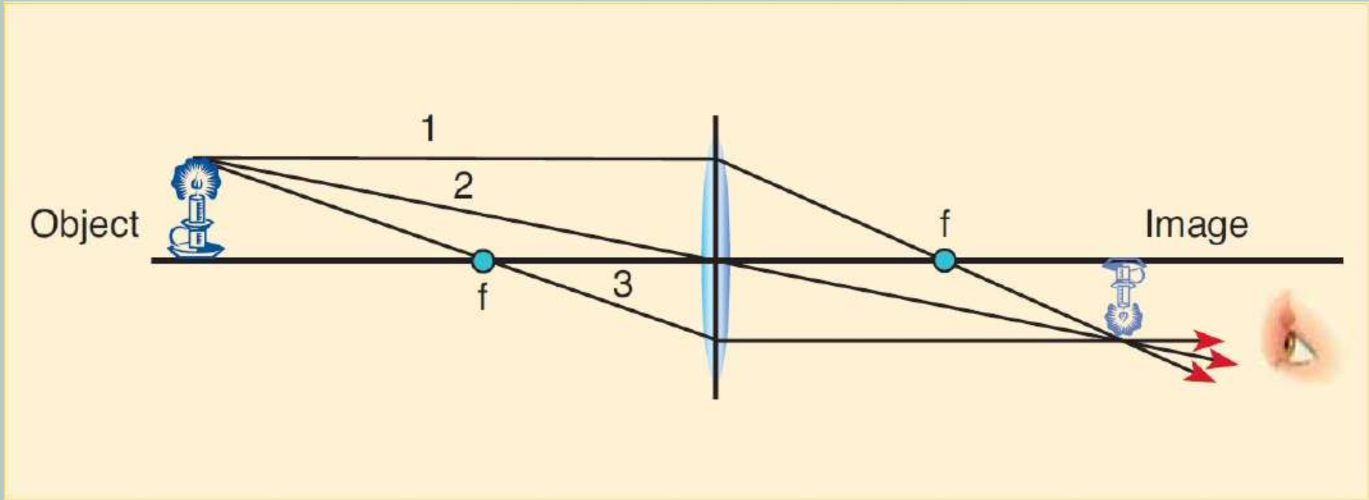
23-7 Thin Lenses; Ray Tracing

Ray diagrams for thin lenses:

- 1st- Ray parallel to principal axis transmits _______ focal point.
  - Converging: through the far
  - Diverging: as if it's from the near
- 2nd- Ray aimed toward the _____focal point transmits parallel to principal axis.
  - Converging: near
  - Diverging: far
- 3rd- Ray through the center of the lens transmits undeflected

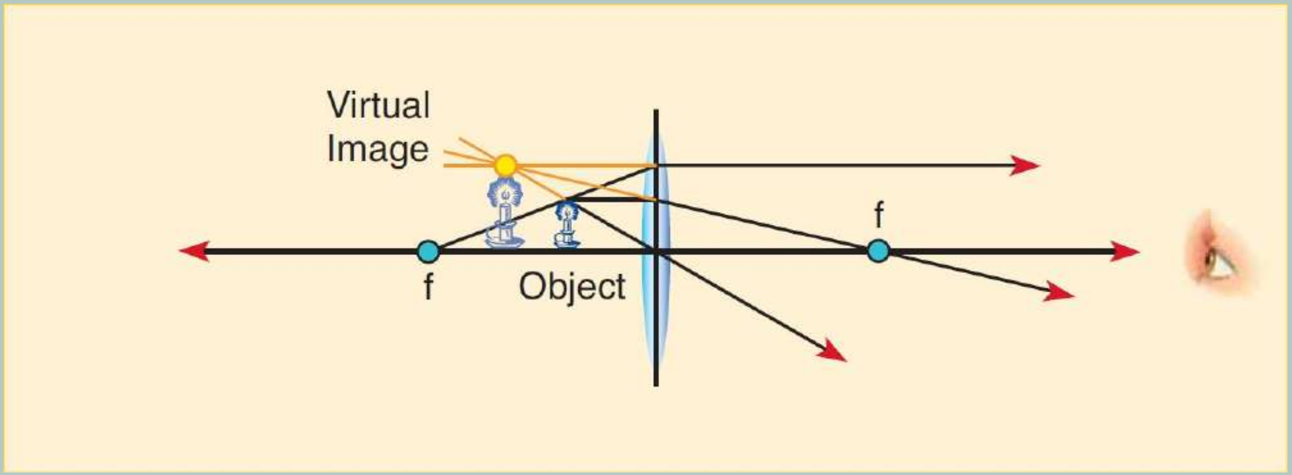
practice…

Convex lens, object outside focal point



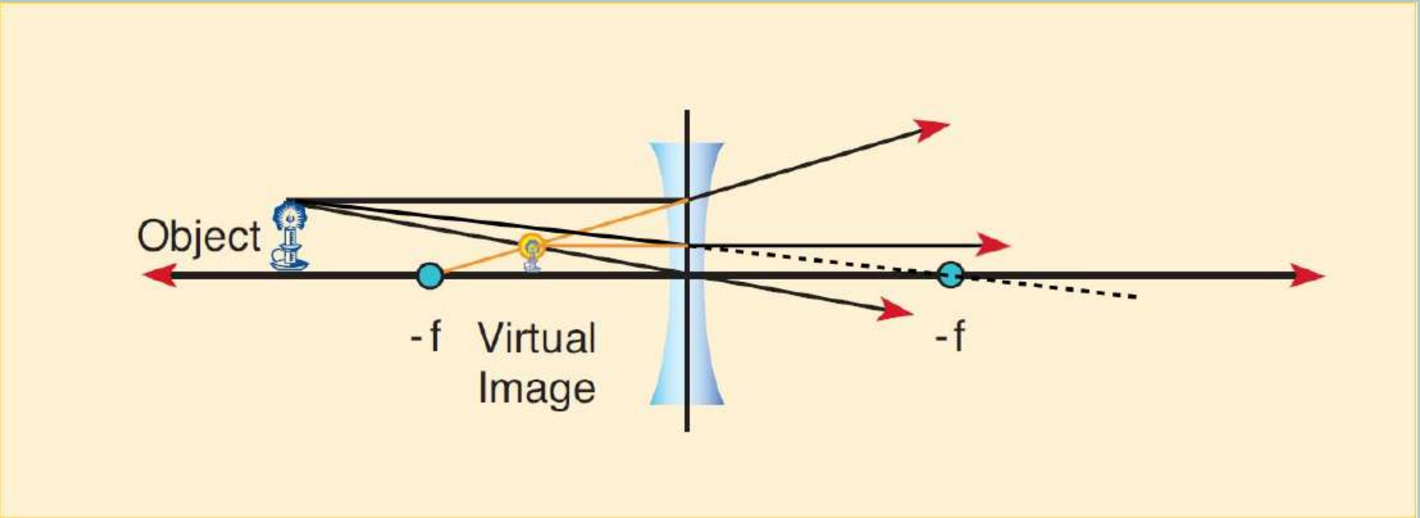
real, smaller, inverted

Convex lens, object inside focal point



virtual, larger, upright

Diverging Lens, object outside focal point



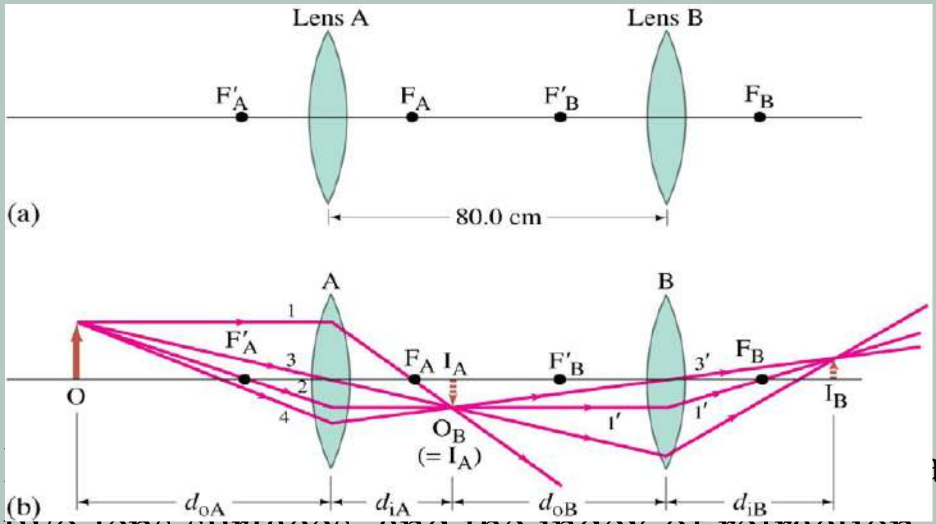
virtual, smaller, upright

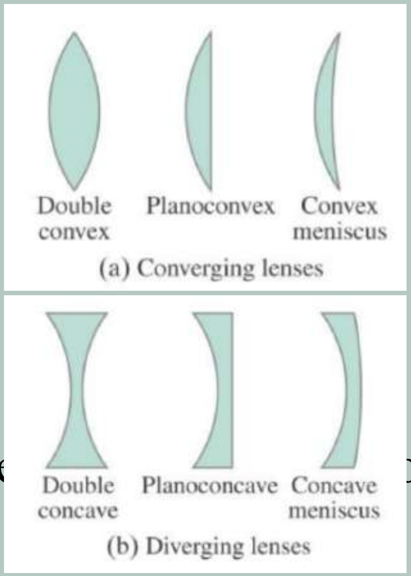
Geometric Optics Sign Conventions

1. f is positive for converging lenses/mirrors, else is it negative.
2. d_o is positive when the object is on the same side as the incident light, else it is negative.
3. d_i is positive if the image is formed by the physical light rays; else it is negative.
4. h_i is positive if the image is upright, else it is negative

23-9 Combinations of Lenses

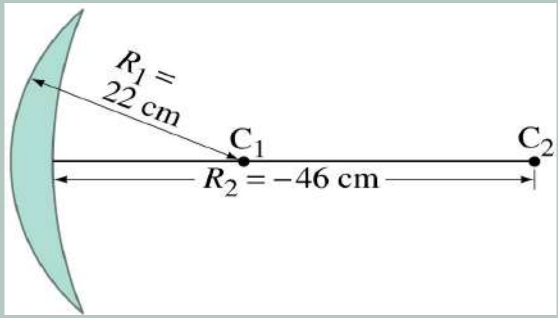
- In lens combinations, the image formed by the first lens becomes the object for the second lens (this is where object distances may be negative).





- … ates the … of the two lens surfaces, and the index of refraction, to the …

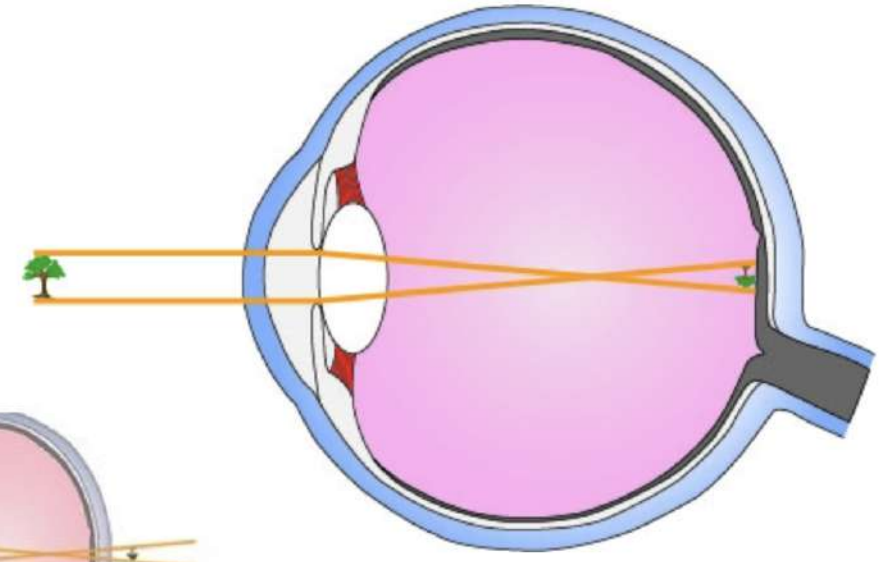
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$



Common Uses of Lenses

- Optical Correction

nearsighted: sees objects near
farsighted: sees objects far



ure 3. Ray diagram for the human eye.

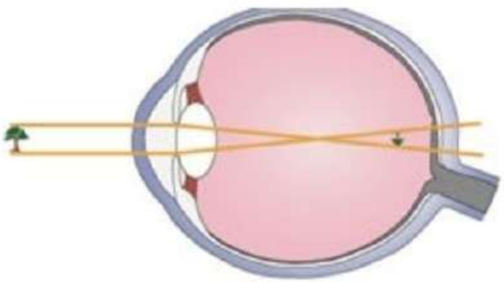


Figure 6 Nearsightedness.

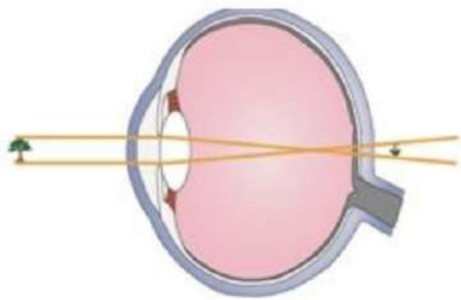


Figure 7 Farsightedness.

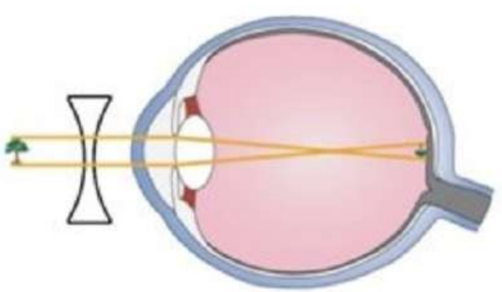


Figure 8 Corrected nearsightedness.

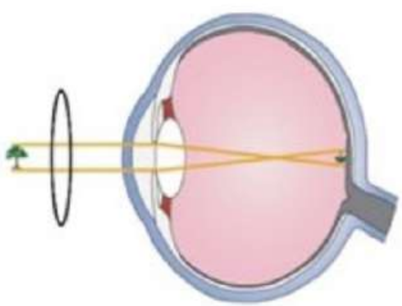


Figure 9 Corrected farsightedness.

Common Uses of Lenses

- Telescopes/Microscopes

Objective lens: focuses the image, image is inverted, real, and smaller

**brings the object “closer” **

Eyepiece: magnifies the image, image is upright and virtual

** only works short distances**

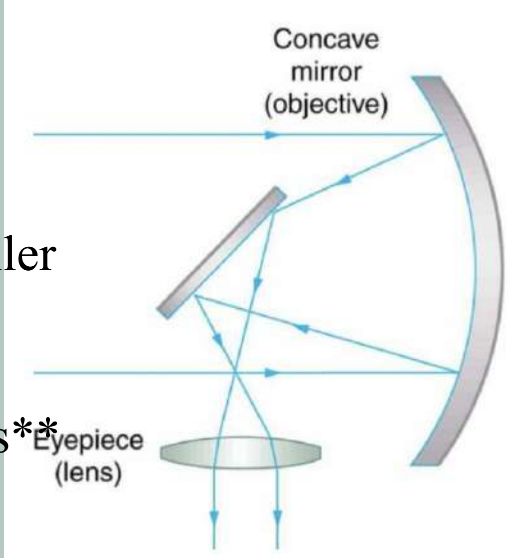


Figure 3. A two-element telescope composed of a mirror as the objective and a lens for the eyepiece is shown. This telescope forms an image in the same manner as the two-convex-lens telescope already discussed, but it does not suffer

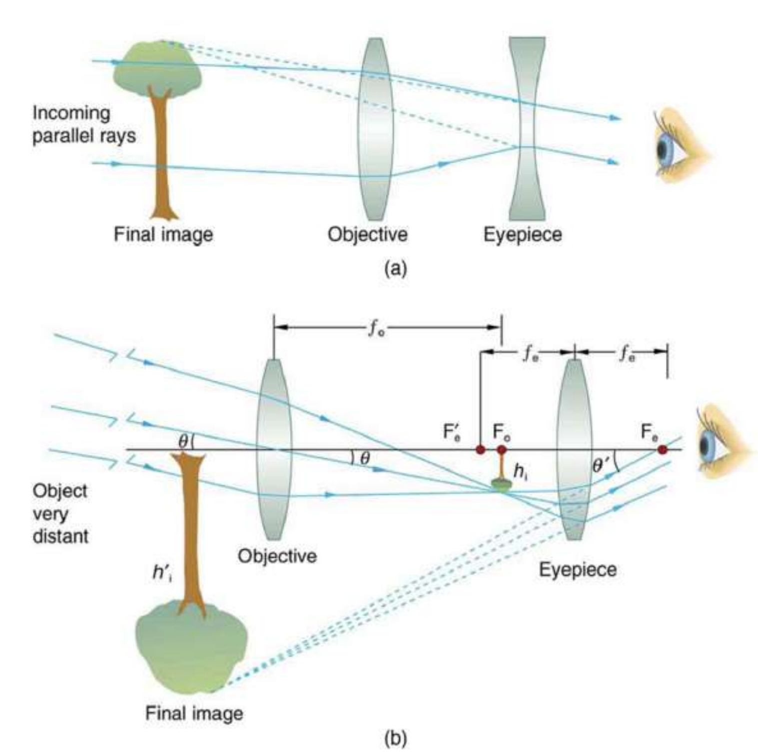


Figure 1. (a) Galileo made telescopes with a convex objective and a concave eyepiece. These produce an upright image and are used in spyglasses. (b) Most simple telescopes have two convex lenses. The objective forms a case 1 image that is the object for the eyepiece. The eyepiece forms a case 2 final image that is magnified.

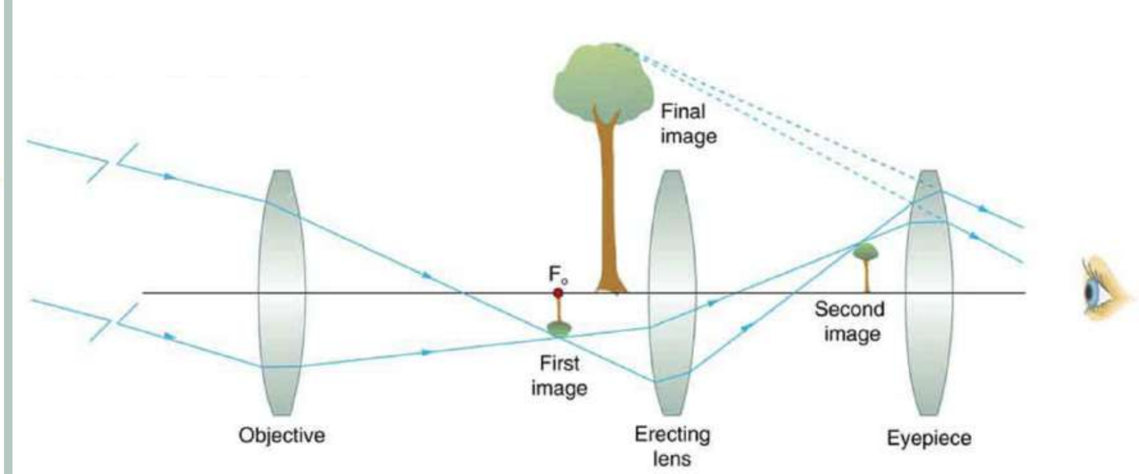


Figure 2. This arrangement of three lenses in a telescope produces an upright final image. The first two lenses are far enough apart that the second lens inverts the image of the first one more time. The third lens acts as a magnifier and keeps the image upright and in a location that is easy to view.

Optical Instruments