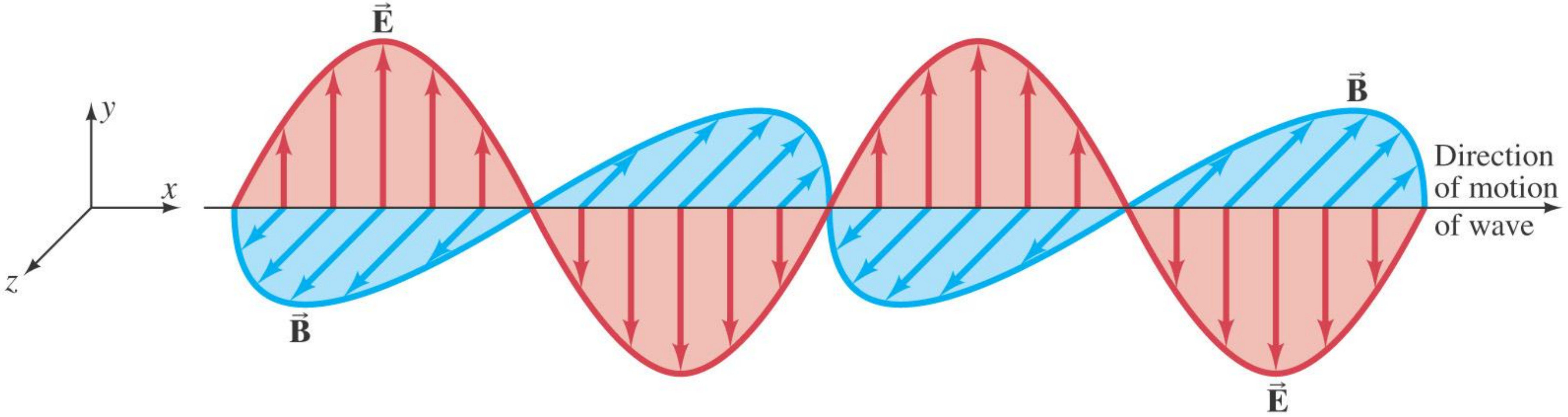
Chapters 22-23

Light, Mirrors and Lenses

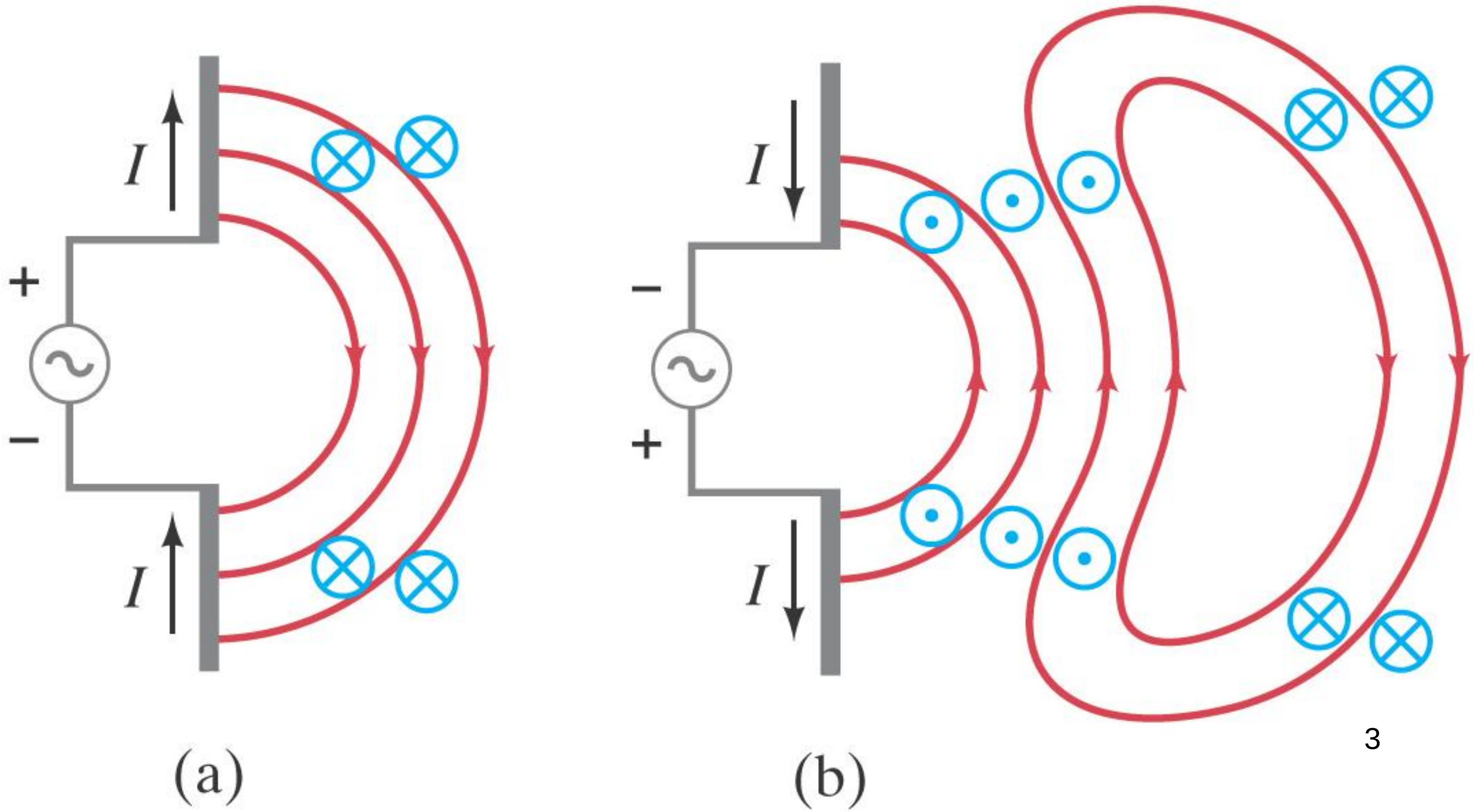
Chapter 22

Electromagnetic Waves



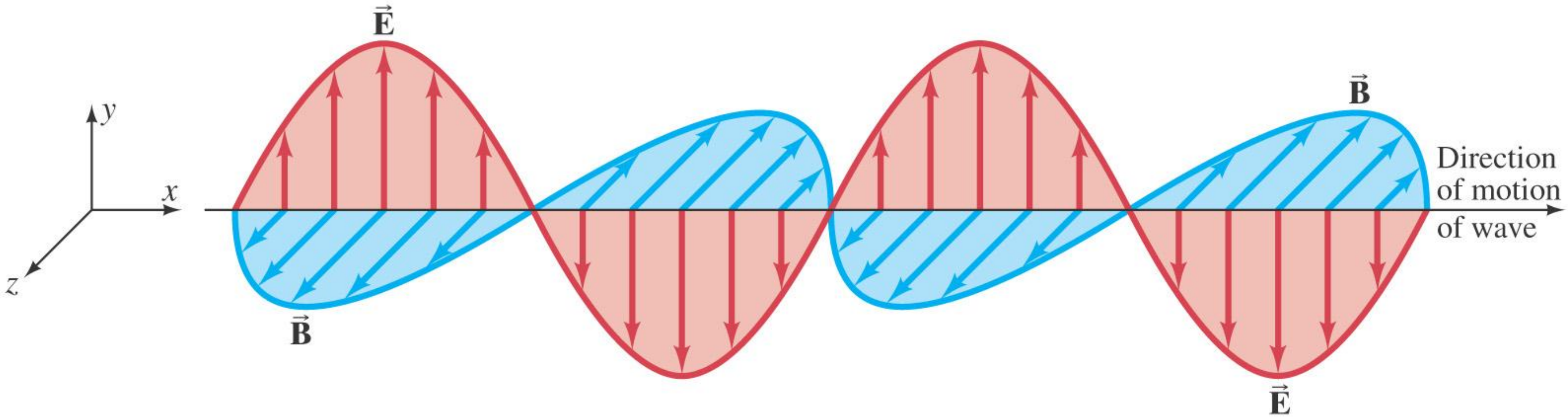
22.2 Production of Electromagnetic Waves

Oscillating charges will produce electromagnetic waves:

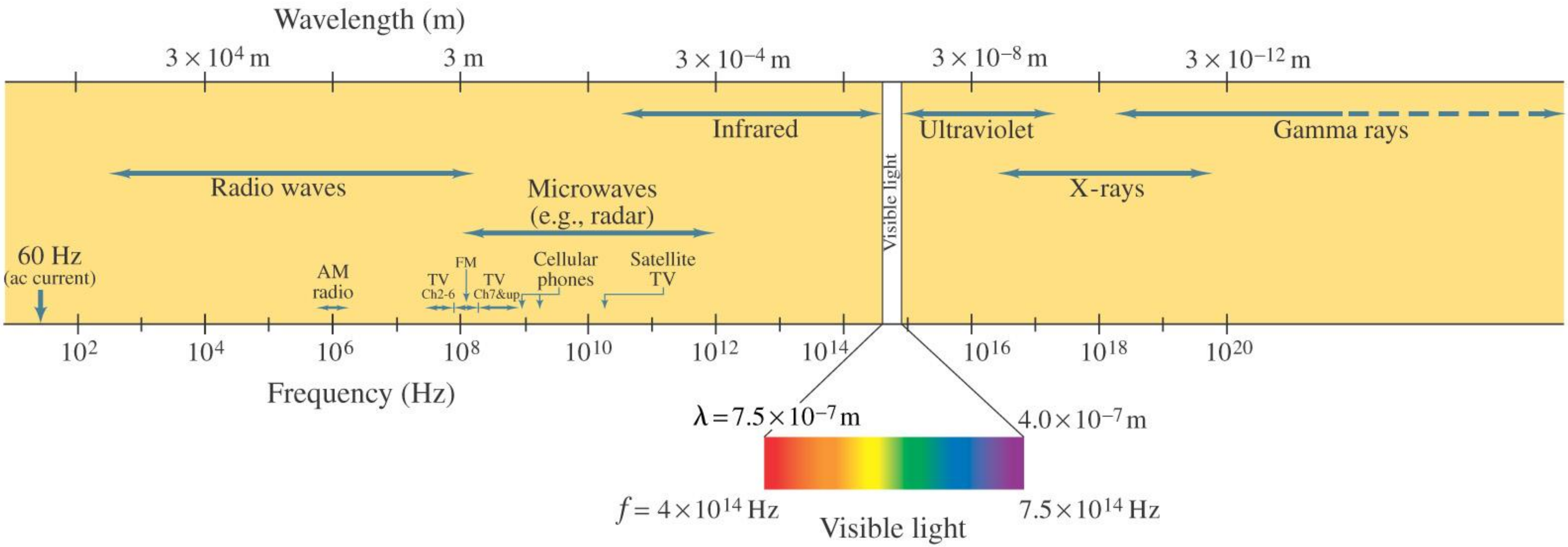


22.2 Production of Electromagnetic Waves

The electric and magnetic waves are perpendicular to each other, and to the direction of propagation.



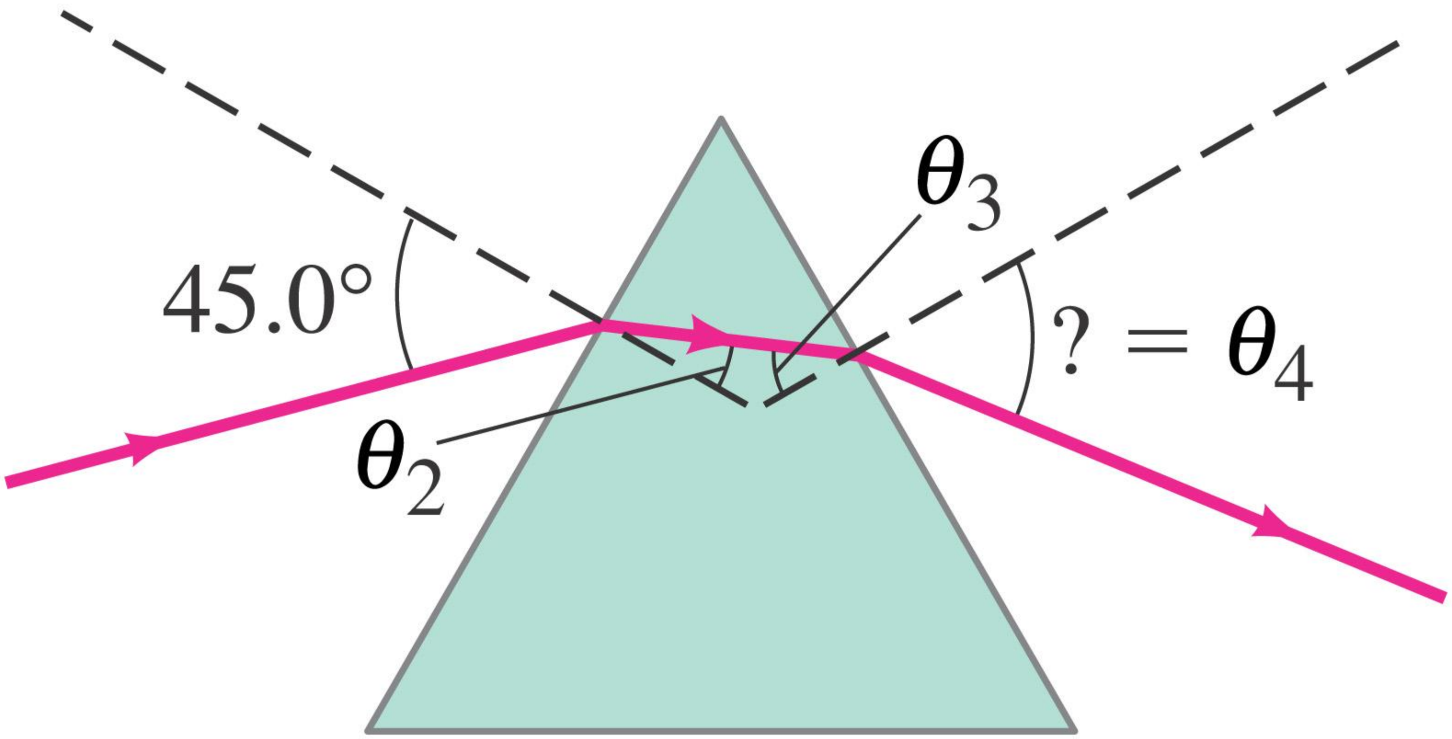
Electromagnetic Spectrum



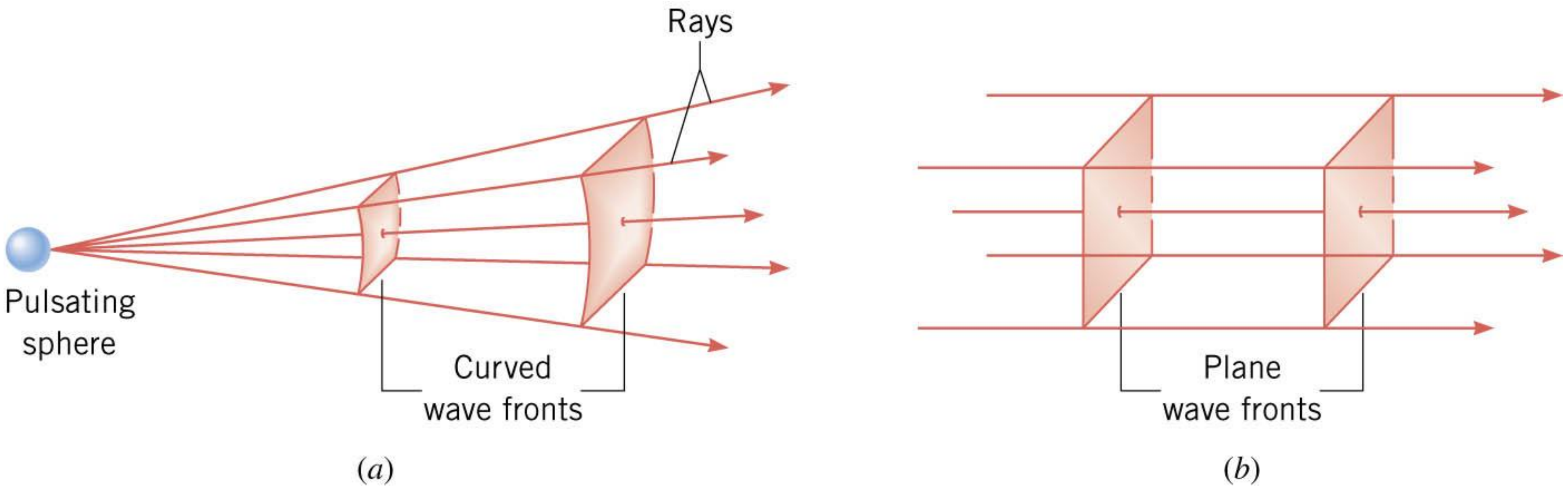
- Very small portion of the spectrum will stimulate sense of sight in eyes
- all λ's of electromagnetic radiation travel at speed of light 3 x 10^8 m/s
- know 6 different types as em radiation, λ range of visible portion
- high frequency gamma rays, X-rays have highest energy
- em radiation does not require a medium to propagate

Chapter 23

Light: Geometric Optics



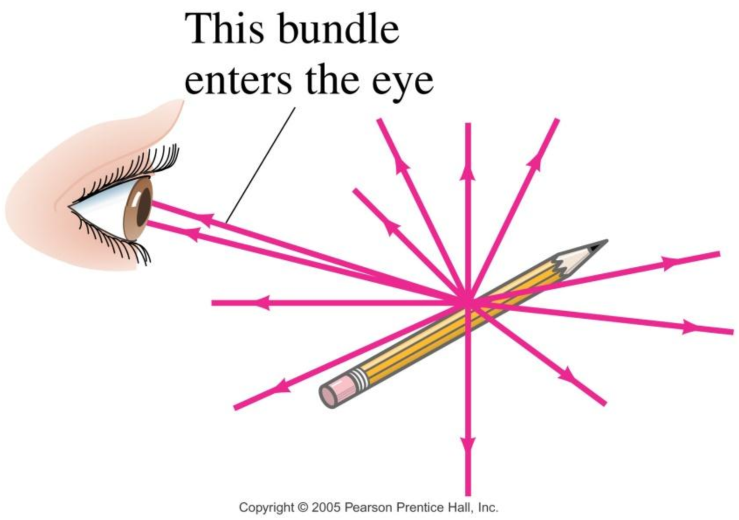
Light Rays

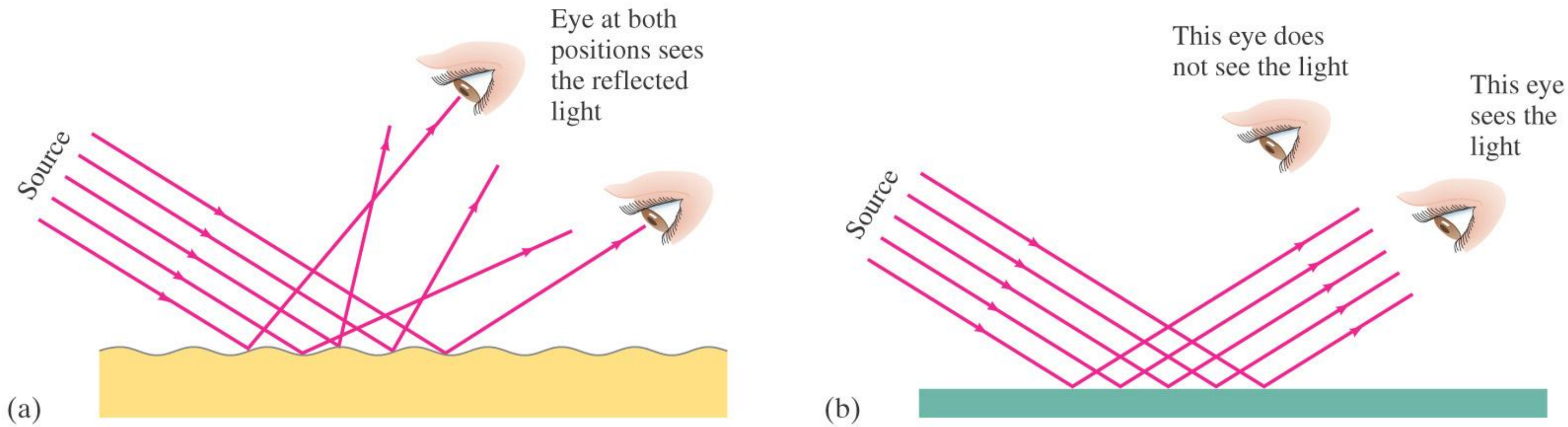


Light rays (arrows as in geometry) used to represent the propagating wave fronts they are perpendicular to

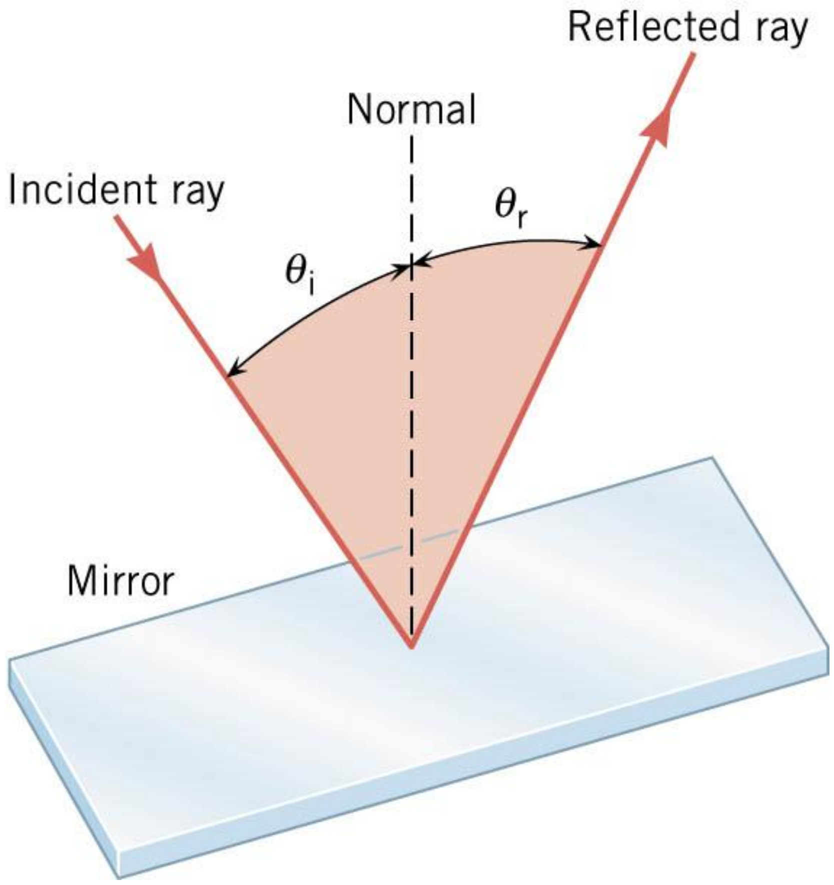
Light rays must enter the eye for it to be “seen”

Objects either emit light (source) or reflect light





Law of Reflection



angles of incidence (incoming) and reflection (outgoing) rays are measured FROM THE NORMAL to the reflecting surface NOT from the surface

Law of Reflection:

angle of incidence (θ_i) = angle of reflection (θ_r)

Image Characteristics

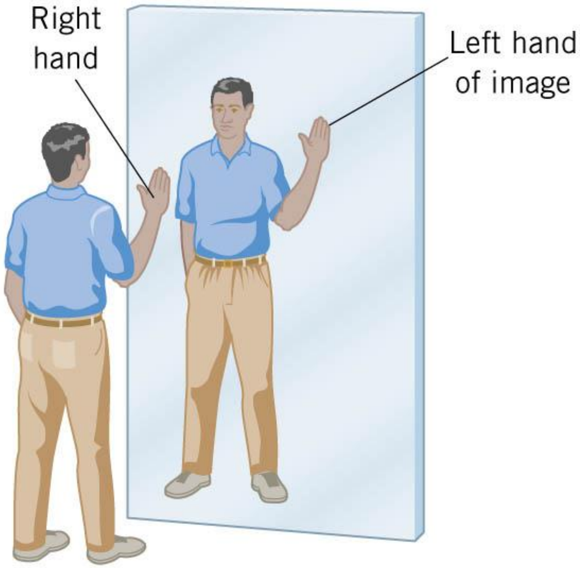
- “Object” is the real thing in front of the mirror
- Image has 3 characteristics

1. Nature
   - Real or virtual
2. Orientation
   - Upright (correct side up) or inverted (upside down)
3. Size
   - Larger than the object, same size, smaller than object

Image Nature

- Real image
  - are created in front of the mirror
  - light rays actually converge at a point
  - image can appear on a screen
  - only created by spherical mirrors
- Virtual
  - appear to be created behind the mirror
  - no light rays actually converge at or emanate from a virtual image

Plane Mirrors



(a)

Image characteristics ALWAYS the same:

Nature: Virtual

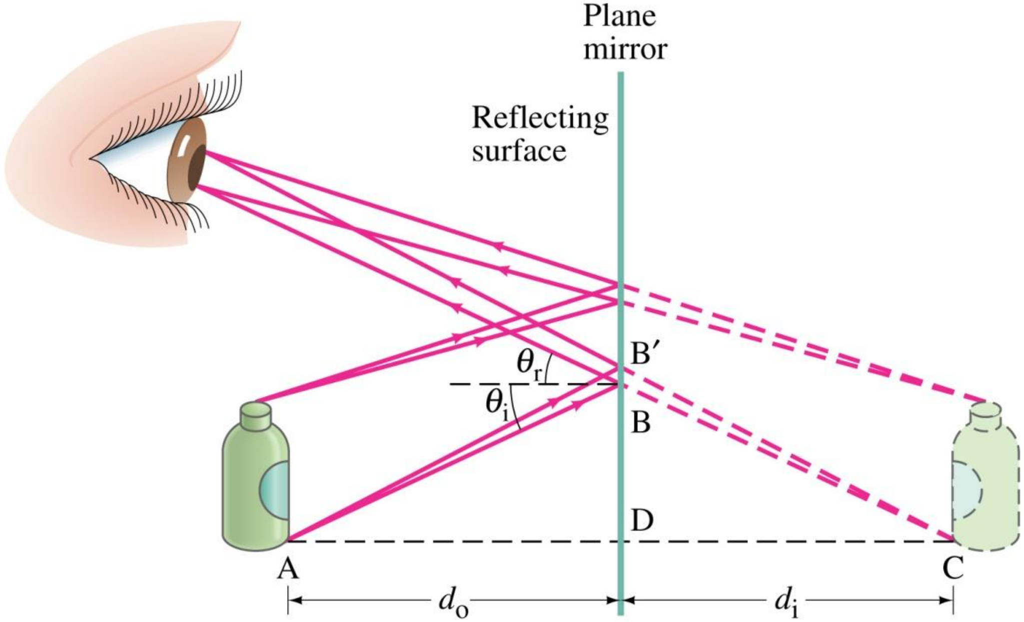
Orientation: upright

Size: same

Plane mirrors also reverse the image left to right

23.2 Reflection; Image Formation by a Plane Mirror

What you see when you look into a plane (flat) mirror is an image, which appears to be behind the mirror.



h_o = object height

h_i = image height

d_o = object distance

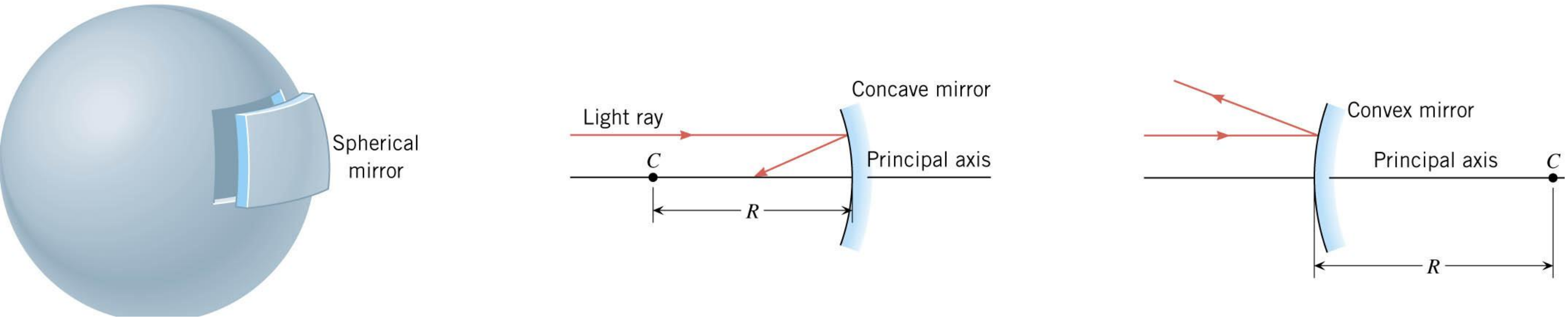
d_i = image distance

For plane mirrors

$d_o = d_i$ $h_o = h_i$

since reflected rays will not intersect on the real side you must extend the reflected ray to the back side to find virtual image

Spherical Mirrors

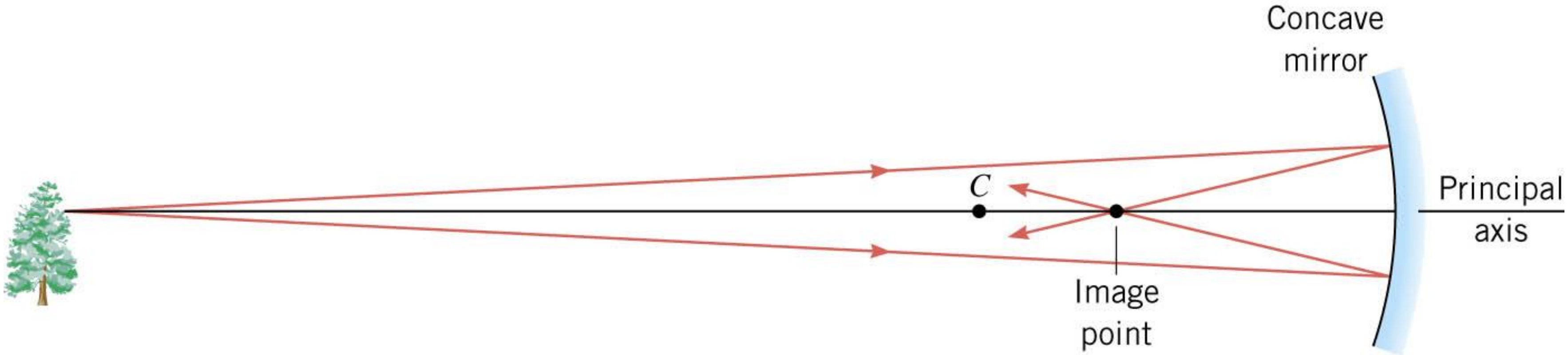


C = center of curvature of the sphere

R = radius of curvature; distance from C to back of mirror

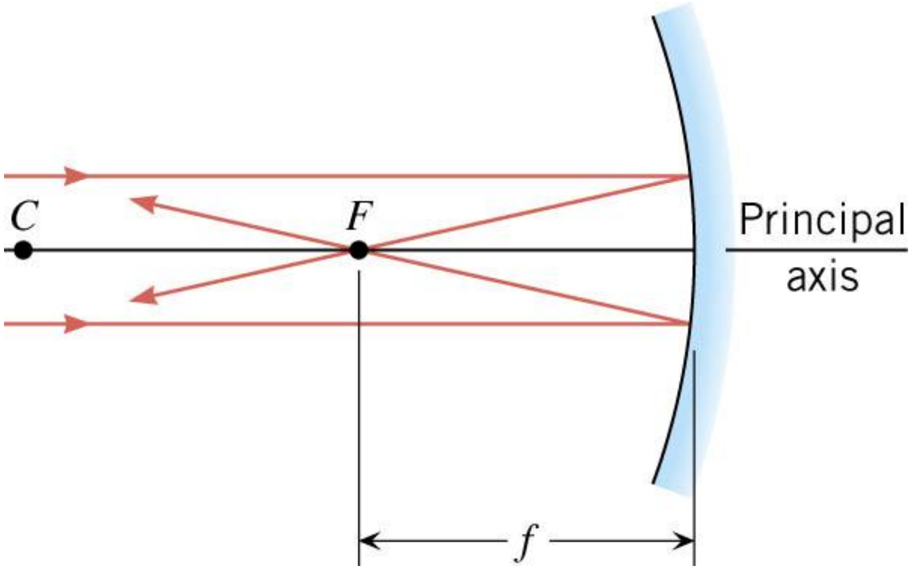
- light ray parallel to principal axis are focussed
  - concave – towards the axis
  - convex – away from the axis

Incident parallel rays



focal point F

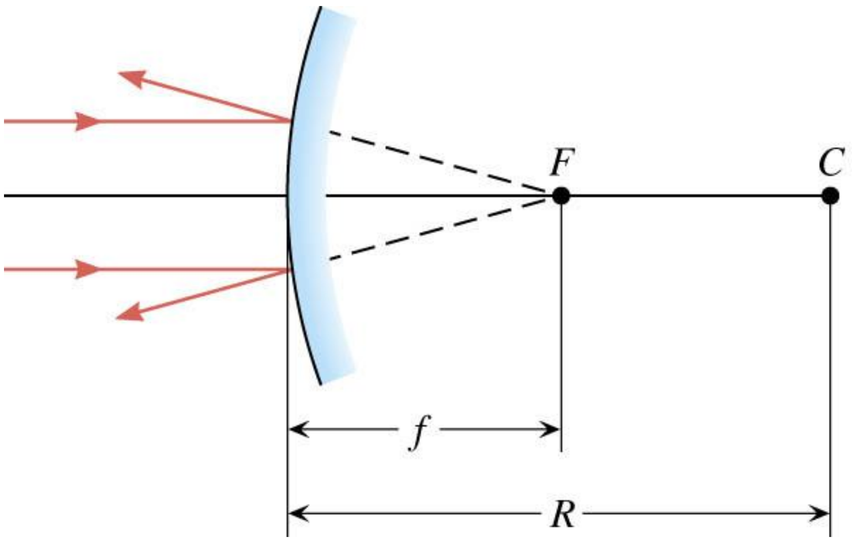
Concave



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

parallel incident rays focussed through focal point F in front of mirror

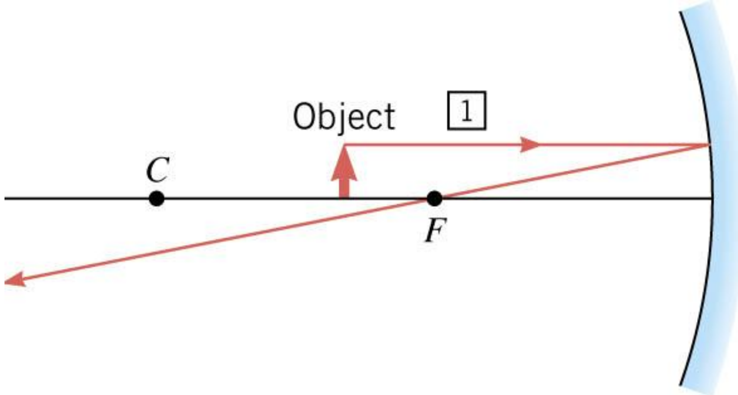
Convex

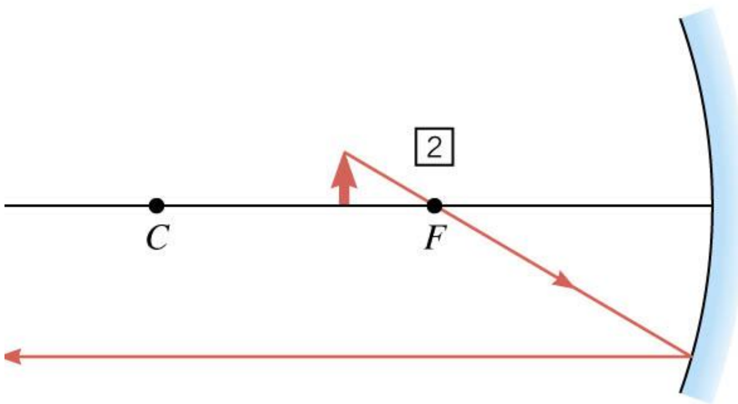


$$f = -\frac{R}{2} \text{ negative focal length}$$

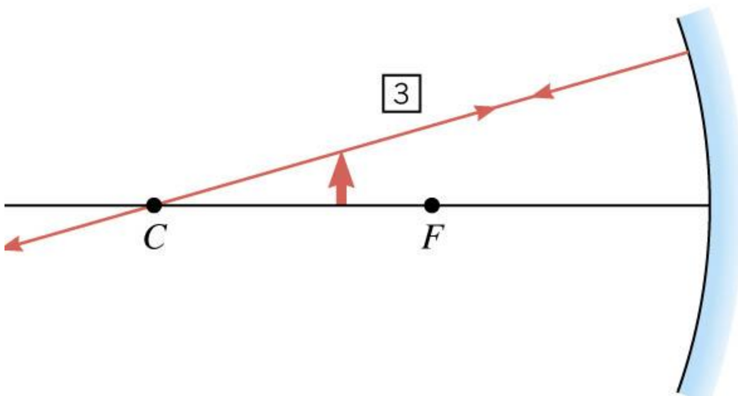
parallel incident rays appear to come from virtual focal point F behind mirror

Rays 1,2,3 for RTD's





Opposite of ray 1; through F on way to mirror, out parallel



Through C – back on itself; not always possible

need 2 rays intersecting to locate tip of the object

Concave Mirrors

our objects will usually be upright

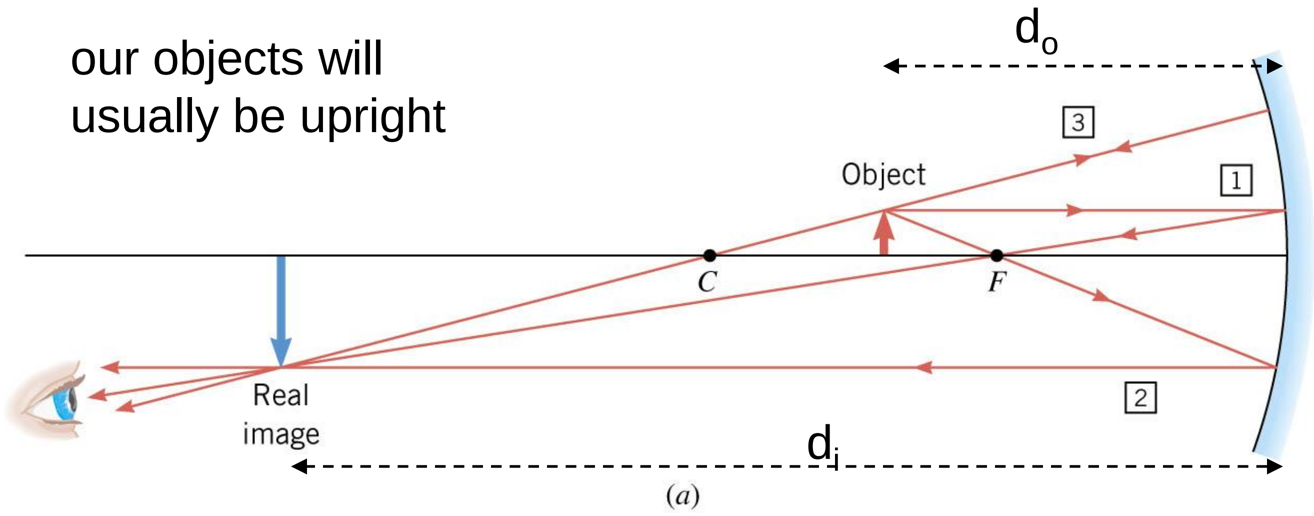
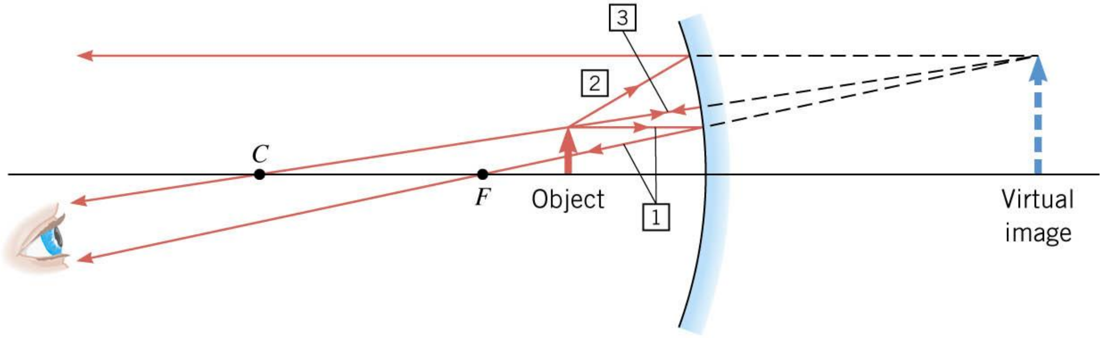


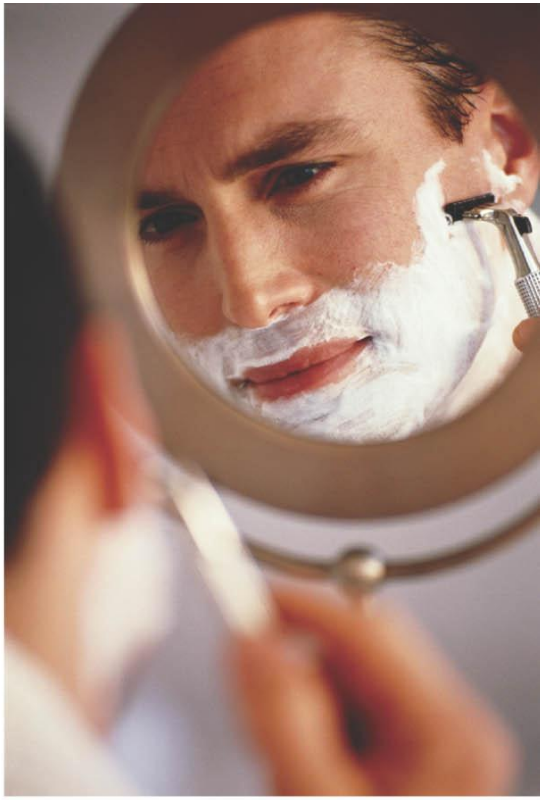
Image characteristics vary depending on location of object

Virtual Image from Concave Mirror

when object is inside focal point F
image becomes virtual, upright, larger



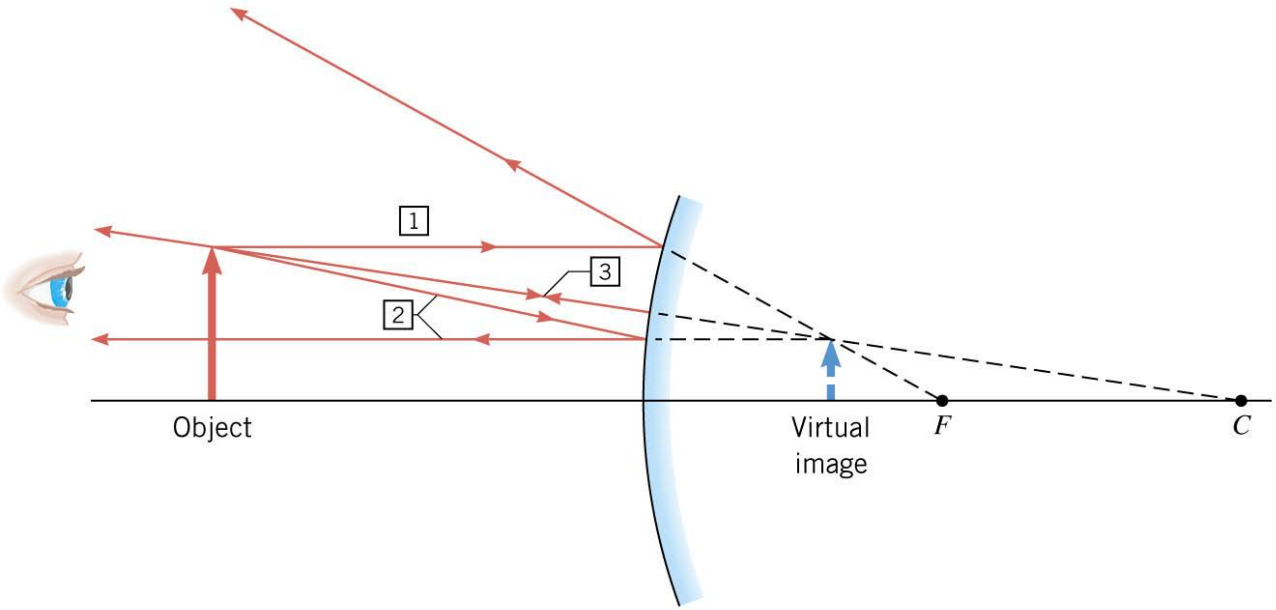
(a)



(b)

Convex Mirrors

since reflected rays will not intersect on the real side you must extend the reflected ray to the back side to find virtual image



(a)

(b)

- Image characteristics ALWAYS: virtual, upright, smaller
- Car mirror on side

Mirror Calculations

Lens-Mirror Equation

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

Magnification Equation

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

focal length

$$f = \frac{R}{2}$$ concave

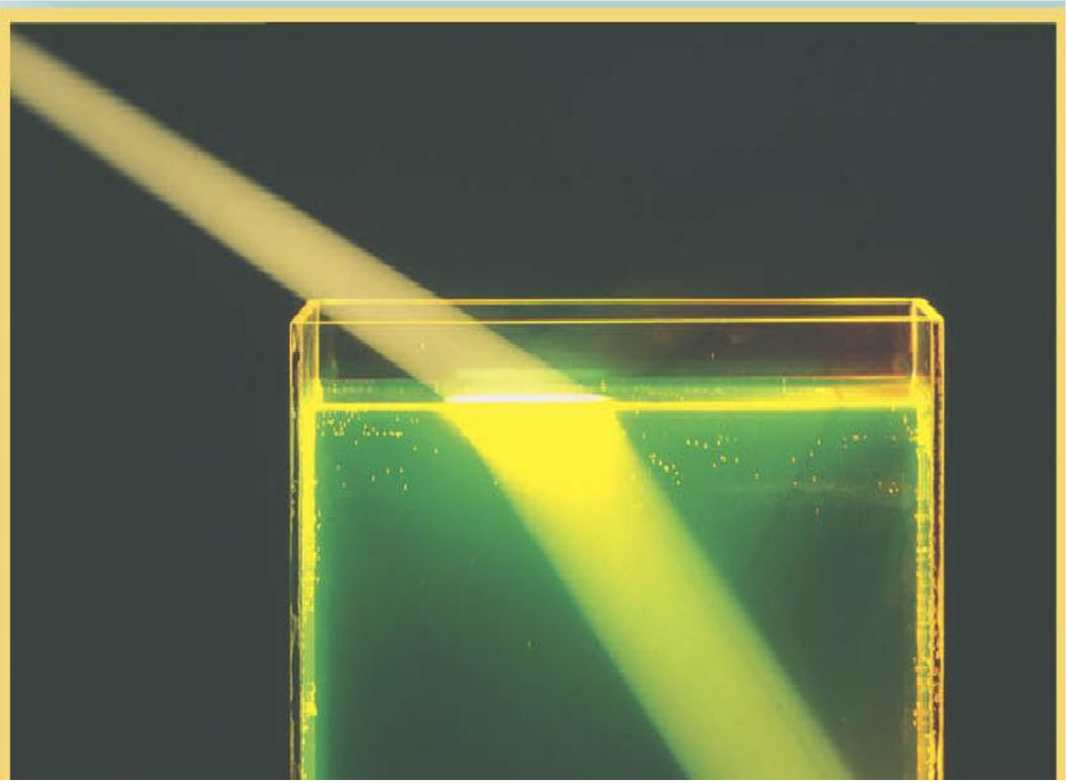
$$f = -\frac{R}{2}$$ convex

Sign Conventions for Spherical Mirrors

	+	–
d_o	real object	XXXXXX
d_i	real image	virtual image
f	concave converging	convex diverging
h_i	upright image	inverted image
m	upright image	inverted image

$|m| > 1.0$ larger image $|m| = 1.0$ same size $|m| < 1.0$ smaller image

Refraction & Lenses

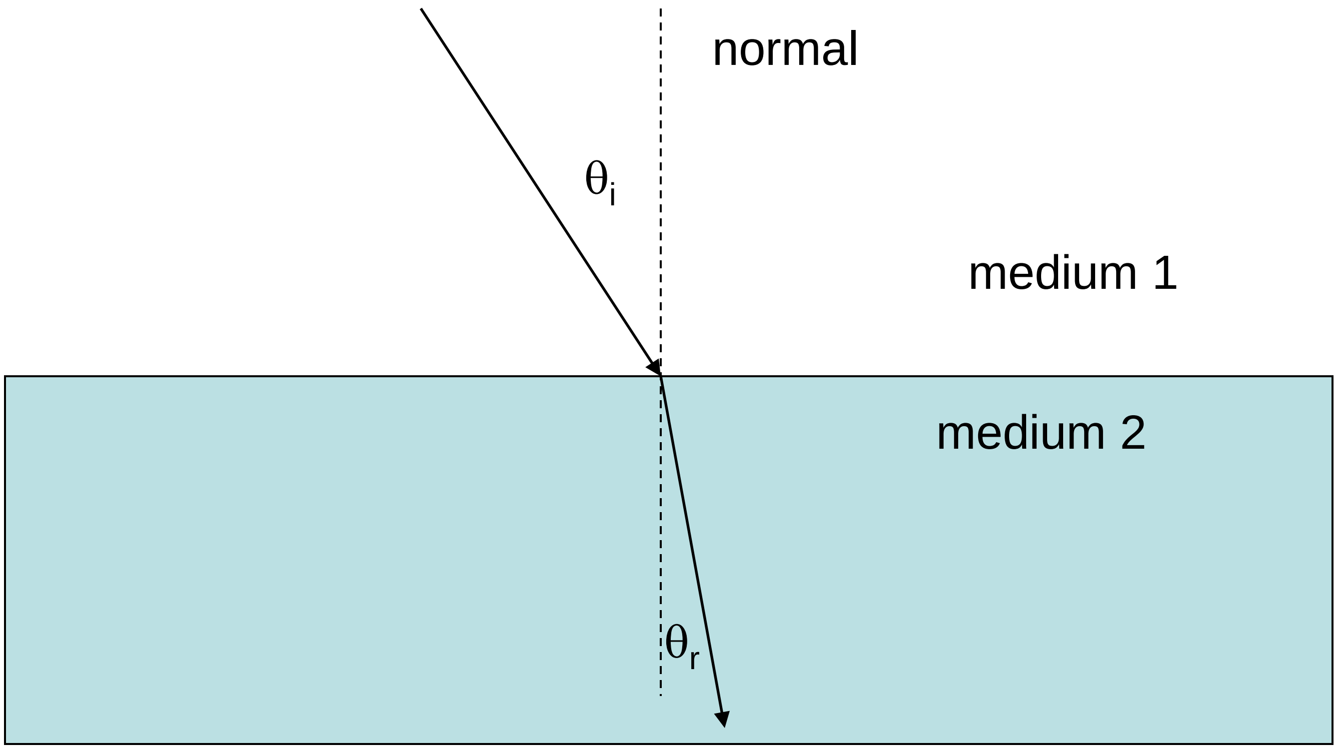


Refraction of light

change in direction of a light ray when it travels from one transparent medium into a different transparent medium of different optical density

Refraction

- Light ray must be incident on the different medium at an angle $\theta_i \neq 0^o$
- All angles measured from the normal



Index of Refraction *n*

- Even though light is electromagnetic radiation and does not require a medium it does change speed when it enters a medium of different optical density
- Index of refraction *n* is a relative measure of this velocity change

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

c = speed of light in vacuum = 3.00 x 10^8 m/s

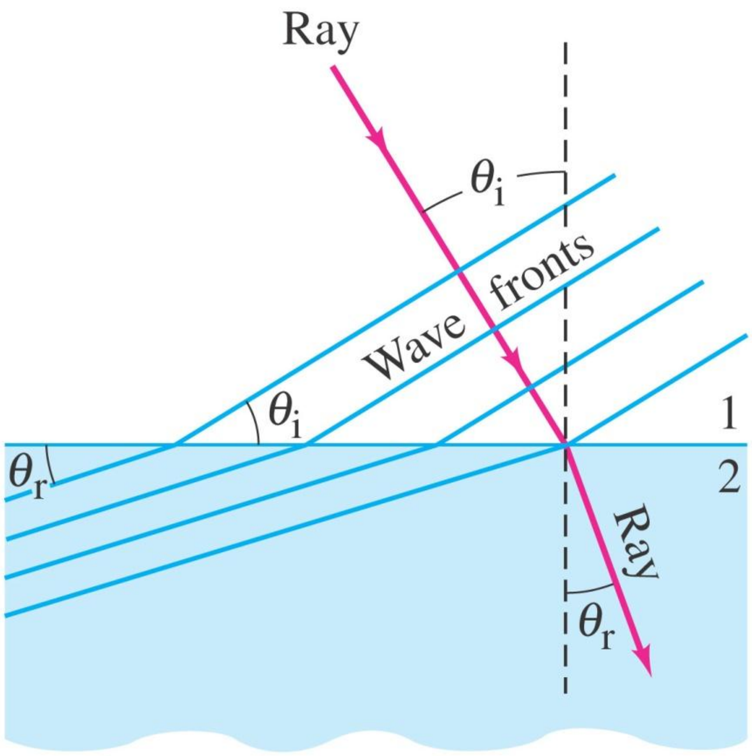
v = speed of light in refracting medium

- *n* is always ≥ 1.0 since speed of light in material other than air or vacuum is less than 3 x 10^8 m/s
- no units for index since it is a coefficient

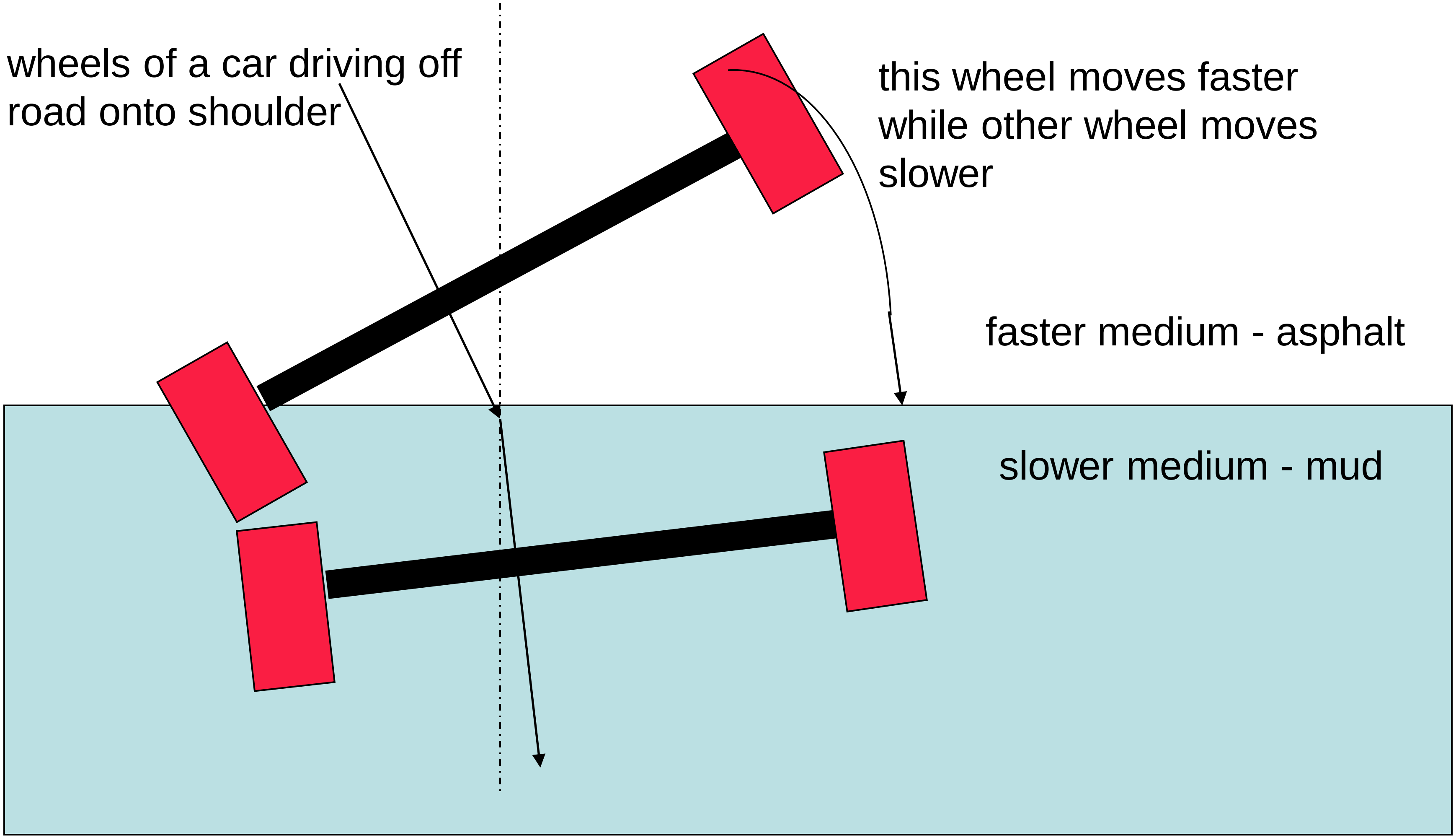
TABLE 23–1
Indices of Refraction†

Medium	$n = c/v$
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
Lucite or Plexiglas	1.51
Sodium chloride	1.53
Diamond	2.42

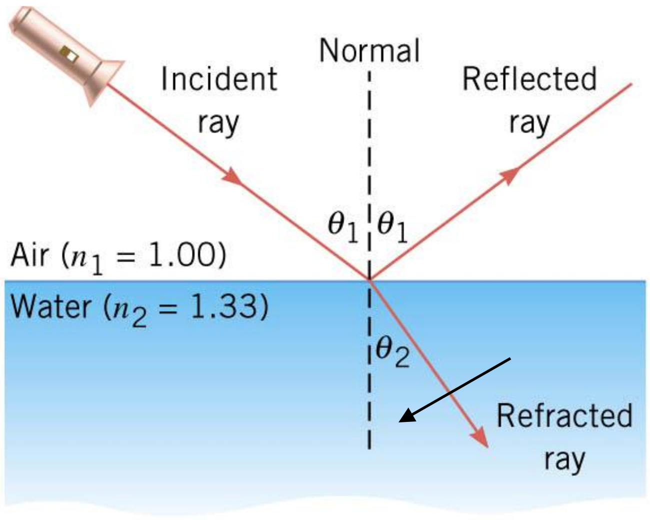
† $\lambda = 589$ nm.



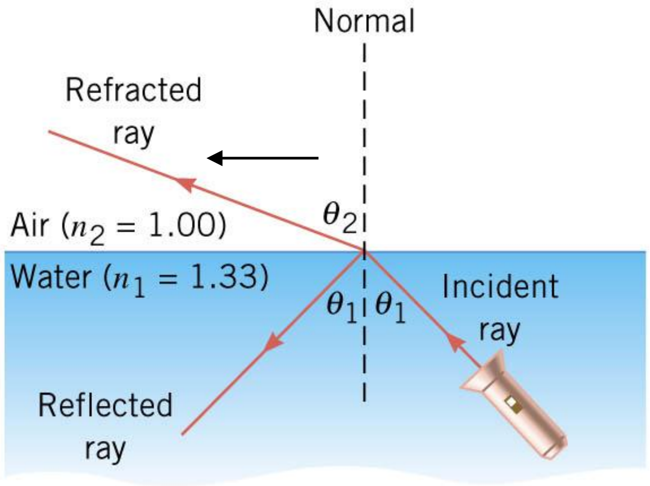
Direction change due to speed change



this explains why light ray must be incident at angle > 0^o



(a)

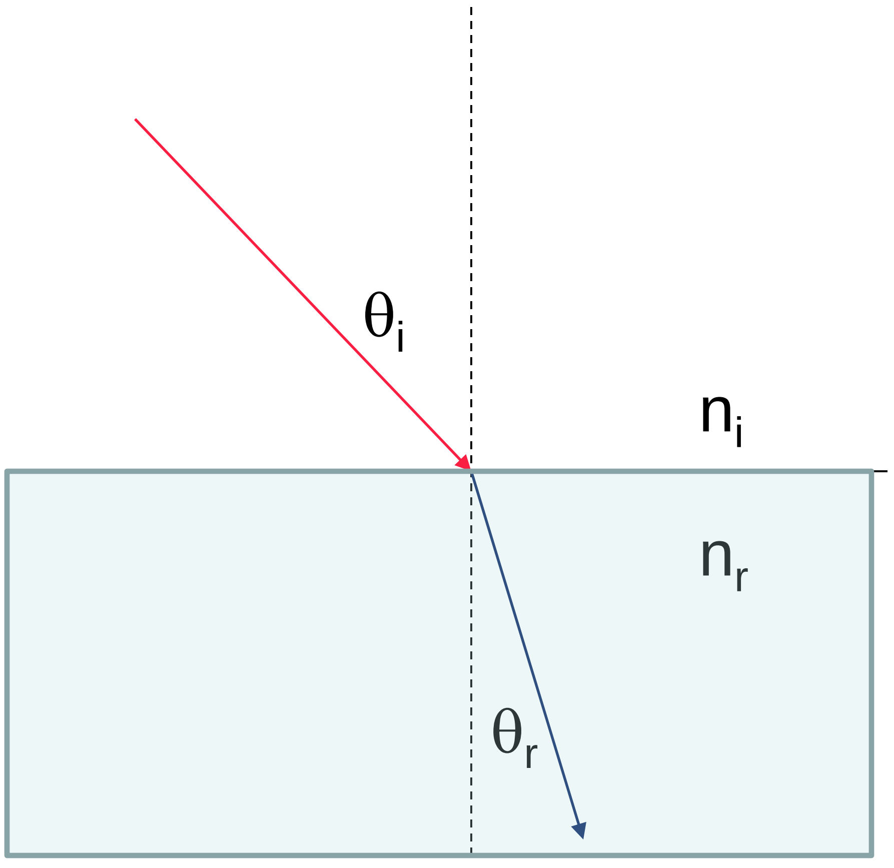


(b)

You must be able to predict direction of refraction

- Bends towards the normal
  - less dense to more dense
  - faster to slower medium
  - $n_i < n_r$
- Bends away from the normal
  - more dense to less dense
  - slower to faster medium
  - $n_i > n_r$

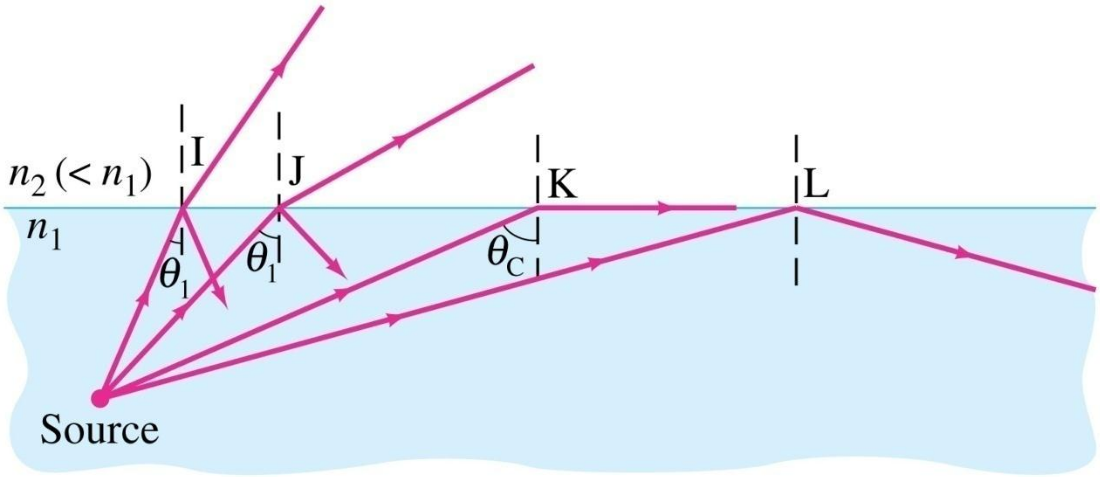
Snell's Law



$$n_i \sin\theta_i = n_r \sin\theta_r$$

23.6 Total Internal Reflection

When light travels from slower to faster medium there is an angle of incidence for which the angle of refraction will be 90°; this is called the critical angle θ_c:



$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

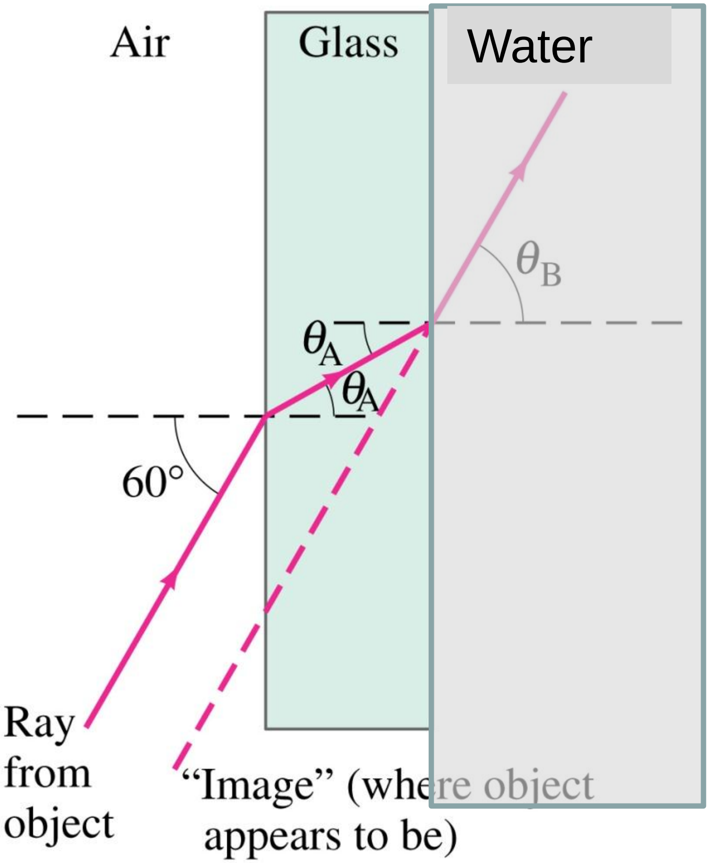
$$\sin \theta_C = \frac{n_2}{n_1} \sin 90^\circ = \frac{n_2}{n_1}$$

How does refraction change when the mediums change?

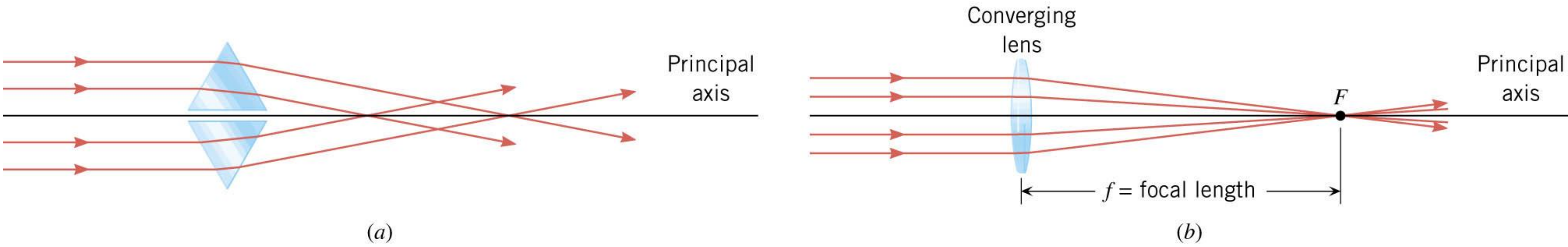
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

If exit medium of air is replaced with water the index of refraction n_2 increases therefore θ_B will….

decrease



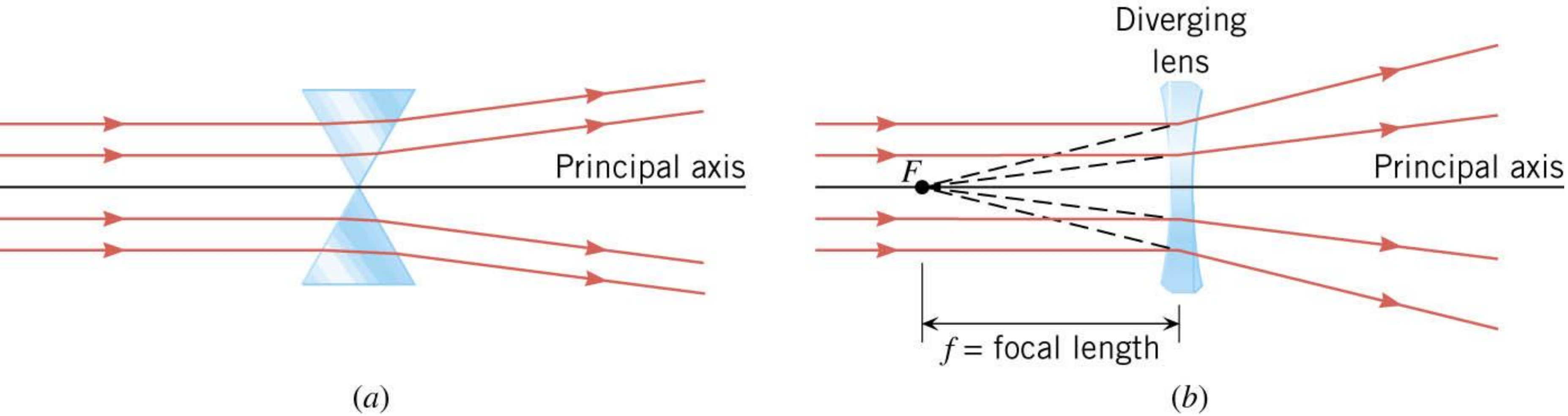
Converging lens



Light rays are refracted twice

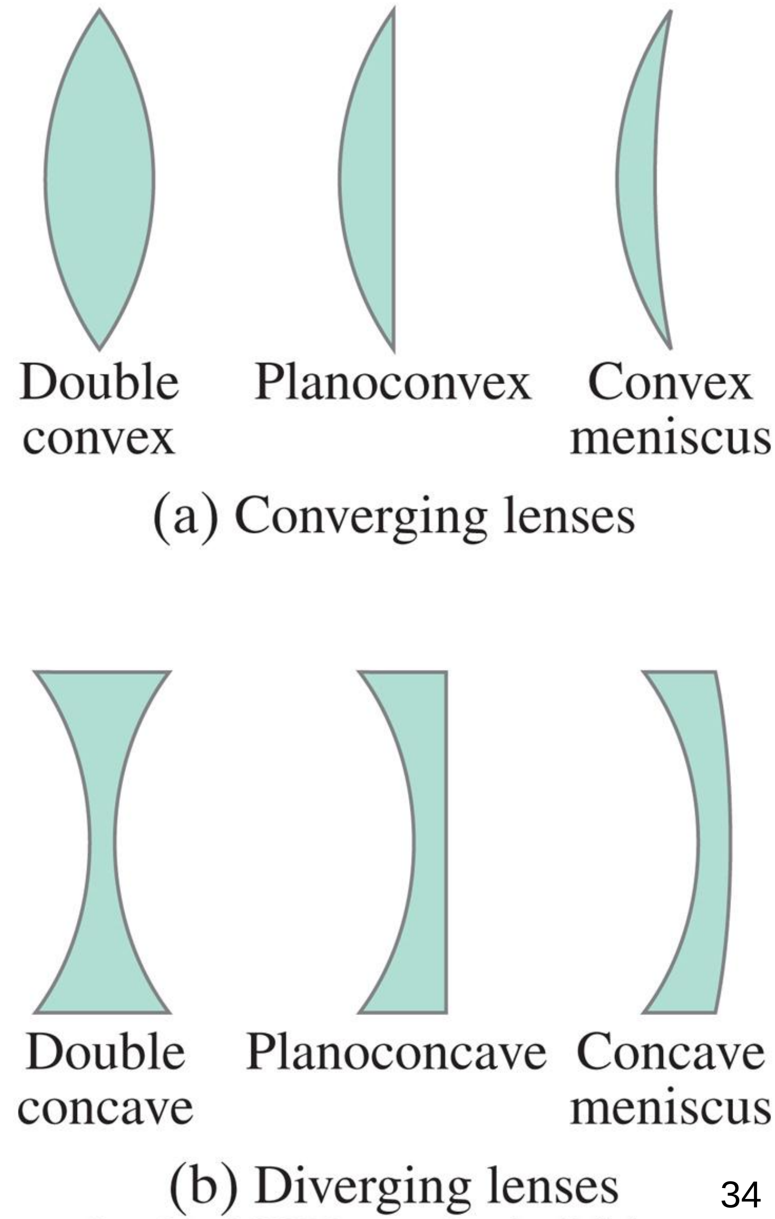
- towards normal entering glass
- away from normal exiting glass

Diverging lens

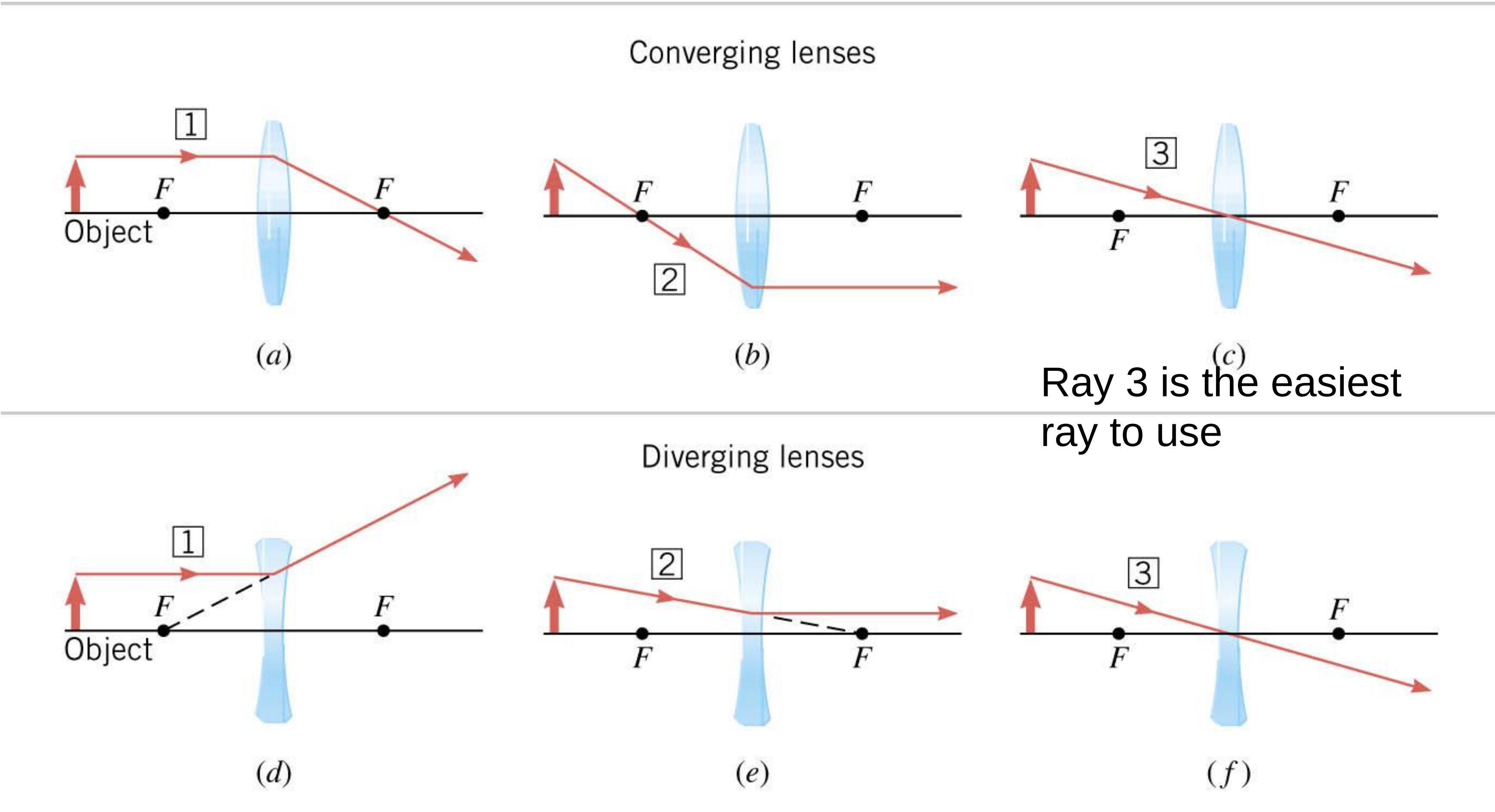


23.7 Thin Lenses; Ray Tracing

Thin lenses are those whose thickness is small compared to their radius of curvature. They may be either converging (a) or diverging (b).

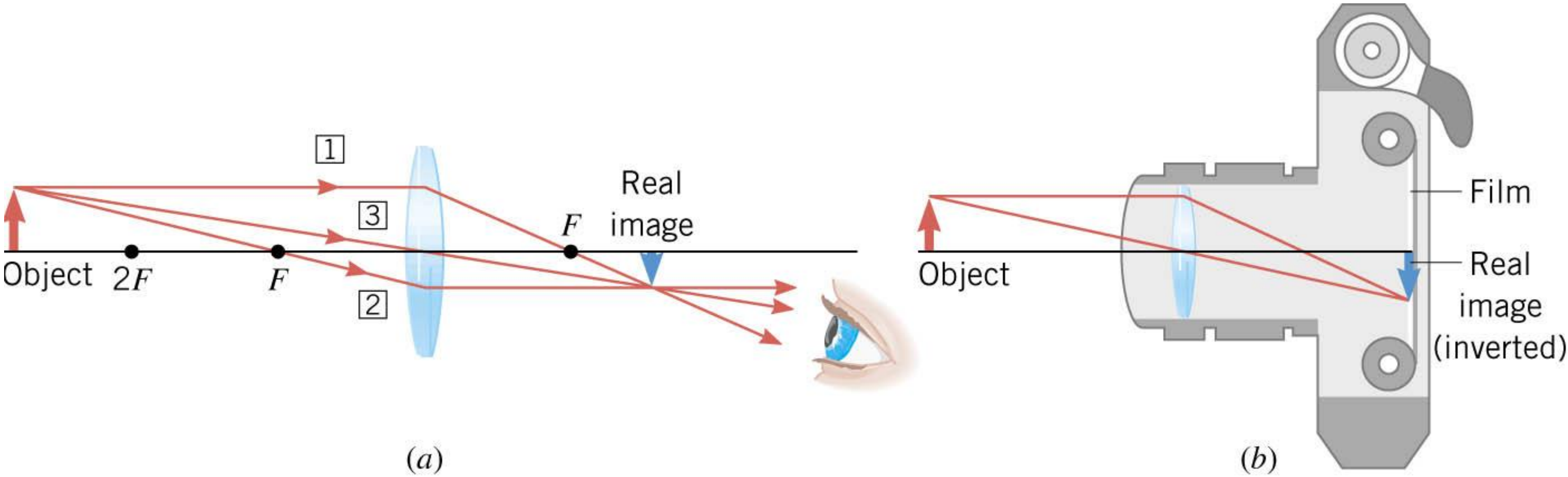


3 Ray Brothers are back!



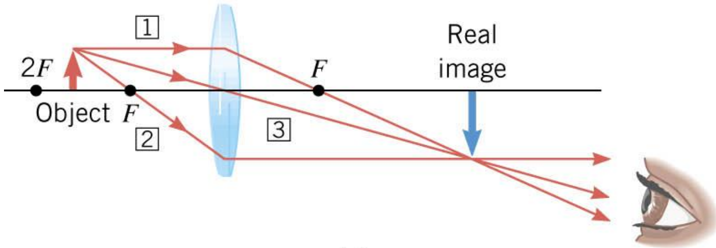
Ray 3 is the easiest ray to use

RTD for converging lens

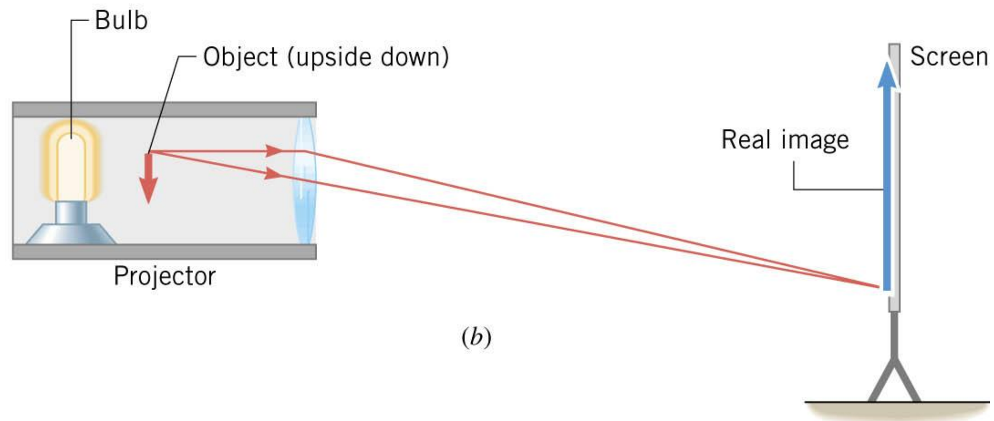


- Image characteristics the same as for concave mirror

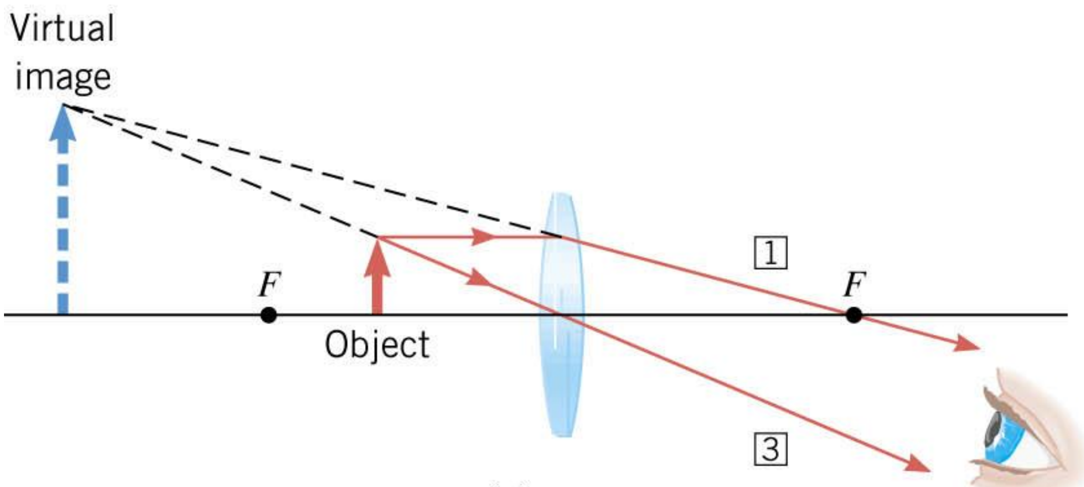
- real images form on EXIT side of lens, not on the "front" side as with mirrors.



(a)



(b)

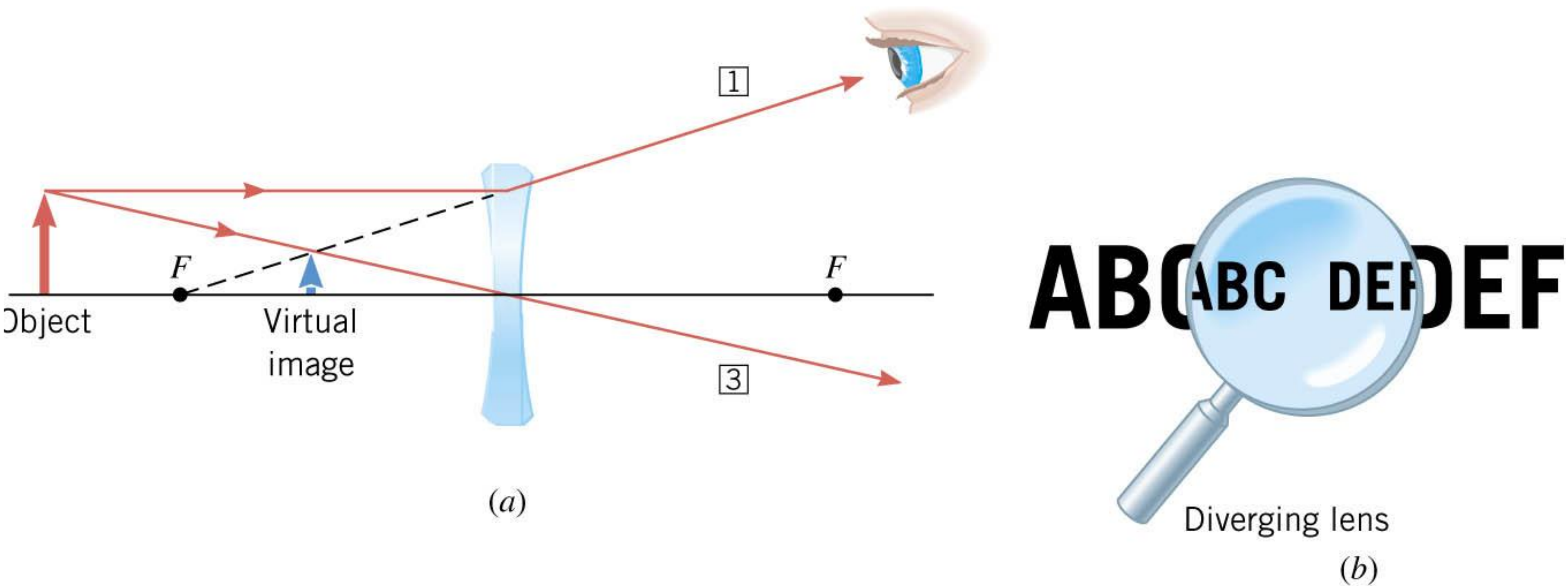


(a)

(b)

virtual images form on ENTRANCE side of lens

RTD for diverging lens



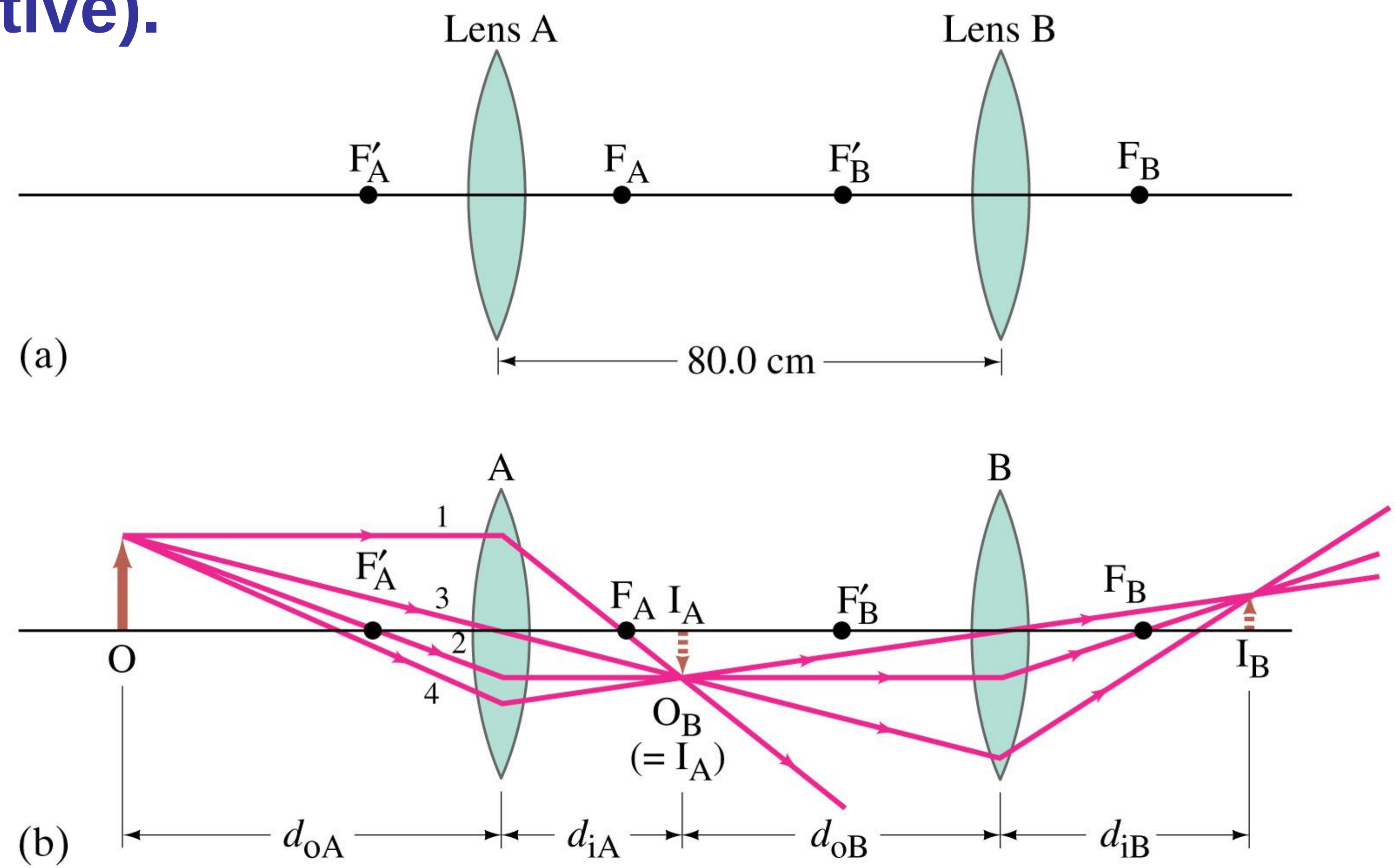
Sign Conventions for Lenses (p792)

	+	–
d_o	real object	XXXXXX
d_i	real image (exit side)	virtual image (entrance side)
f	converging	diverging
h_i	upright image	inverted image
m	upright image	inverted image

$|m| > 1.0$ larger image $|m| = 1.0$ same size $|m| < 1.0$ smaller image

23.9 Combinations of Lenses

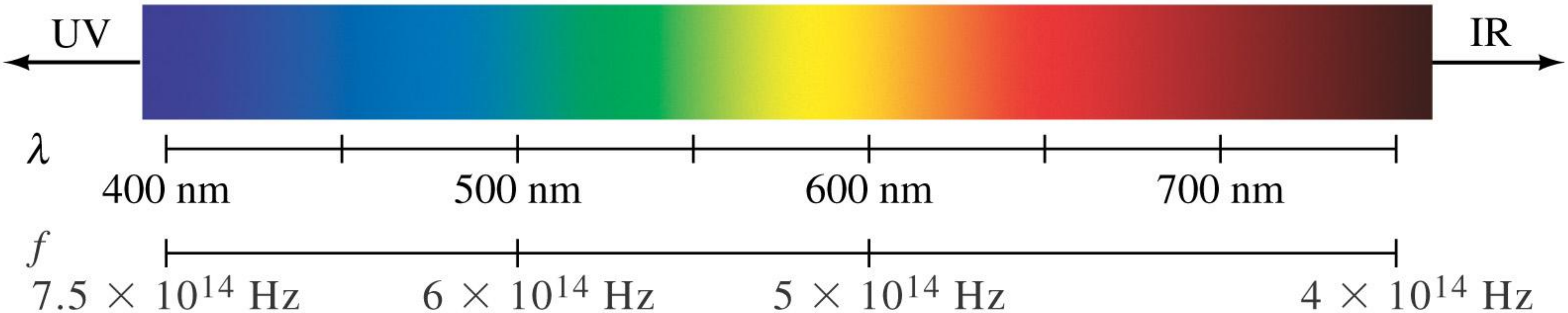
In lens combinations, the image formed by the first lens becomes the object for the second lens (this is where object distances may be negative).



The Visible Spectrum and Dispersion

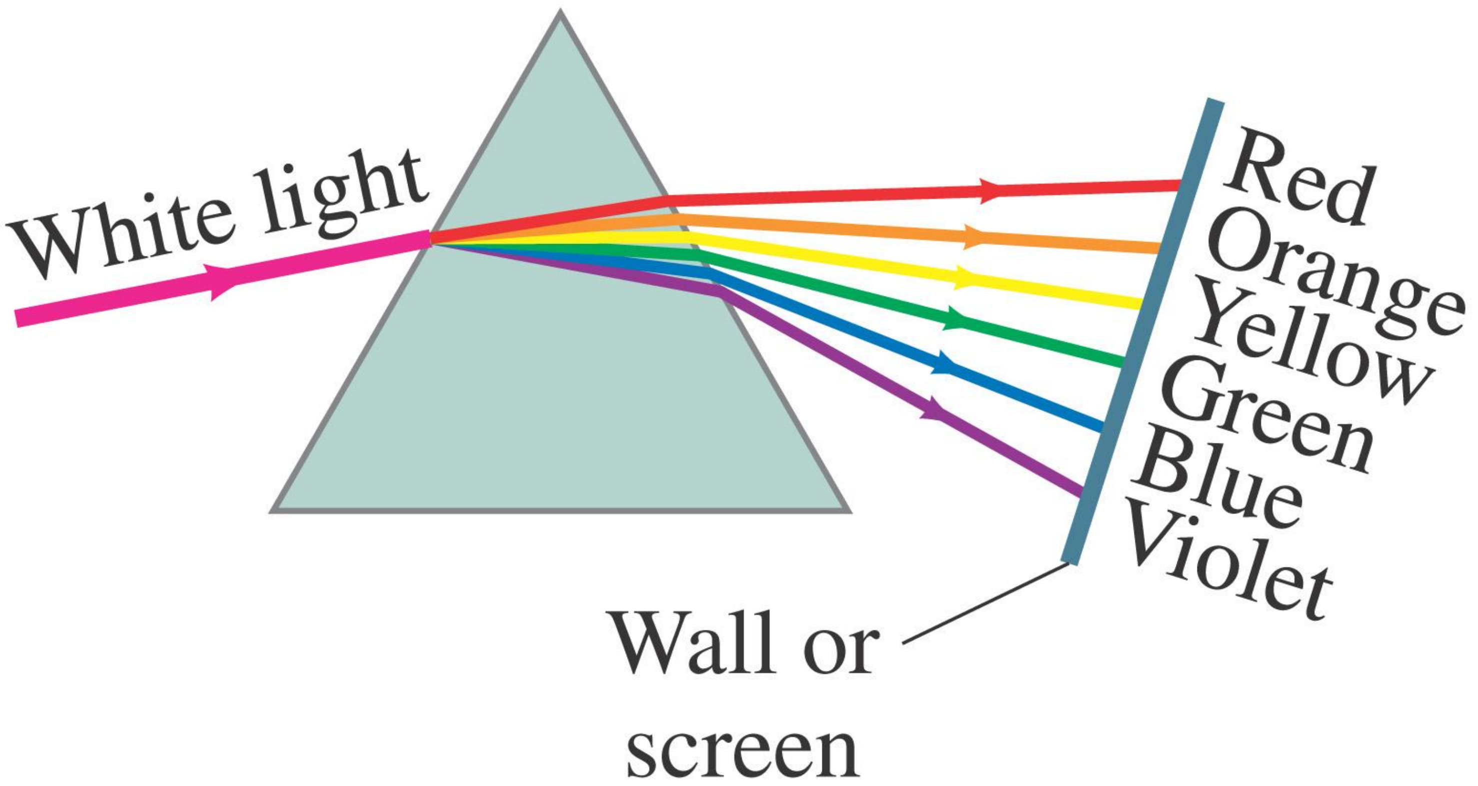
Wavelengths of visible light: 400 nm to 750 nm

Shorter wavelengths are ultraviolet; longer are infrared



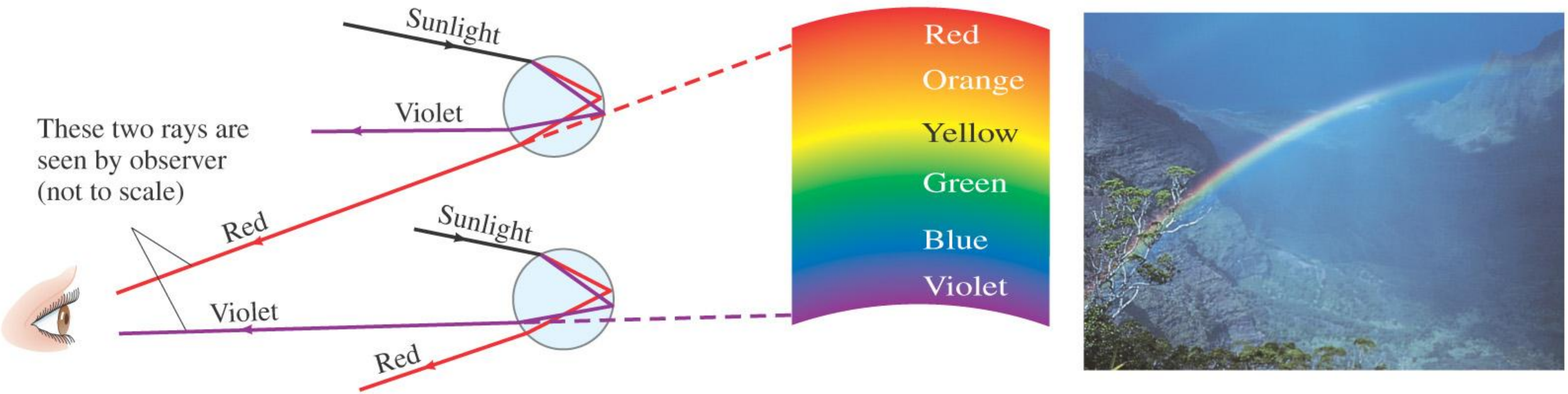
The Visible Spectrum and Dispersion

The various wavelengths of visible light refract different amounts – another example of the wave nature of light



Formation of Rainbows

Actual rainbows are created by dispersion in tiny drops of water.



(a) (b)

"I set My bow in the cloud, and it shall be for a sign of a covenant between Me and the earth." Genesis 9:13

CHAPTER 24
THIN FILM INTERFERENCE

24.8 Interference by Thin Films

Another way path lengths can differ, and waves interfere, is if the travel through different media.

If there is a very thin film of material – a few wavelengths thick – light will reflect from both the bottom and the top of the layer, causing interference.

This can be seen in soap bubbles and oil slicks, for example.

demo

3 things to account for in thin film interference problems

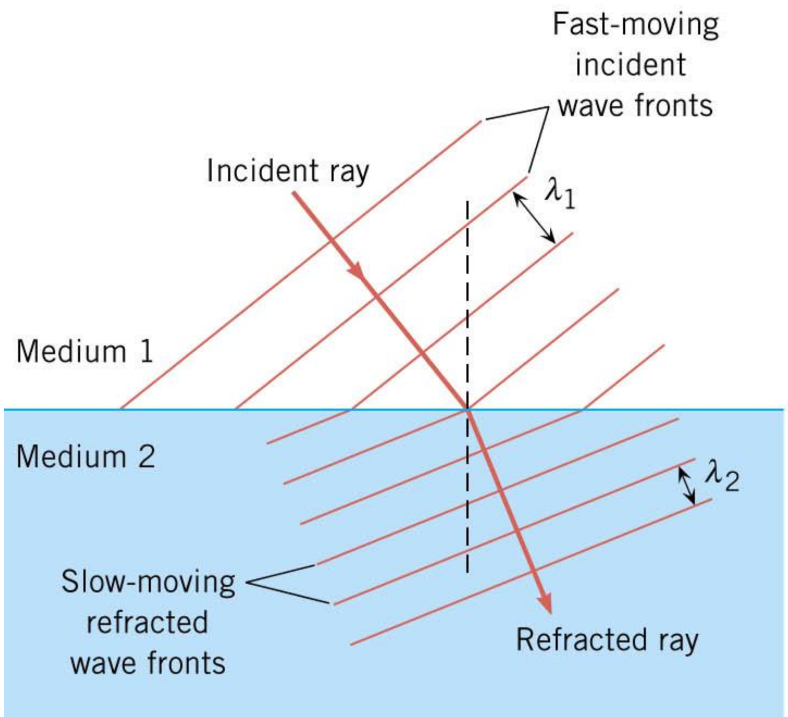
1) wavelength change due to speed of light decreasing compared to speed in air (vacuum) = 3×10^8 m/s

2) constructive interference or destructive interference occurring at the top surface of the film

3) waves reflected at boundaries undergoing inversion or not due to index of refraction difference

24.8 Interference by Thin Films

The wavelength of the light will be different in the oil and the air. Index of refraction n is a measure of this speed change.



(a)

$$n = \frac{c}{v} = \frac{f\lambda_{air}}{f\lambda_{film}} = \frac{\lambda_{air}}{\lambda_{film}}$$

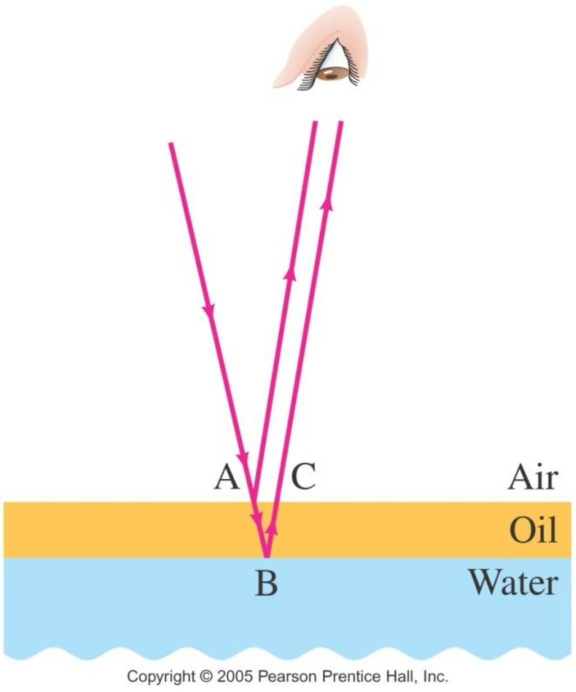
$$\lambda_{film} = \frac{\lambda_{air}}{n}$$

Path length difference for interference

For the eye to see bright region at AC there must be a PLD = mλ m = 1,2,3..

For the eye to see a dark region at AC there must be a PLD = m(λ/2) m = 1, 3, 5..

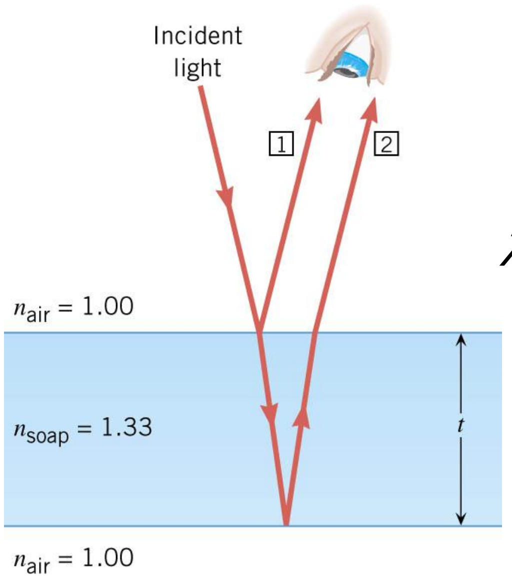
There is always a PLD = 2t due to the transmitted wave 2 passing through the film and being reflected off the bottom surface.



Constructive: PLD = mλ= 2t

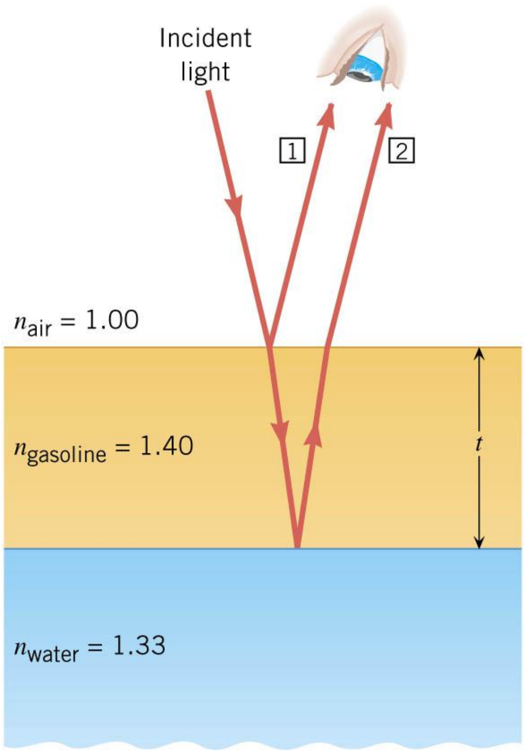
Destructive: PLD = m(λ/2) = 2t

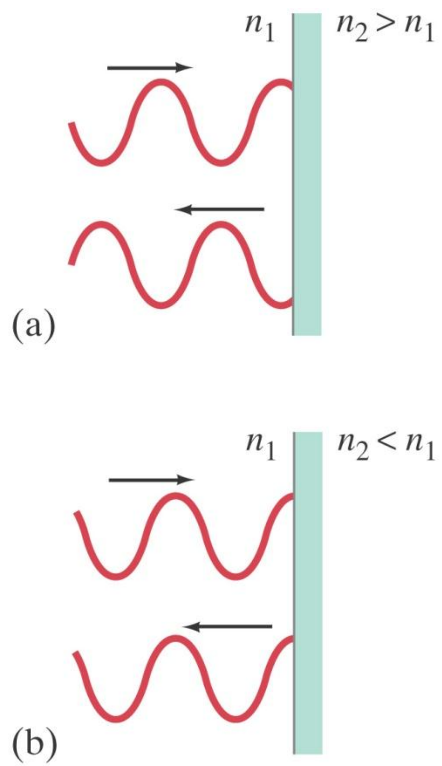
BUT one more factor involved



$$\lambda_{film} = \frac{\lambda_{air}}{n}$$

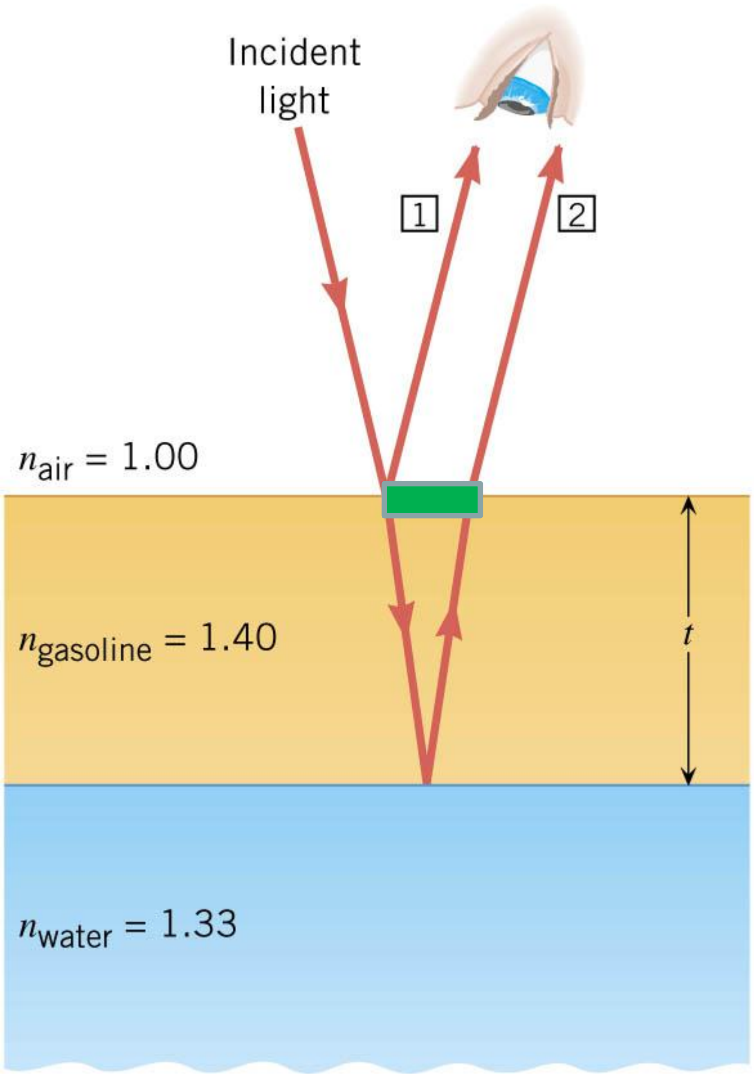
Inversion of wave at boundary





There is a half cycle inversion when wave reflects from a higher index (n) medium, as at the air-to-gasoline boundary. Similar to rope fixed to a wall.

There is no inversion when wave reflects reflects from a lower index medium, as at the gasoline-to-water boundary. Similar to rope free to move at boundary.



There will be a λ/2 PLD between waves 1 and 2 due to inversion at top surface but not at second surface.

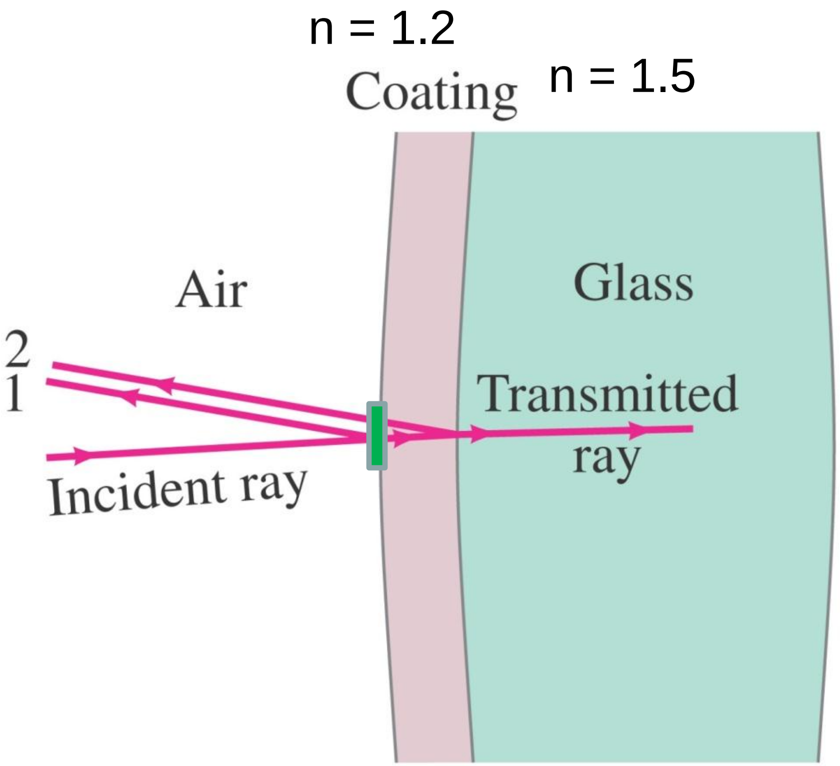
Constructive (bright spot)

PLD = mλ= 2t + λ/2 m = 1, 2, 3

Destructive (dark spot)

PLD = m(λ/2) = 2t + λ/2 m = 1, 3, 5

$$\lambda_{film} = \frac{\lambda_{air}}{n}$$



$$\lambda_{film} = \frac{\lambda_{air}}{n}$$

The PLD between waves 1 and 2 will only be due to the travel through the coating because the $\lambda/2$ inversion happens at both boundaries, so net result is they are both still in phase.

Constructive (bright spot)

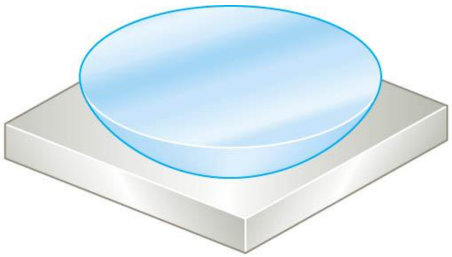
PLD = $m\lambda = 2t$ $m = 1, 2, 3$

Destructive (dark spot)

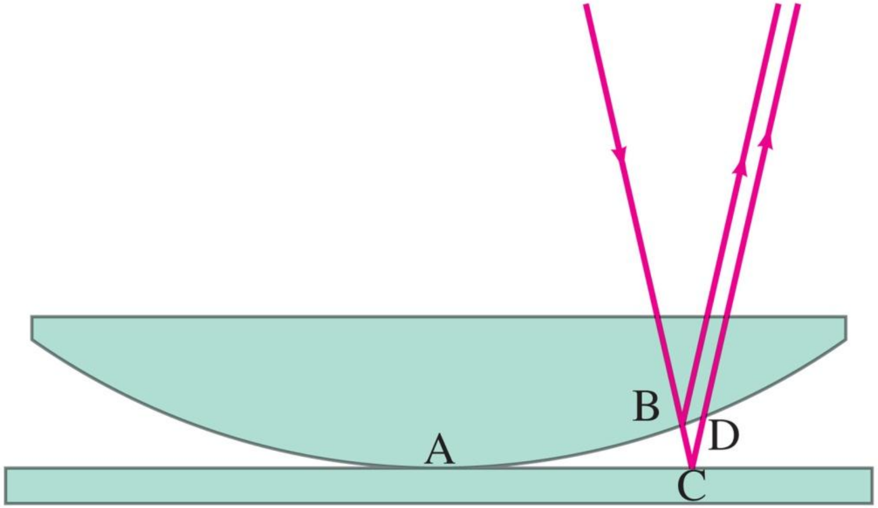
PLD = $m(\lambda/2) = 2t$ $m = 1, 3, 5$

24.8 Interference by Thin Films

A similar effect takes place when a shallowly curved piece of glass is placed on a flat one. When viewed from above, concentric circles appear that are called Newton's rings.



(a)



(a)

(b)