Chapter 23. Light – Geometric Optics

There are 3 basic ways to gather light and focus it to make an image.
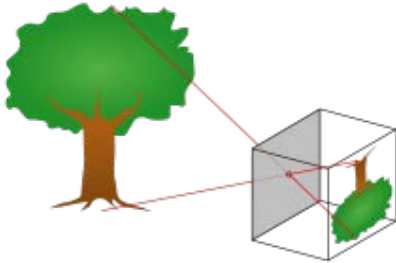
Pinhole - Simple geometry

Mirror - Reflection
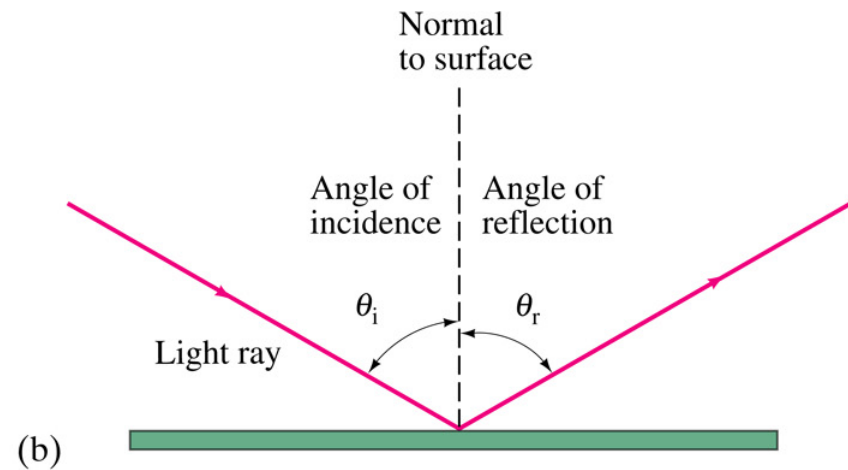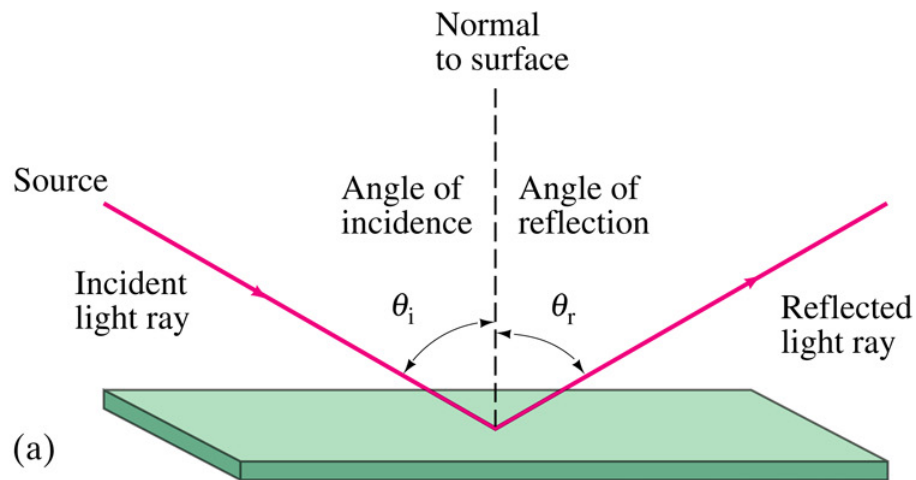
Lens - Refraction

Pinhole Camera Image Formation

(the pinhole camera is the "perfect" optical system)

The Law of Reflection

Law of reflection: the angle of reflection (that the ray makes with the normal to a surface) equals the angle of incidence.
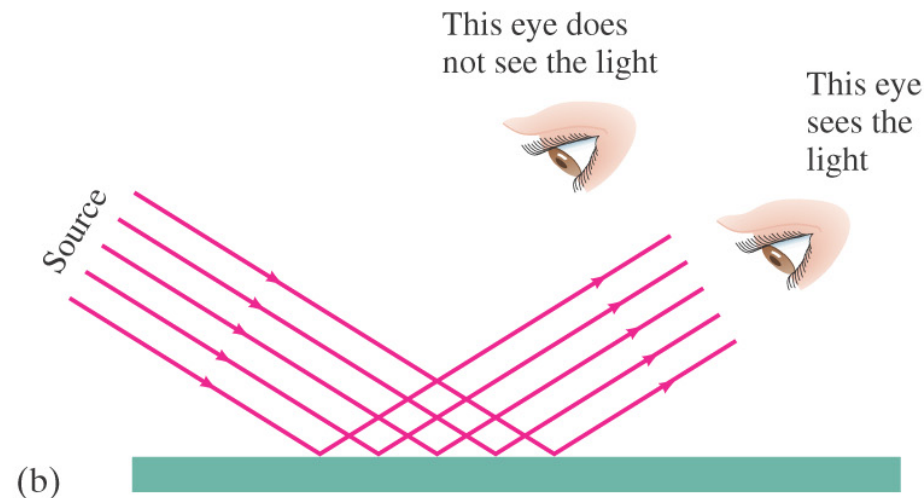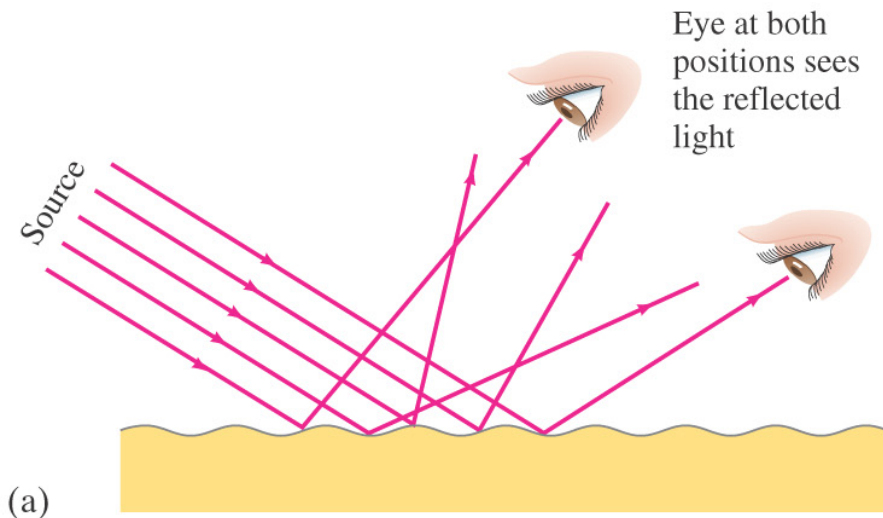
23.2 Reflection; Image Formation by a Plane Mirror

When light reflects from a rough surface, the law of reflection still holds, but the angle of incidence varies. This is called diffuse reflection.
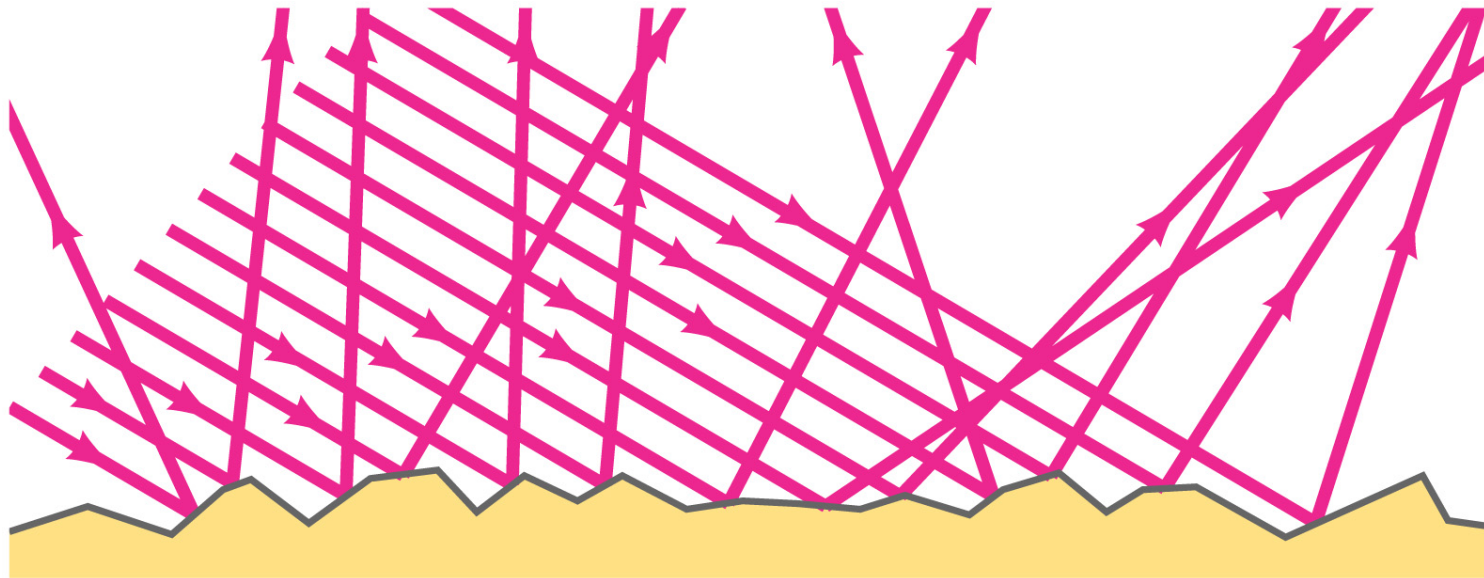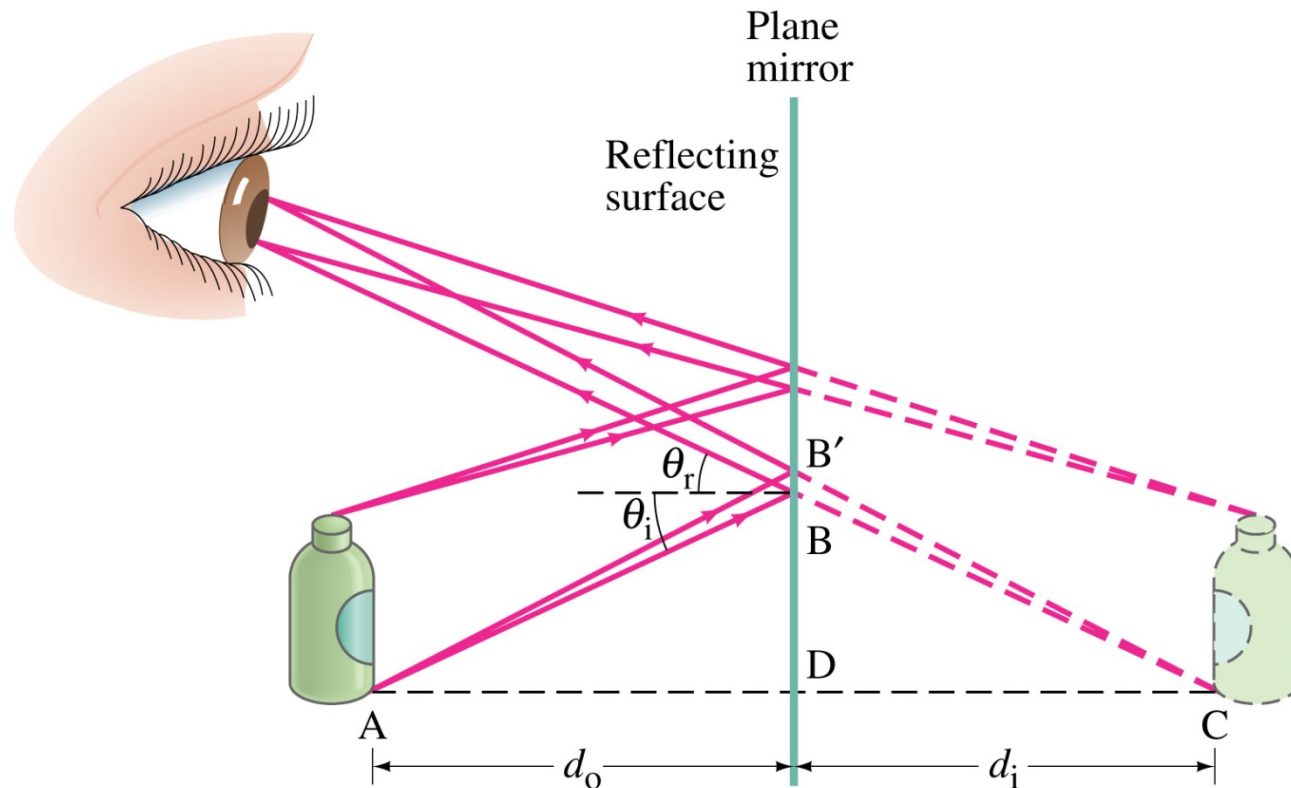
Reflection; Image Formation by a Plane Mirror

With diffuse reflection, your eye sees reflected light at all angles. With specular reflection (from a mirror), your eye must be in the correct position.

Eye at both positions sees the reflected light

Source

(a)

This eye does not see the light

This eye sees the light

Source

(b)

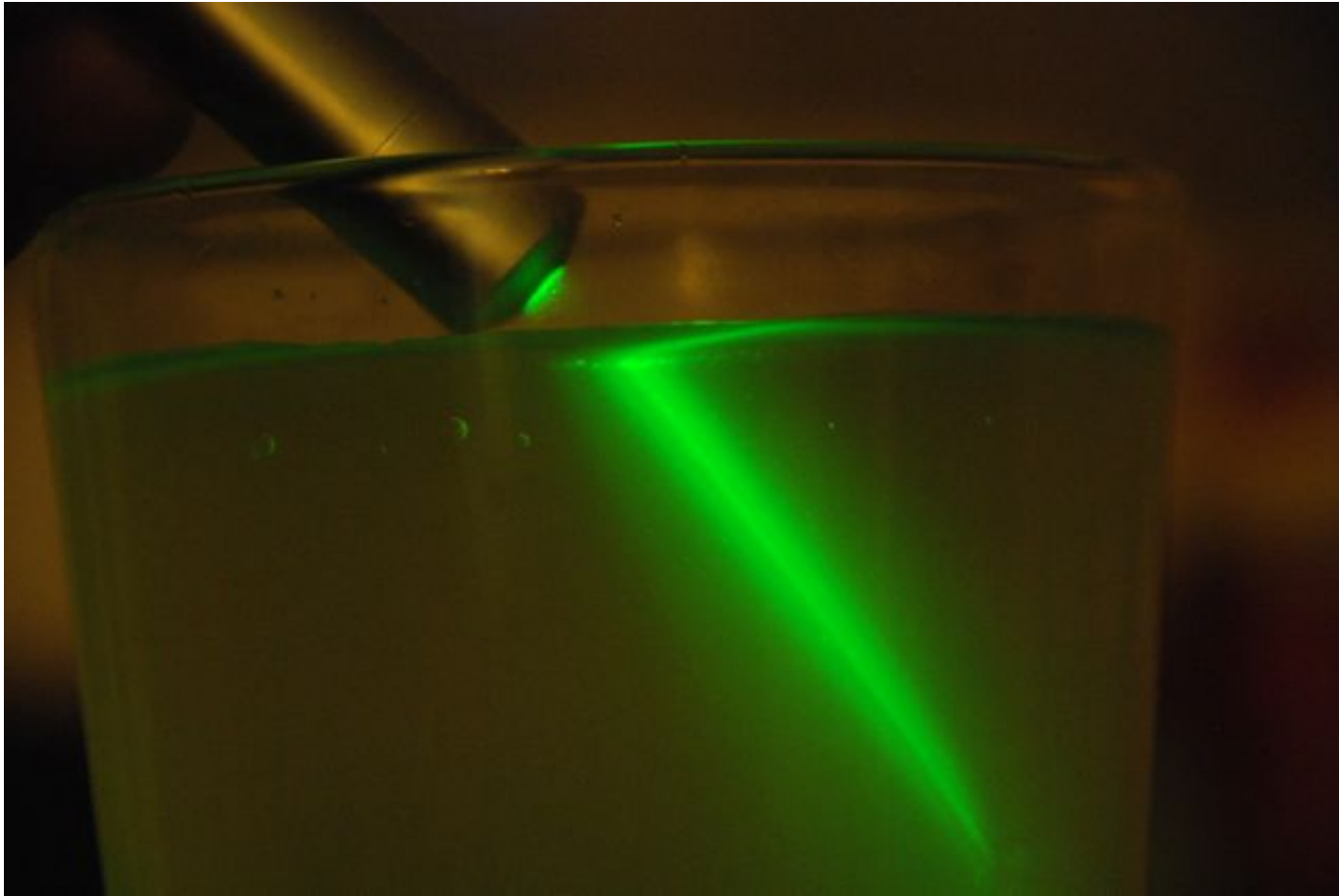# Reflection; Virtual Images

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

Plane mirror

Reflecting surface

θ_r

θ_i

B'

B

D

A

C

d_o

d_i

Copyright © 2005 Pearson Prentice Hall, Inc.

Beam of Light bent upon entering water

- Ray bends <u>toward</u> the normal
- Angles obey Snell's Law

23.4 Index of Refraction

In general, light slows somewhat when traveling through a medium. The index of refraction of the medium is the ratio of the speed of light in vacuum to the speed of light in the medium:

$$n = \frac{c}{v} \qquad \text{(23-4)}$$

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.

23.5 Refraction: Snell's Law

• **Light changes direction when crossing a boundary from one medium to another.**

• **This is called refraction.**

• **The angle the outgoing ray makes with the normal is called the angle of refraction.**

• **The angle of refraction depends on a property of the two media, called the refractive index**

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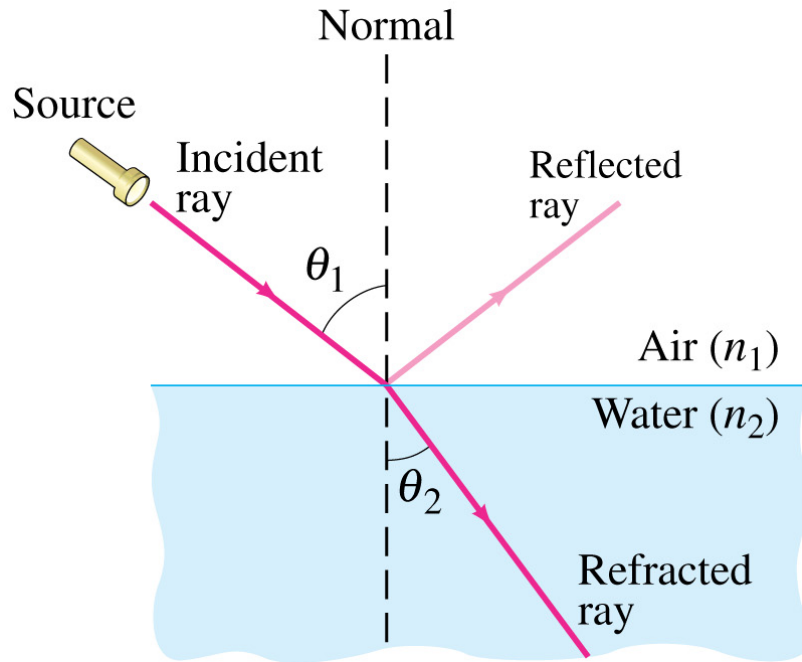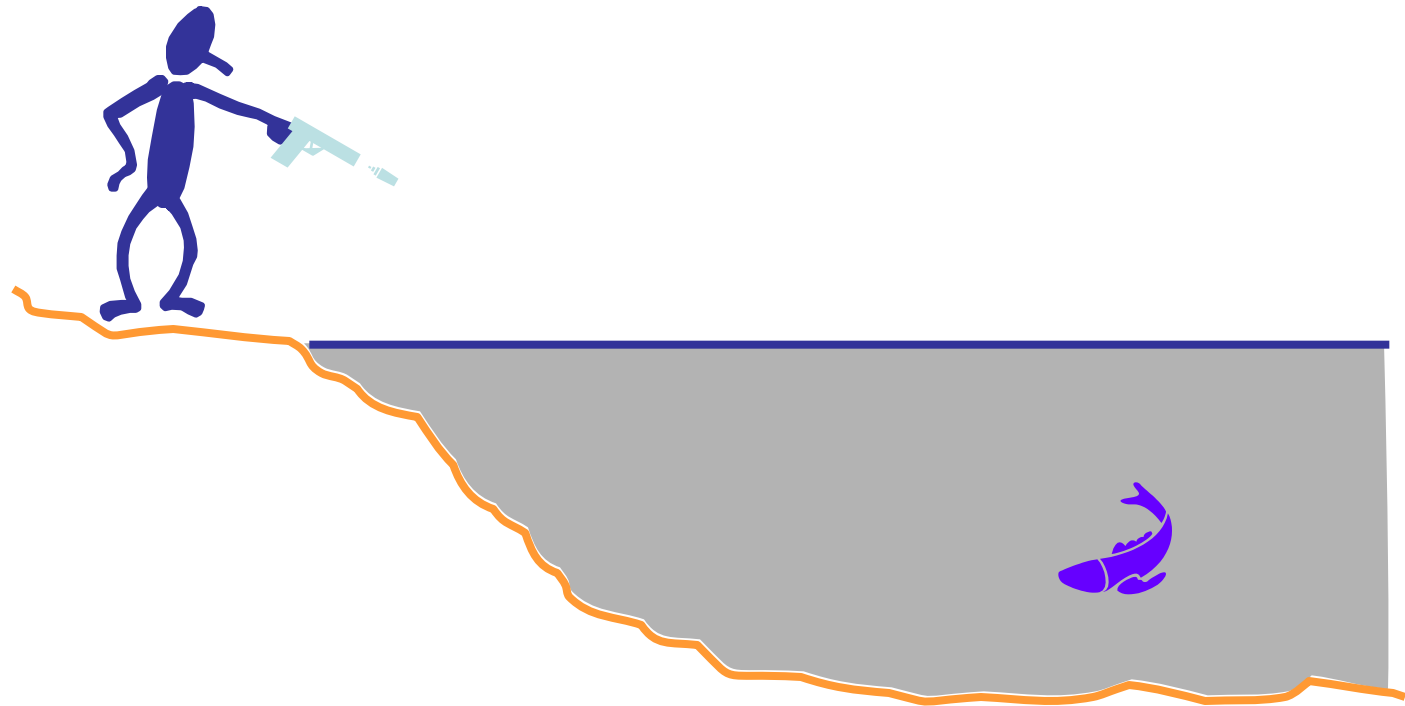

(a) $n_2 > n_1$
Ray bends toward ⊥
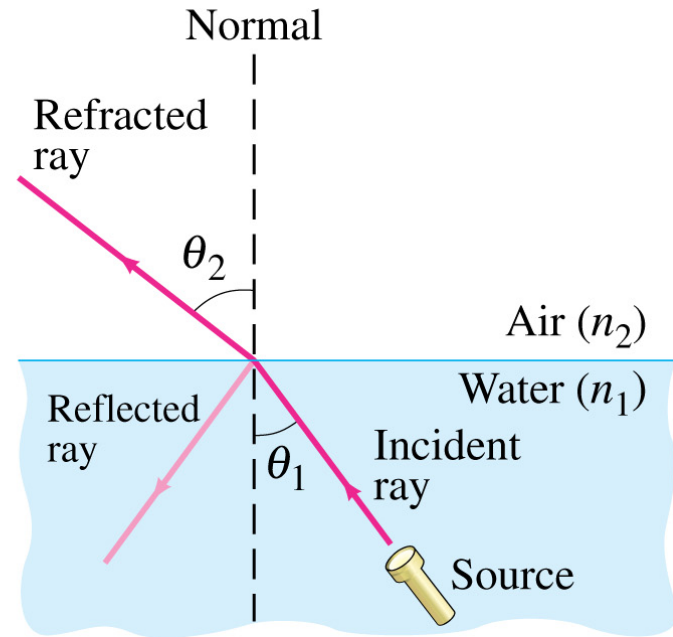
(b) $n_1 > n_2$
Ray bends away from ⊥

ConcepTest 23.5a Gone Fishin' I

To shoot a fish with a gun, should you aim directly at the image, slightly above, or slightly below?

1) aim directly at the image

2) aim slightly above

3) aim slightly below
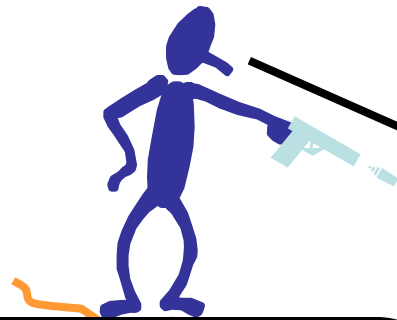
ConcepTest 23.5a Gone Fishin' I

To shoot a fish with a gun, should you aim directly at the image, slightly above, or slightly below?
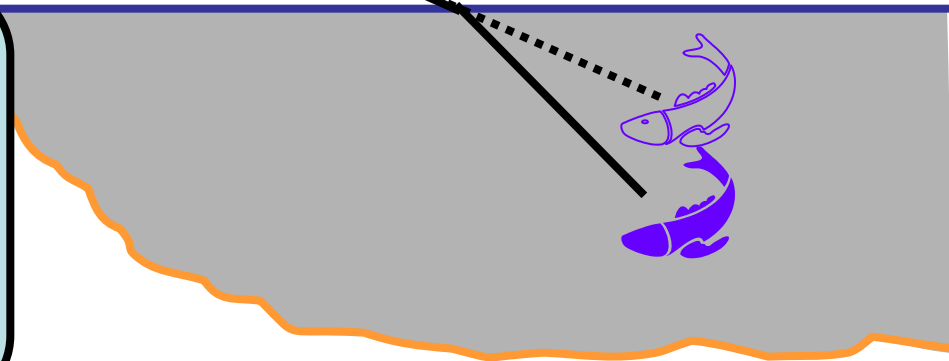
1) aim directly at the image

2) aim slightly above

3) aim slightly below

Due to refraction, the image will appear **higher** than the actual fish, so you have to **aim** **lower** to compensate.

23.6 Total Internal Reflection

If light passes into a medium with a smaller index of refraction, the angle of refraction is larger. There is an angle of incidence for which the angle of refraction will be 90° ; this is called the critical angle:

$$\sin \theta_C = \frac{n_2}{n_1} \sin 90° = \frac{n_2}{n_1}$$

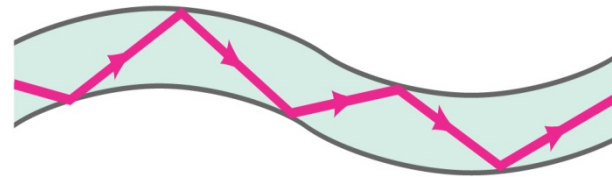**If the angle of incidence is larger than this, no transmission occurs. This is called total internal reflection.**

An individual optical fiber

Copyright © 2005 Pearson Prentice Hall, Inc.
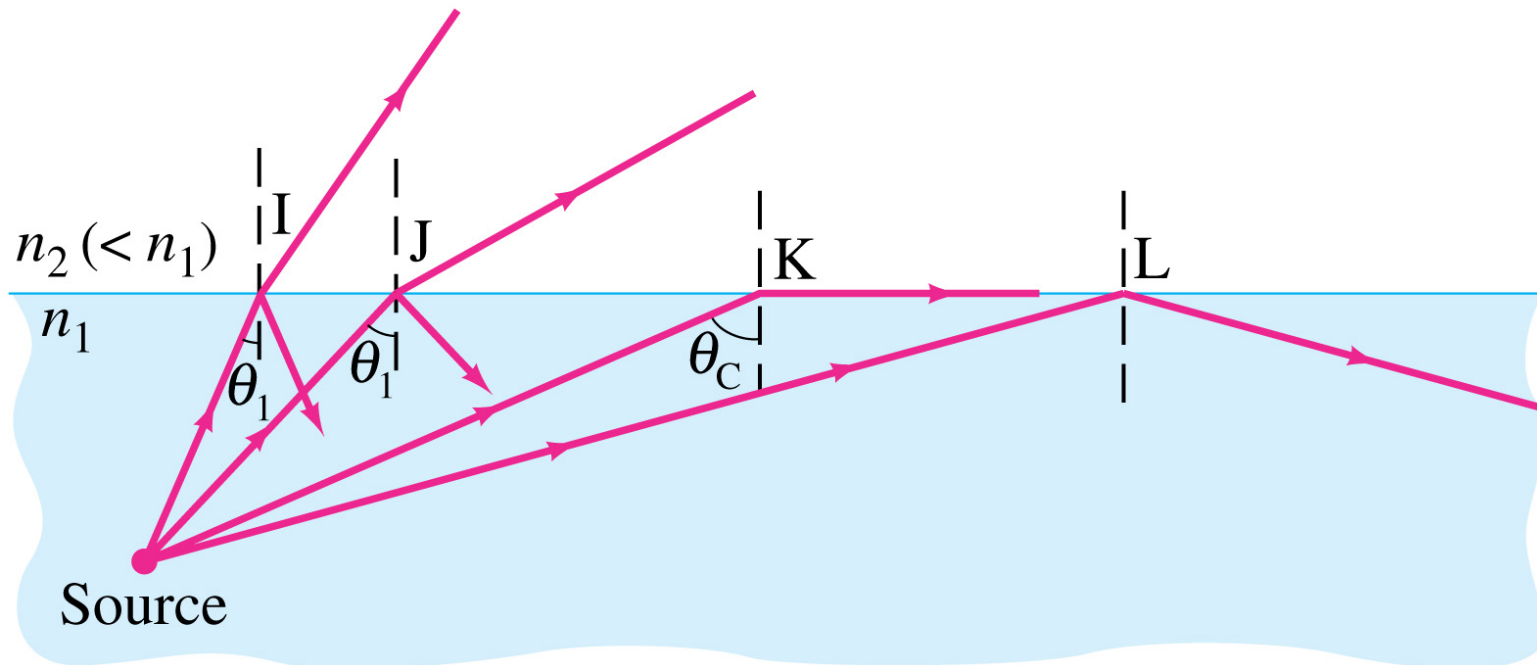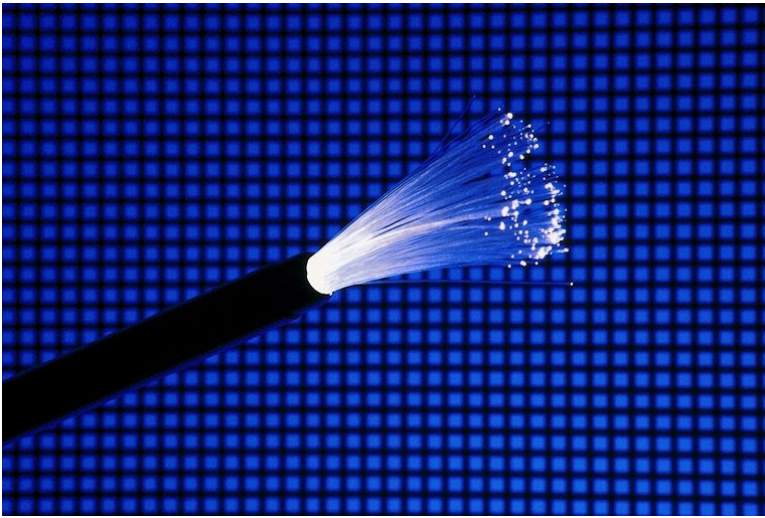
Fiber optic cables consist of many individual fibers, each can carry multiple optical signals
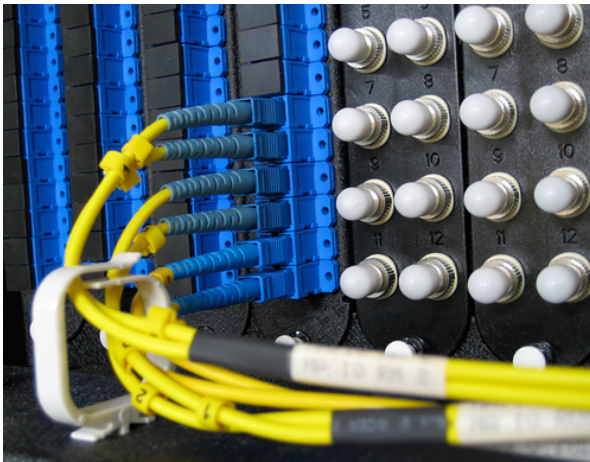
High performance data cables for computers and communications

Medical Endoscope, used to see inside the body

Chapter 23. Light – Geometric Optics

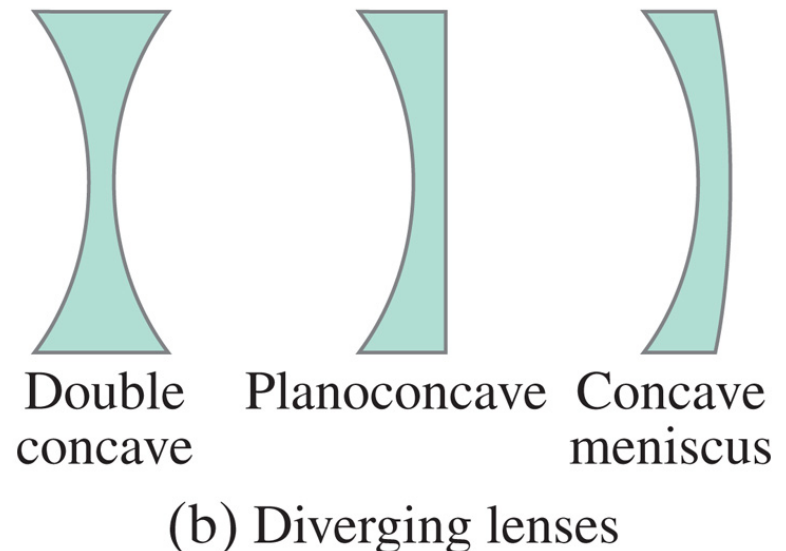There are 3 basic ways to gather light and focus it to make an image.

Pinhole - Simple geometry

Mirror - Reflection

Lens - Refraction

23.7 Lenses

• **Lenses bend light by refraction, an are designed to bring light to a focus, or diverge it.**

• **Thin lenses are those whose thickness is small compared to their radius of curvature.**

• **They may be either converging (a) or diverging (b).**

• **Thin lenses obey similar rules to mirrors**

Double convex   Planoconvex   Convex meniscus

(a) Converging lenses

Double concave   Planoconcave   Concave meniscus
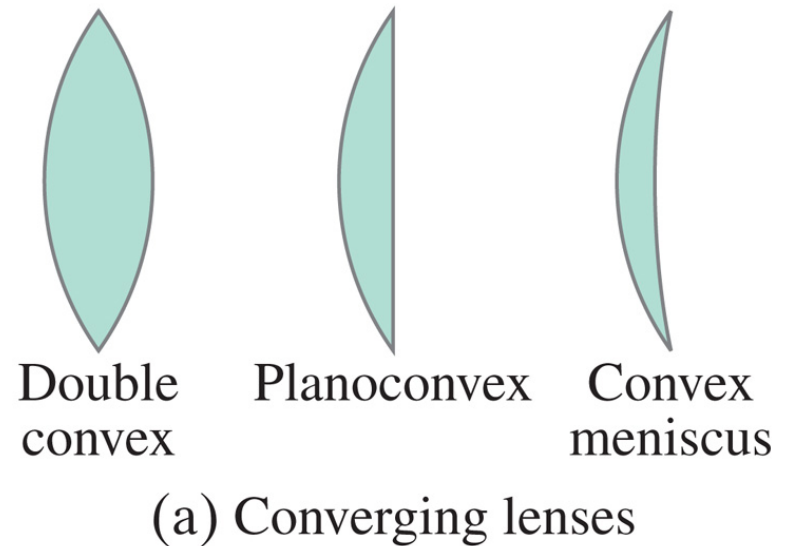
(b) Diverging lenses

23.7 Thin Lenses; Ray Tracing

Parallel rays are brought to a focus by a converging lens (one that is thicker in the center than it is at the edge).

(a)

(b)
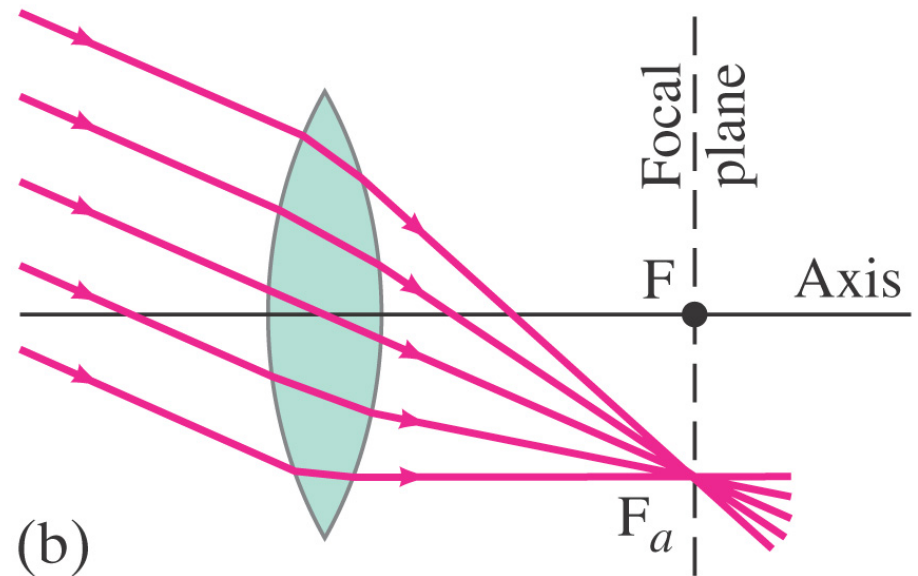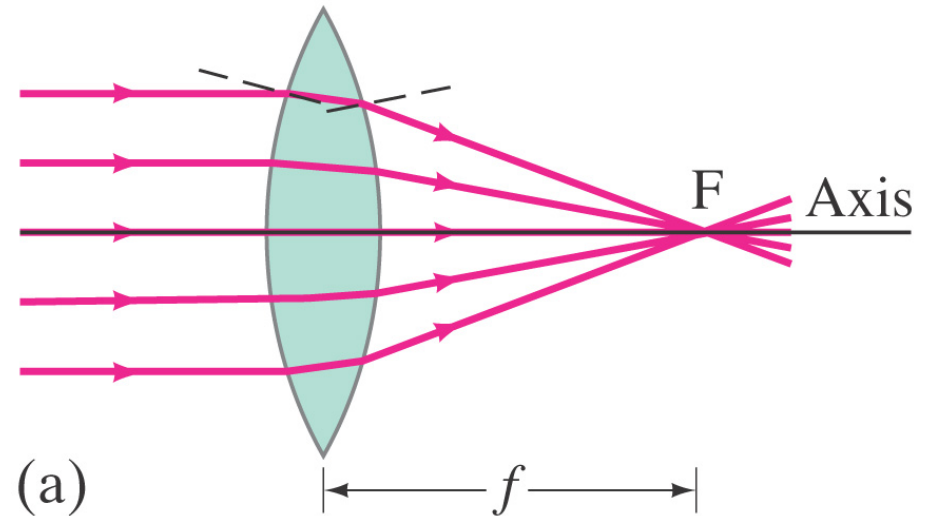
23.7 Thin Lenses; Ray Tracing

A diverging lens (thicker at the edge than in the center) make parallel light diverge; the focal point is that point where the diverging rays would converge if projected back.
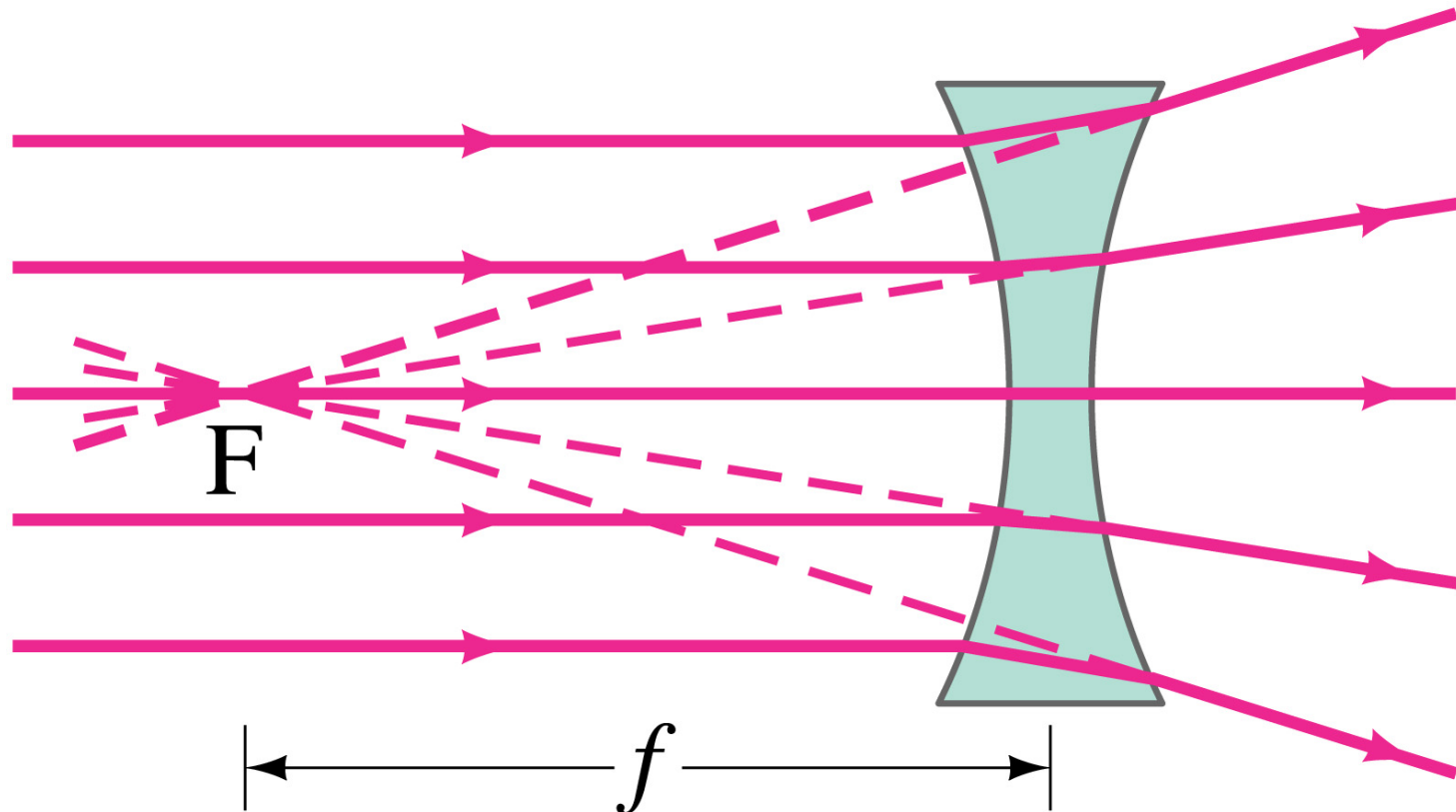
Lens Power, Diopters and Spectacles

The power of a lens is the inverse of its focal length.

$$P = \frac{1}{f} \qquad \text{(23-7)}$$

Lens power is measured in diopters, D.

$1\ D = 1\ m^{-1}$

Optician use this notation because the total power of a set of lenses is the sum of their diopters

23.8 Thin Lens Equation & Magnification

•**The thin lens equation, and lens magnification equations are the same as for mirrors:**

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

•**The power of a lens is positive if it is converging and negative if it is diverging.**

•Mirrors and Lenses obey the same math rules and are used for much the same purposes.

# Formation of Images by thin converging lenses

We use ray diagrams to determine where an image will be. For lenses, we use three key rays, all of which begin on the object:

1. A ray parallel to the axis; after refraction it passes through the focal point

2. A ray through the focal point; after refraction it is parallel to the axis

3. A ray through center of lens continues in the same path.

23.7 Thin Lenses; Ray Tracing

Center line

Object

1

F

O   F′
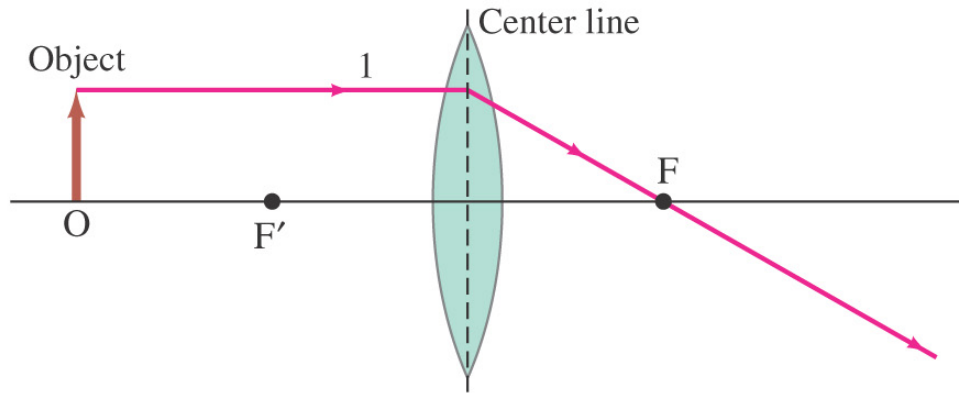
(a) Ray 1 leaves one point on object going parallel to the axis, then refracts through focal point behind.

1

1

F   I

F′

2

2
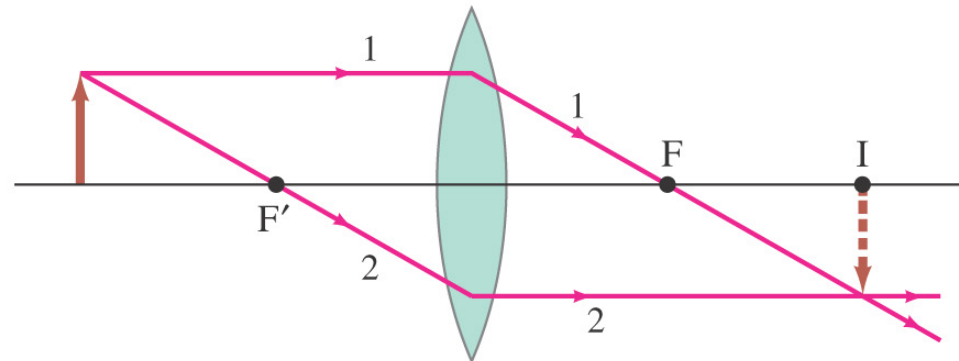
(b) Ray 2 passes through F′ in front of the lens; therefore it is parallel to the axis behind the lens.

Object

1

3

F   I

O   F′

2
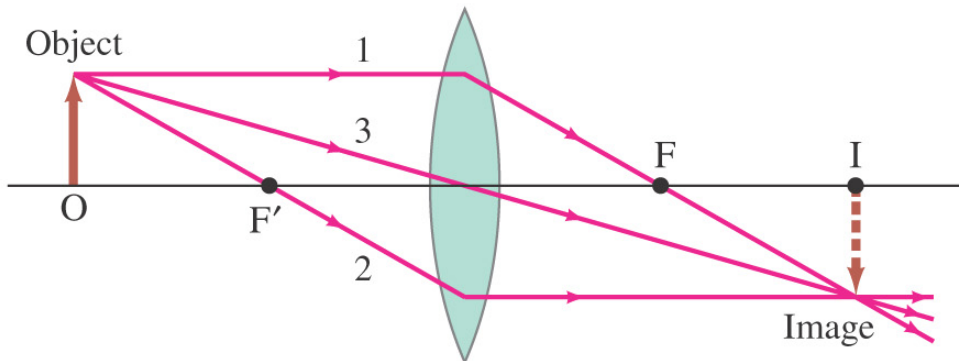
Image

(c) Ray 3 passes straight through the center of the lens (assumed very thin).

23.7 Thin Lenses; Ray Tracing

For a diverging lens, we can use the same three rays; the image is upright and virtual.
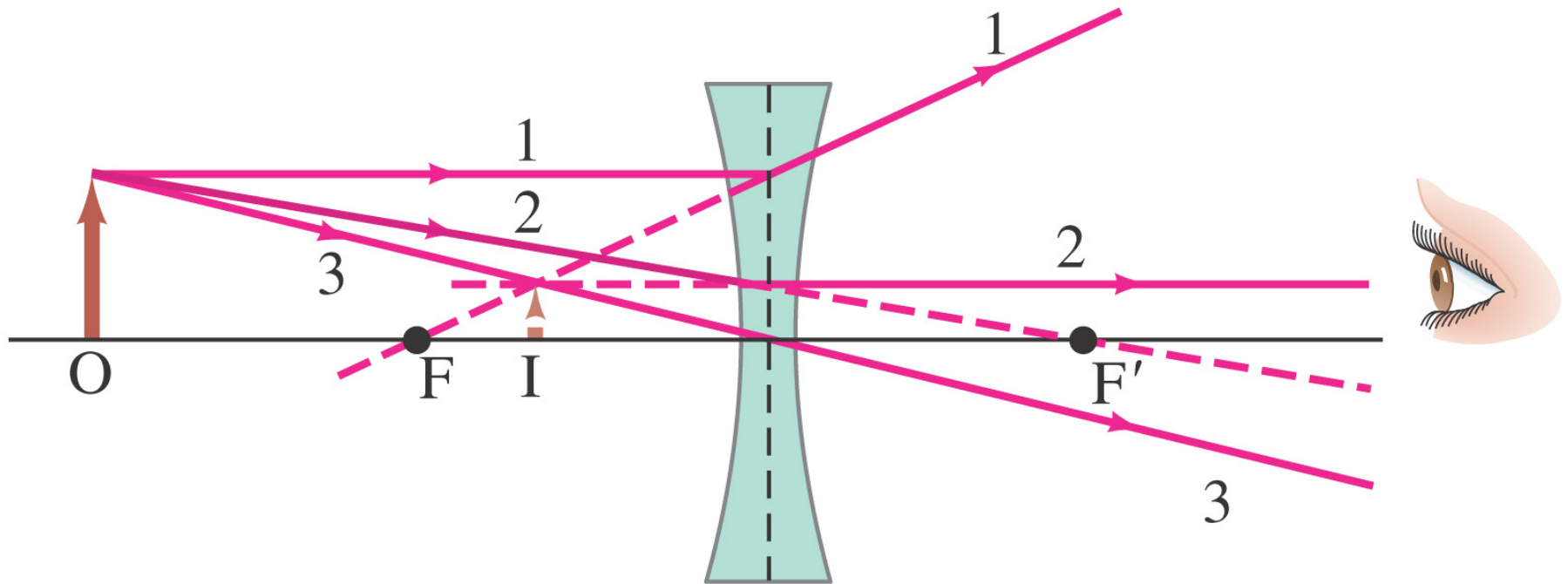
Chapter 23. Light – Geometric Optics

There are 3 basic ways to gather light and focus it to make an image.

Pinhole - Simple geometry

Mirror - Reflection

Lens - Refraction

23.3 Formation of Images by Spherical Mirrors

Spherical mirrors are shaped like sections of a sphere, and may be reflective on either the inside (concave) or outside (convex).

(a) Convex mirror
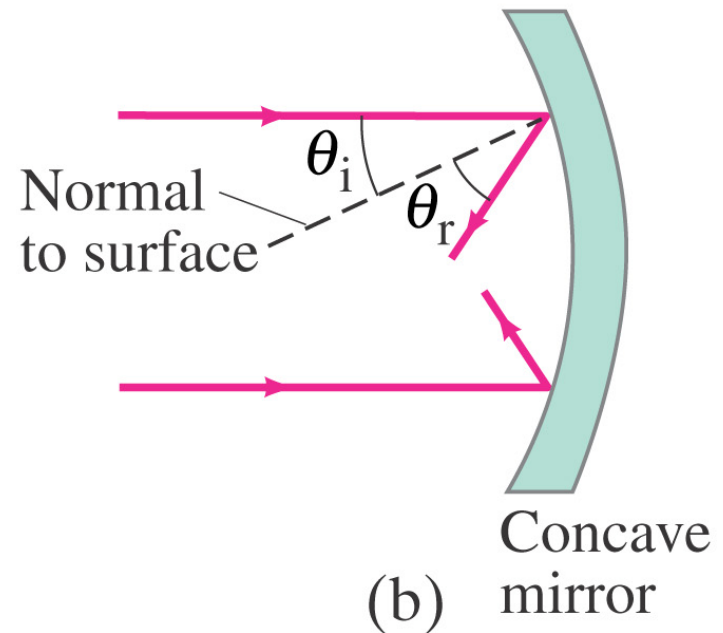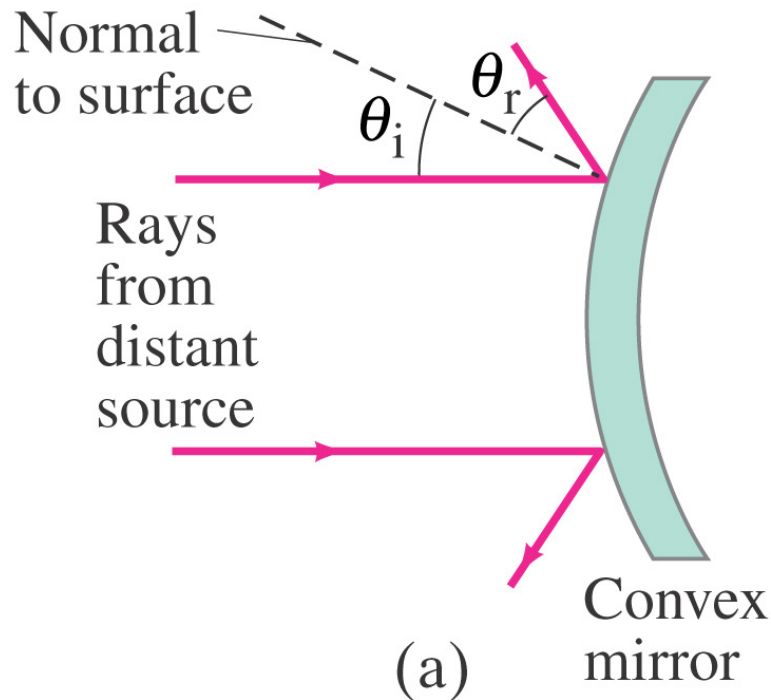
(b) Concave mirror

Reflection from Convex and Concave Surfaces

Outside Bowl

Inside Bowl
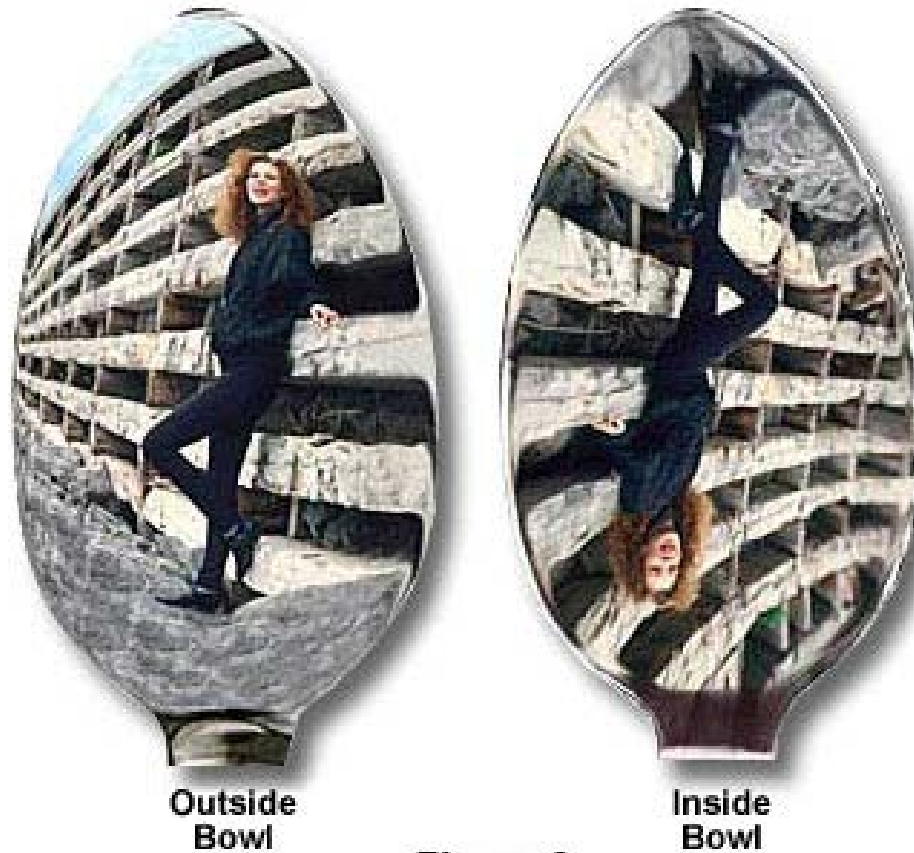
Try this yourself, next time you have a spoon in your hand.

Is the Convex image ALWAYS erect, and the Concave ALWAYS inverted?

23.3 Formation of Images by Spherical Mirrors

Rays coming from a faraway object are effectively parallel.

Mirror

These rays strike the mirror, and they are essentially parallel.
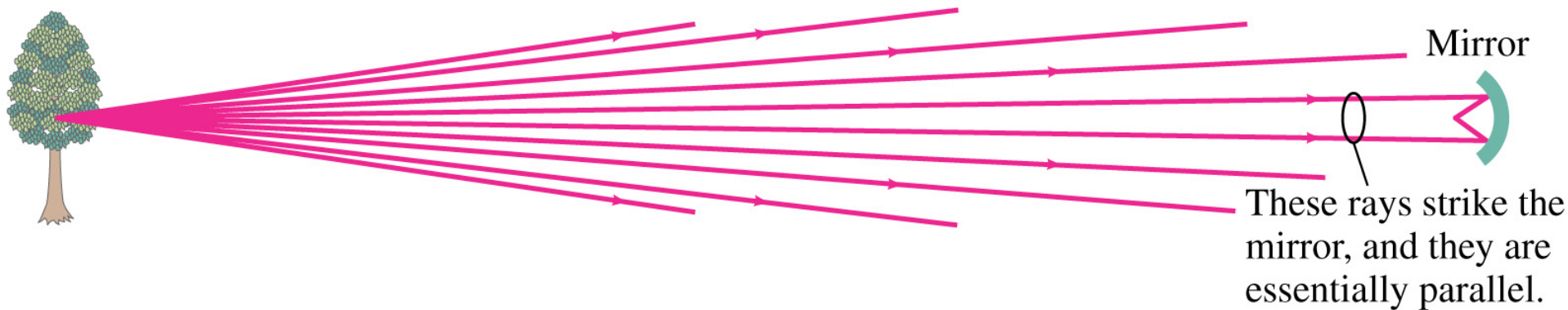
23.3 Formation of Images by Spherical Mirrors

Concave Mirror

Parallel rays striking a spherical mirror converge at a point, called the Focus, or focal point.

The law of reflection does not depend on the wavelength of light, so mirrors produce perfect color images (no chromatic aberration)

If the curvature of the mirror is large, the point becomes spread out. This is called spherical aberration.
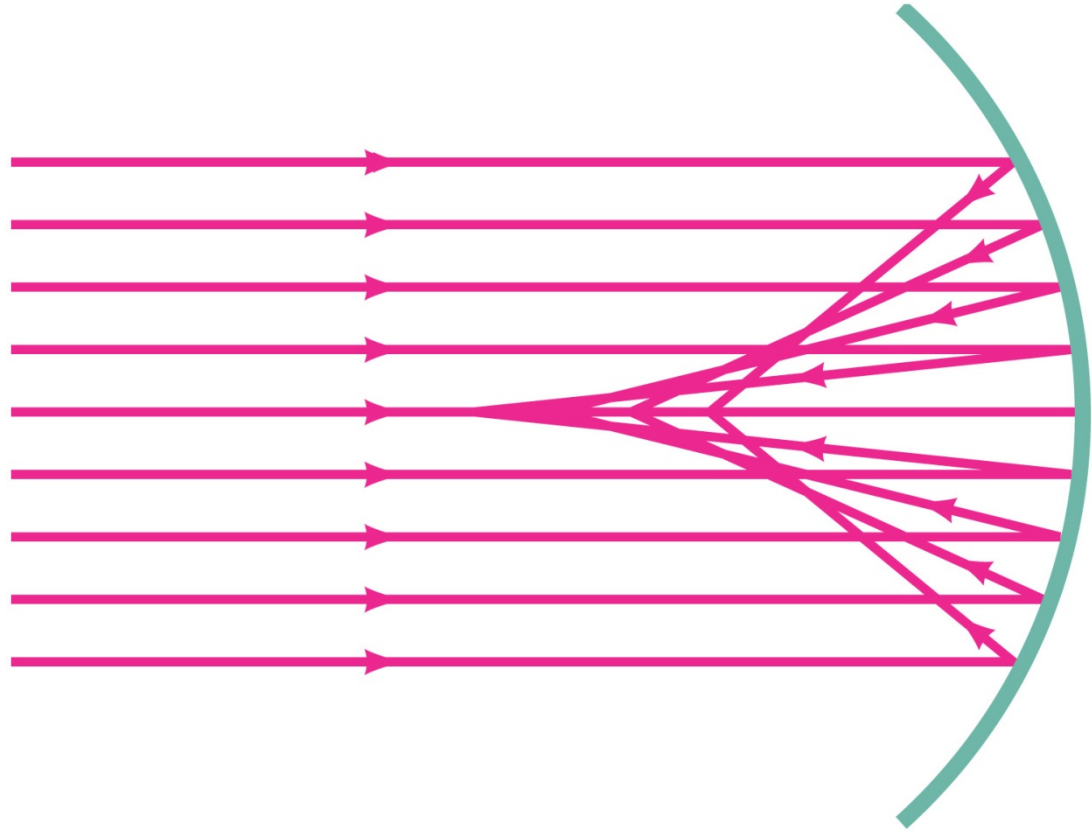
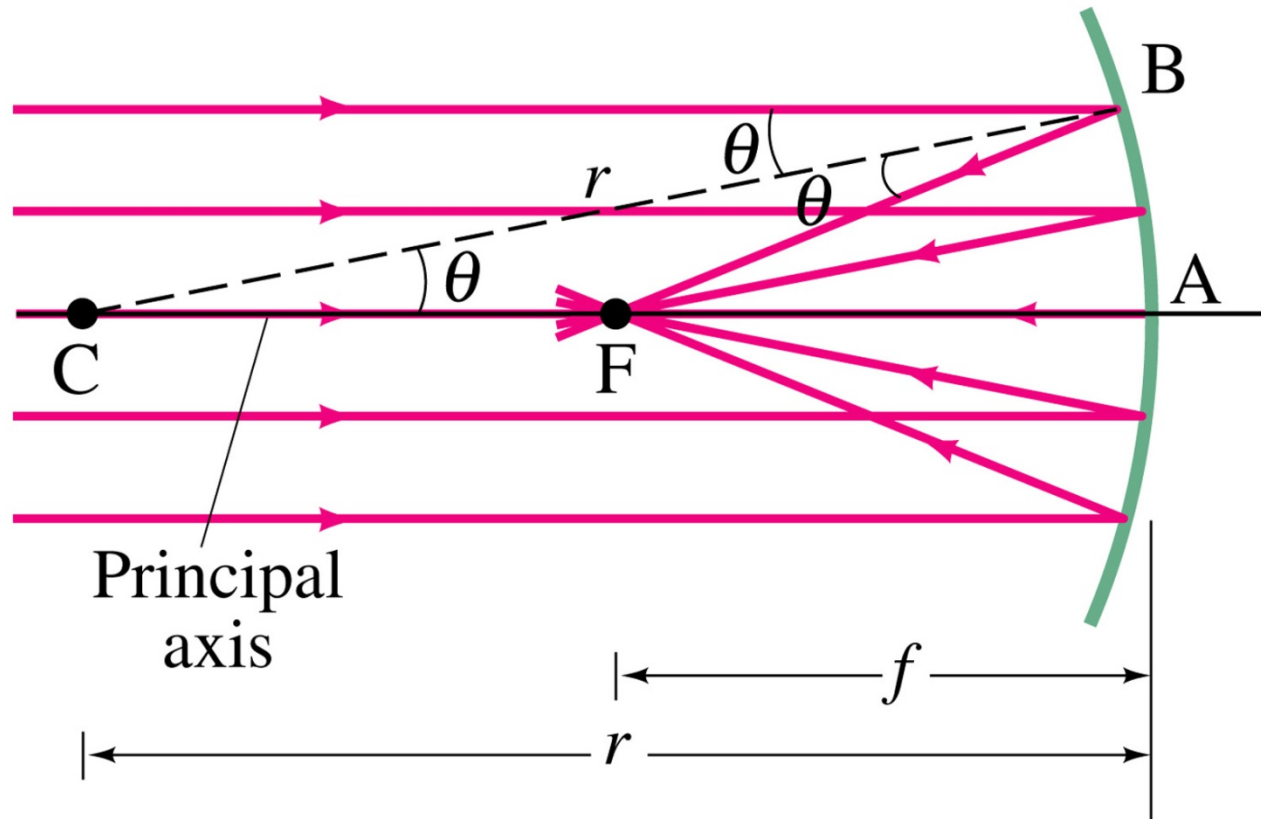# Radius of Curvature and Focal Length

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

Focal Length of a Spherical Mirror

• A deeper curve gives a shorter focal length

• Using geometry, we find that the focal length is half the radius of curvature:

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

• Spherical aberration can be avoided by using a parabolic reflector; which are only a little more difficult/expensive to make.

• Typically used in Telescopes, Camera lenses Lab equipment, shaving/make-up Mirrors, and this solar fire-lighter for campers!

• Mirrors are preferred to lenses in many applications because of their perfect color rendition, greater maximum size, and substantially lower cost.
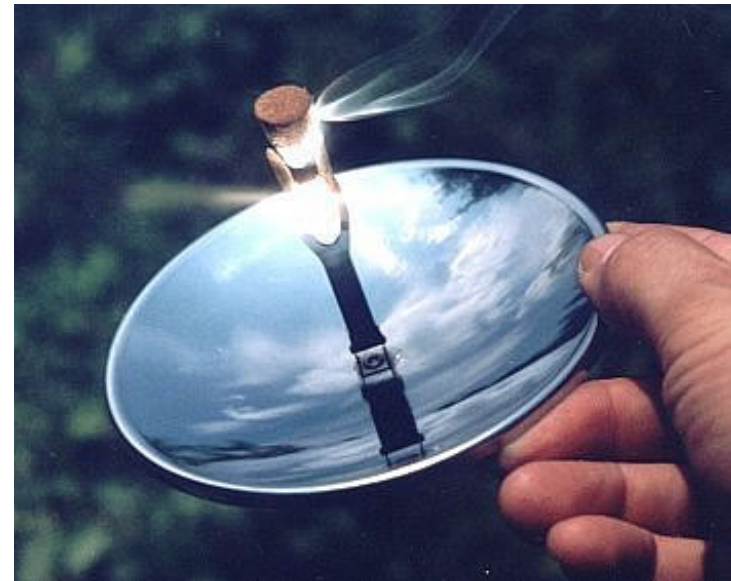
23.3 Formation of Images by Spherical Mirrors

We use ray diagrams to determine where an image will be. For mirrors, we use three key rays, all of which begin on the object:

1. A ray parallel to the axis; after reflection it passes through the focal point

2. A ray through the focal point; after reflection it is parallel to the axis

3. A ray perpendicular to the mirror; it reflects back on itself
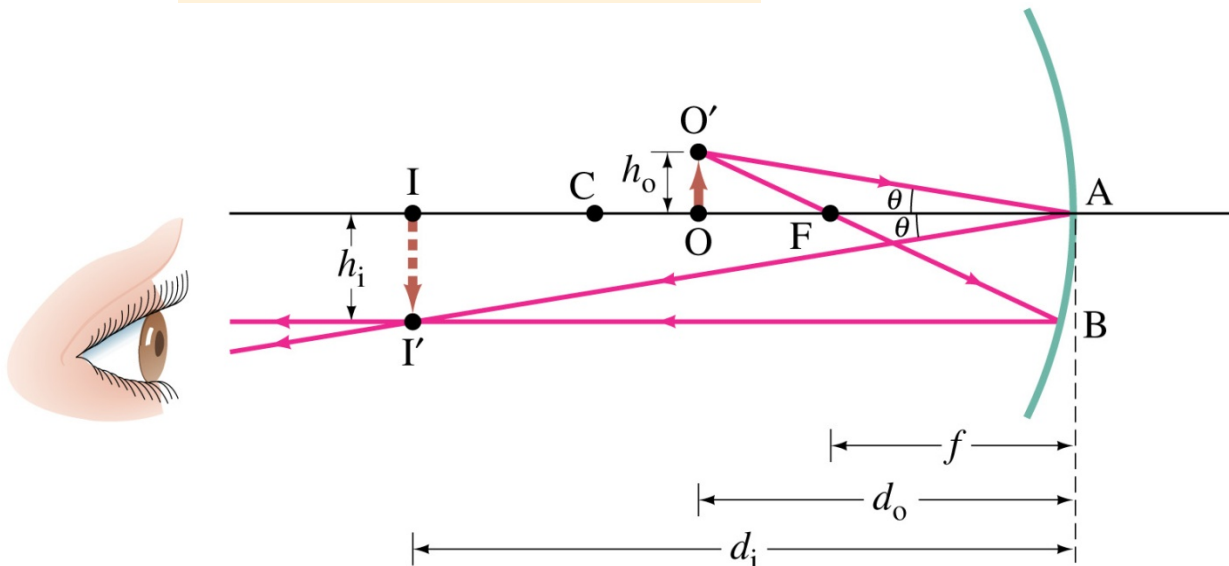
The Mirror Equation

Focal Length is the most important characteristic of an any optical element. It is the distance from the mirror (or lens) surface at which a distant object is brought to focus.

Geometrically, one can derive an equation that relates the object distance, image distance, and focal length of the mirror:

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

(23-2)

Magnification by Mirrors and simple lenses

Magnification is the ratio of image height to object height. (this is an "obvious" definition)

$$m = \frac{h_\text{i}}{h_\text{o}} = -\frac{d_\text{i}}{d_\text{o}}$$

(23-3)

Less obvious but more useful: This ratio is the same as the ratio of Image distance to Object distance!
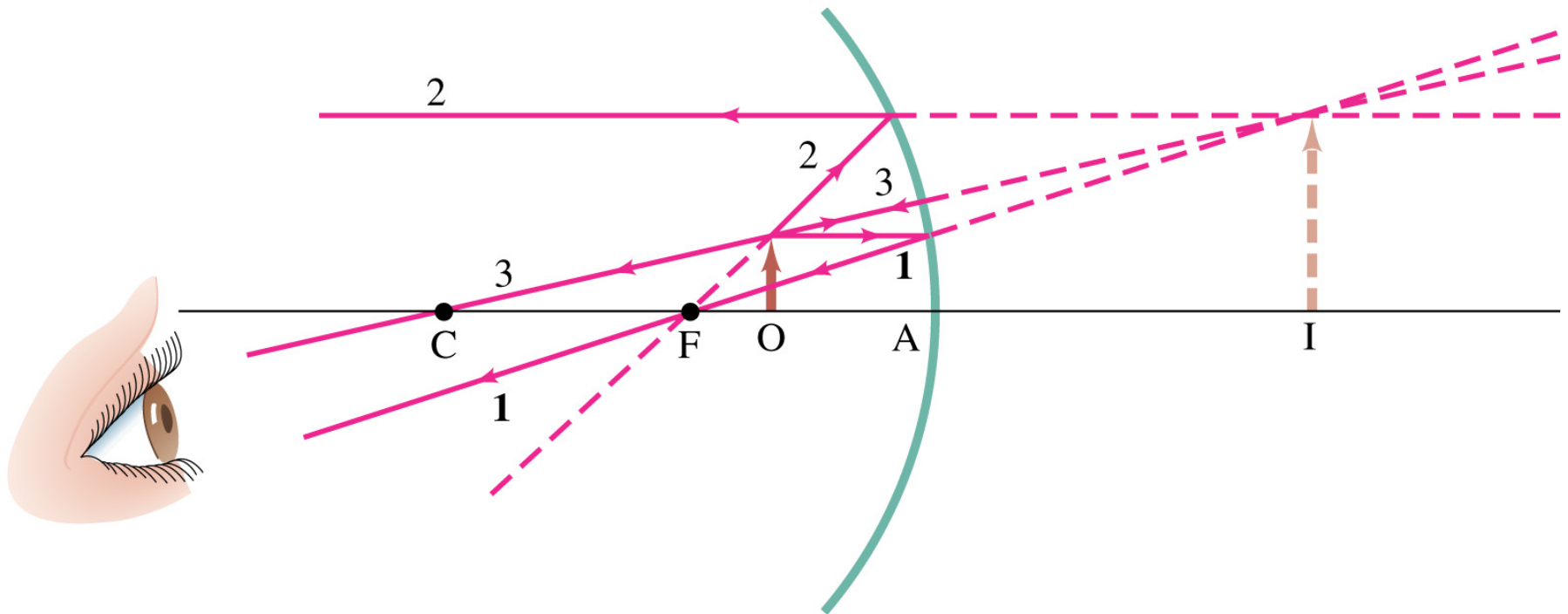
A negative sign indicates that the image is inverted.

-1 < m < 1 means the image is smaller than the object.

23.3 Formation of Images by Spherical Mirrors

Concave Mirror

If an object is inside the focal point, its image will be upright, larger, and virtual.

Convex Mirrors

- **A Convex Mirror has no Focal point.**

- **Hence it Cannot form a Real image**

- **Virtual Images only.**

- **All the mathematical rules for mirrors still apply.**

- **For a convex mirror, the image is always upright, and smaller.**

- **Convex mirrors can compress a large view into a small image.**

- **Often used to provide a view of a whole room, or a street.**

(a)

(b)

Copyright © 2005 Pearson Prentice Hall, Inc.
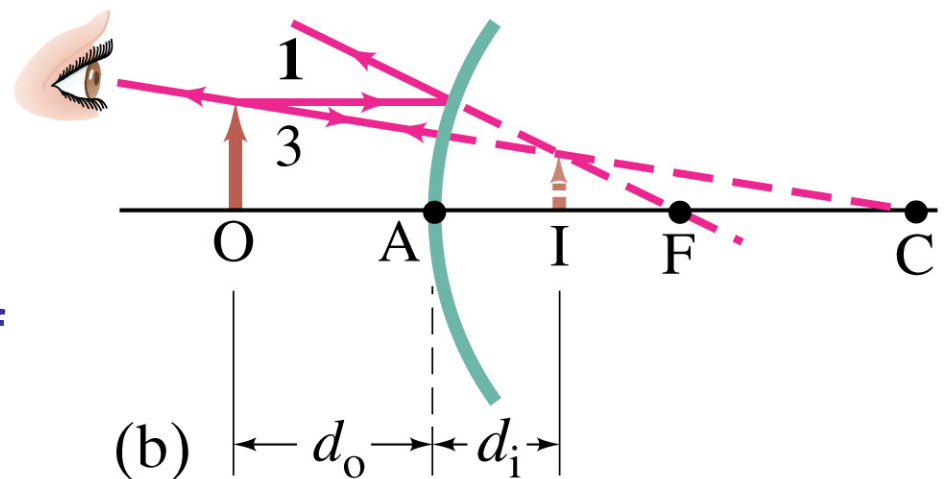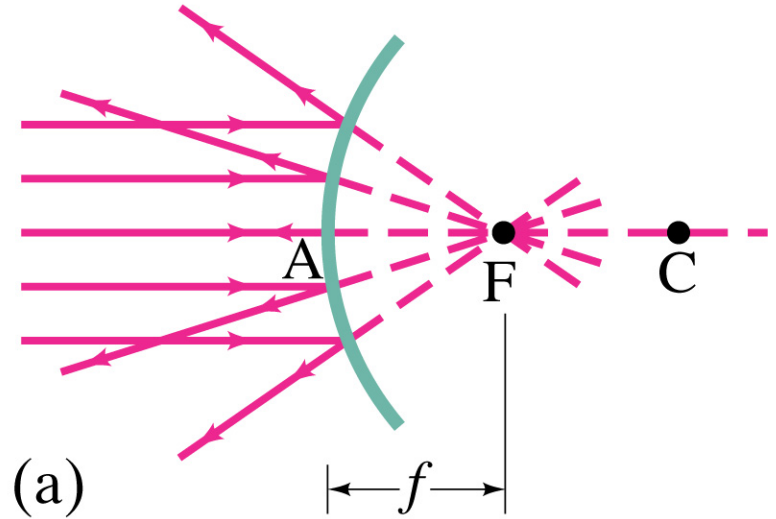
23.3 Formation of Images by Spherical Mirrors

Problem Solving: Spherical Mirrors

1. Draw a ray diagram; the image is where the rays intersect.

2. Apply the mirror and magnification equations.

3. Sign conventions: if the object, image, or focal point is on the reflective side of the mirror, its distance is positive, and negative otherwise. Magnification is positive if image is upright, negative otherwise.

4. Check that your solution agrees with the ray diagram.

Summary of Chapter 23

• Light paths are called rays

• Index of refraction: $n = \dfrac{c}{v}$

• Upon passing into a material with larger n, ray deflects toward the normal

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

• Total internal reflection critical angle: $\sin\theta_C = \dfrac{n_2}{n_1}$

• A converging lens focuses incoming parallel rays to a point

• A diverging lens spreads incoming rays so that they appear to come from a point

• Power of a lens (diopters): $P = 1/f$

• Thin lens equation: $\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{1}{f}$

• Magnification: $m = \dfrac{h_i}{h_o} = -\dfrac{d_i}{d_o}$

• Real image: light passes through it

• Virtual image: light does not pass through

Summary of Chapter 23

- **Light paths are called rays**

- **Angle of reflection equals angle of incidence**

- **Plane mirror: image is virtual, upright, and the same size as the object**

- **Focal length of the mirror:**

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

- **Spherical mirror can be concave or convex**

- **Mirror equation:**
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

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

- **Real image: light passes through it**

- **Virtual image: light does not pass through**