

# Phys102 Lecture 21/22

## Light: Reflection and Refraction

### Key Points

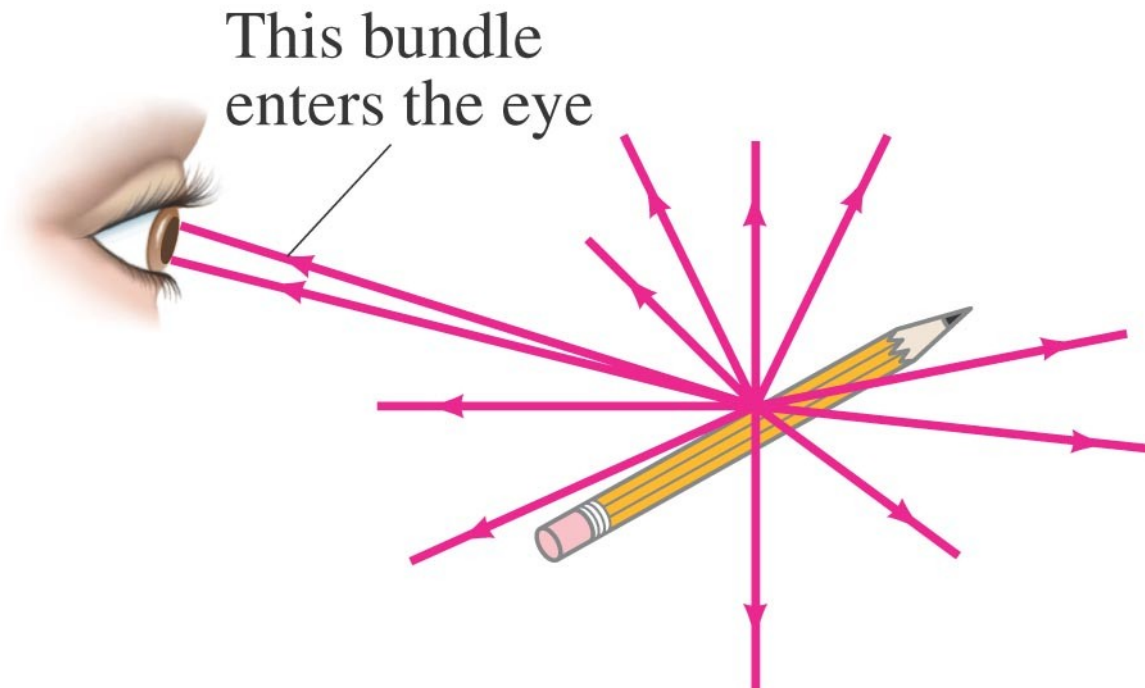
- The Ray Model of Light
- Reflection and Mirrors
- Refraction, Snell's Law
- Total internal Reflection

### References

23-1,2,3,4,5,6.

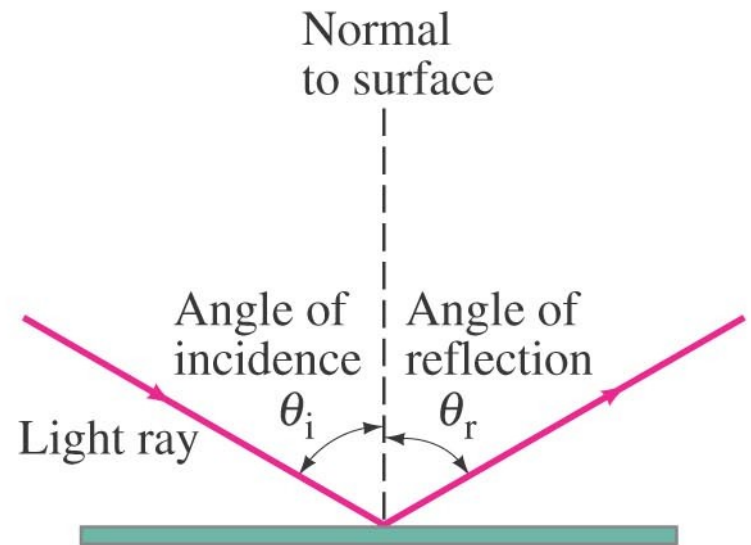
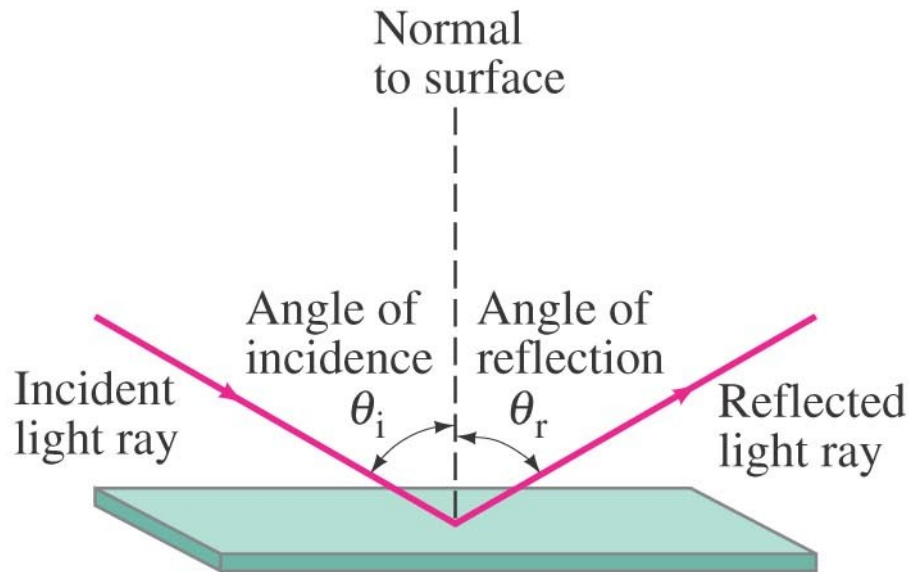
# The Ray Model of Light

Light very often travels in straight lines. We represent light using rays, which are straight lines emanating from an object. This is an idealization, but is very useful for geometric optics.



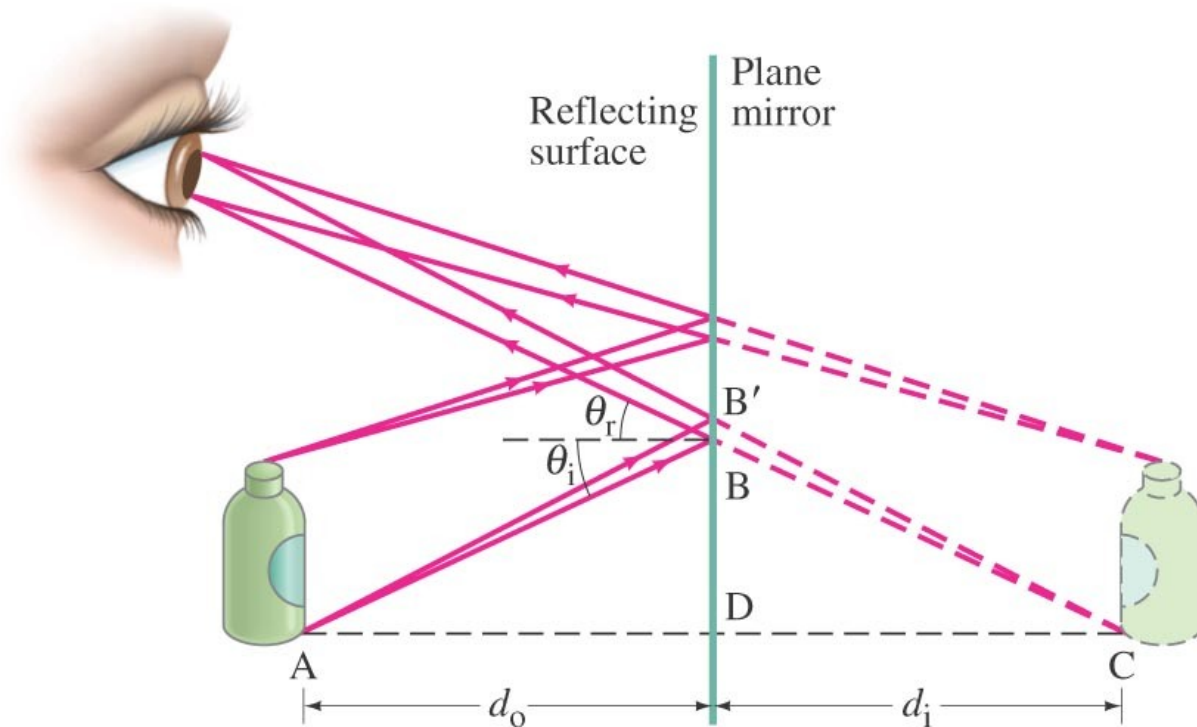
# Reflection

**Law of reflection: the angle of reflection (that the ray makes with the normal to a surface) equals the angle of incidence.**



# 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.



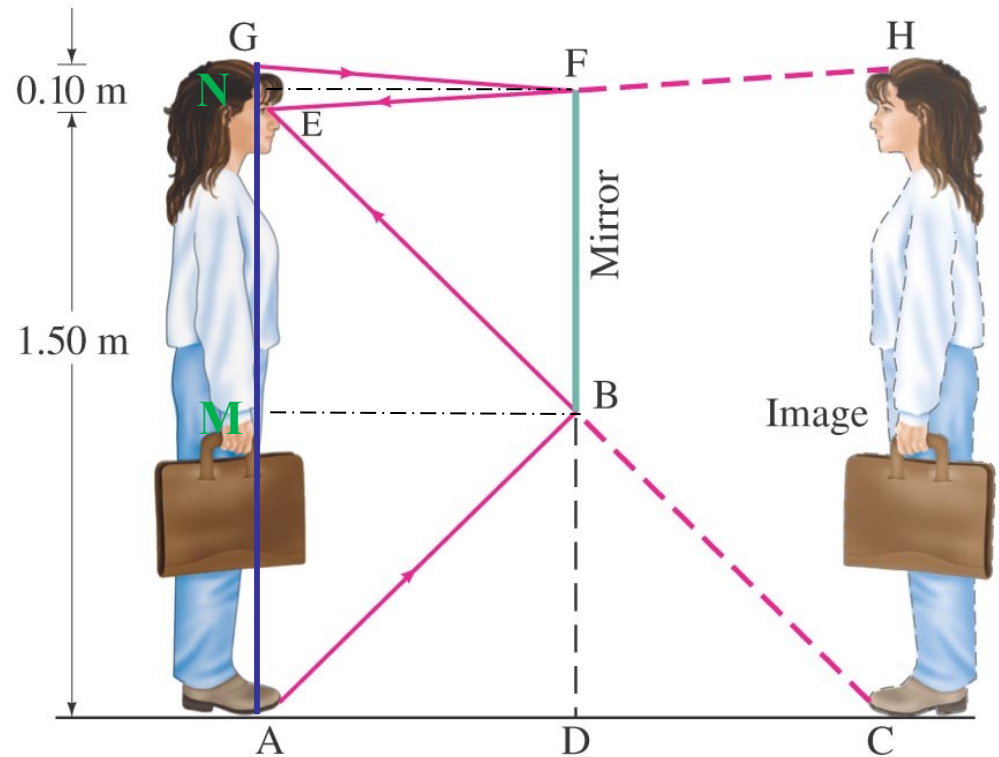
# Image Formation by a Plane Mirror

This is called a virtual image, as the light does not go through it. The distance of the image from the mirror is equal to the distance of the object from the mirror.

# Reflection; Image Formation by a Plane Mirror

**Example: How tall must a full-length mirror be?**

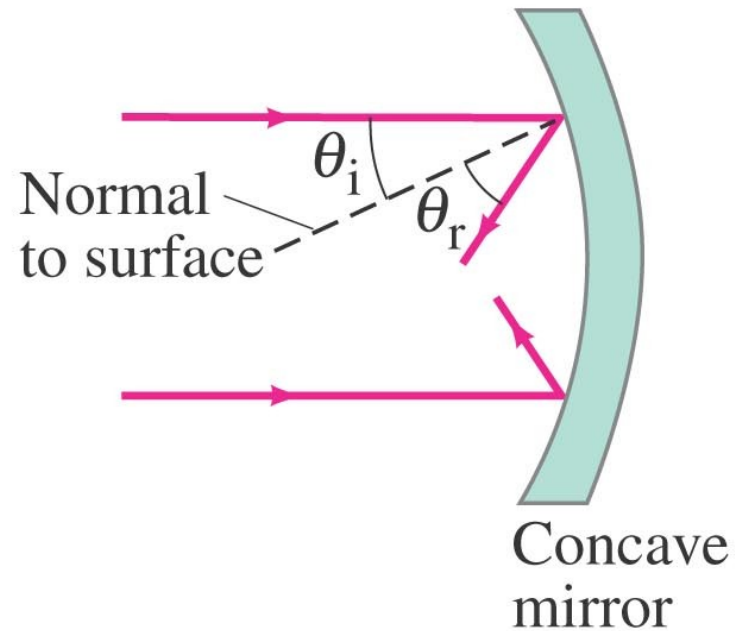
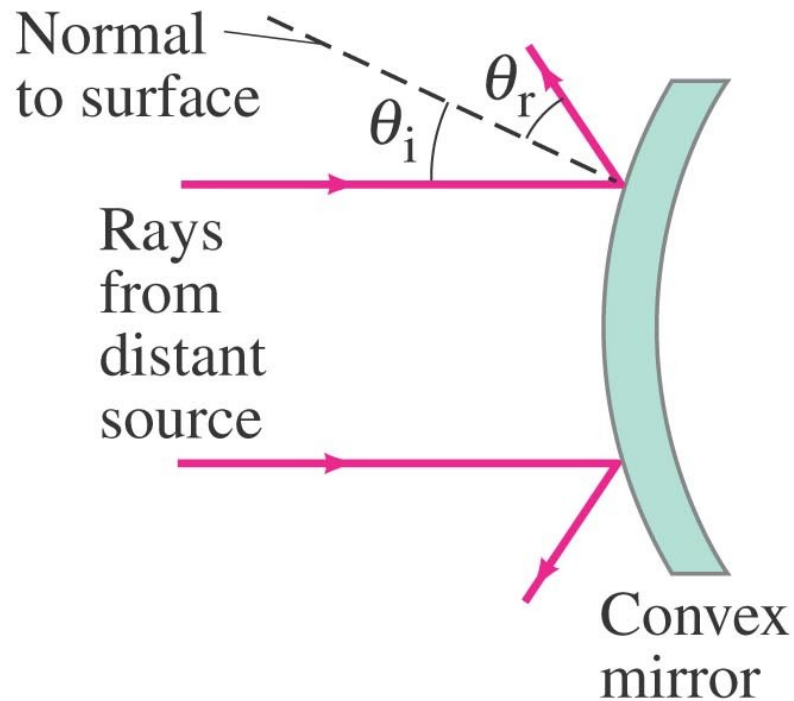
**A woman 1.60 m tall stands in front of a vertical plane mirror. What is the minimum height of the mirror, and how close must its lower edge be to the floor, if she is to be able to see her whole body? Assume her eyes are 10 cm below the top of her head.**



$$\begin{aligned}
 FB &= NM = NE + EM \\
 &= \frac{GE}{2} + \frac{EA}{2} = \frac{GA}{2}
 \end{aligned}$$

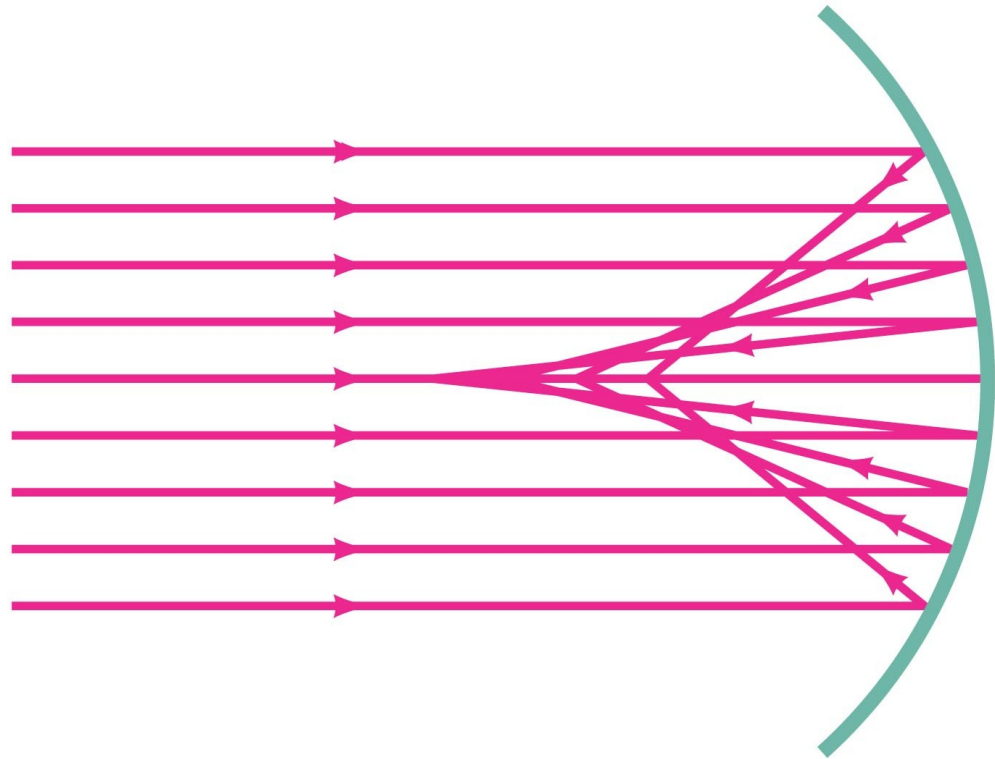
# Formation of Images by Spherical Mirrors

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



# Formation of Images by Spherical Mirrors

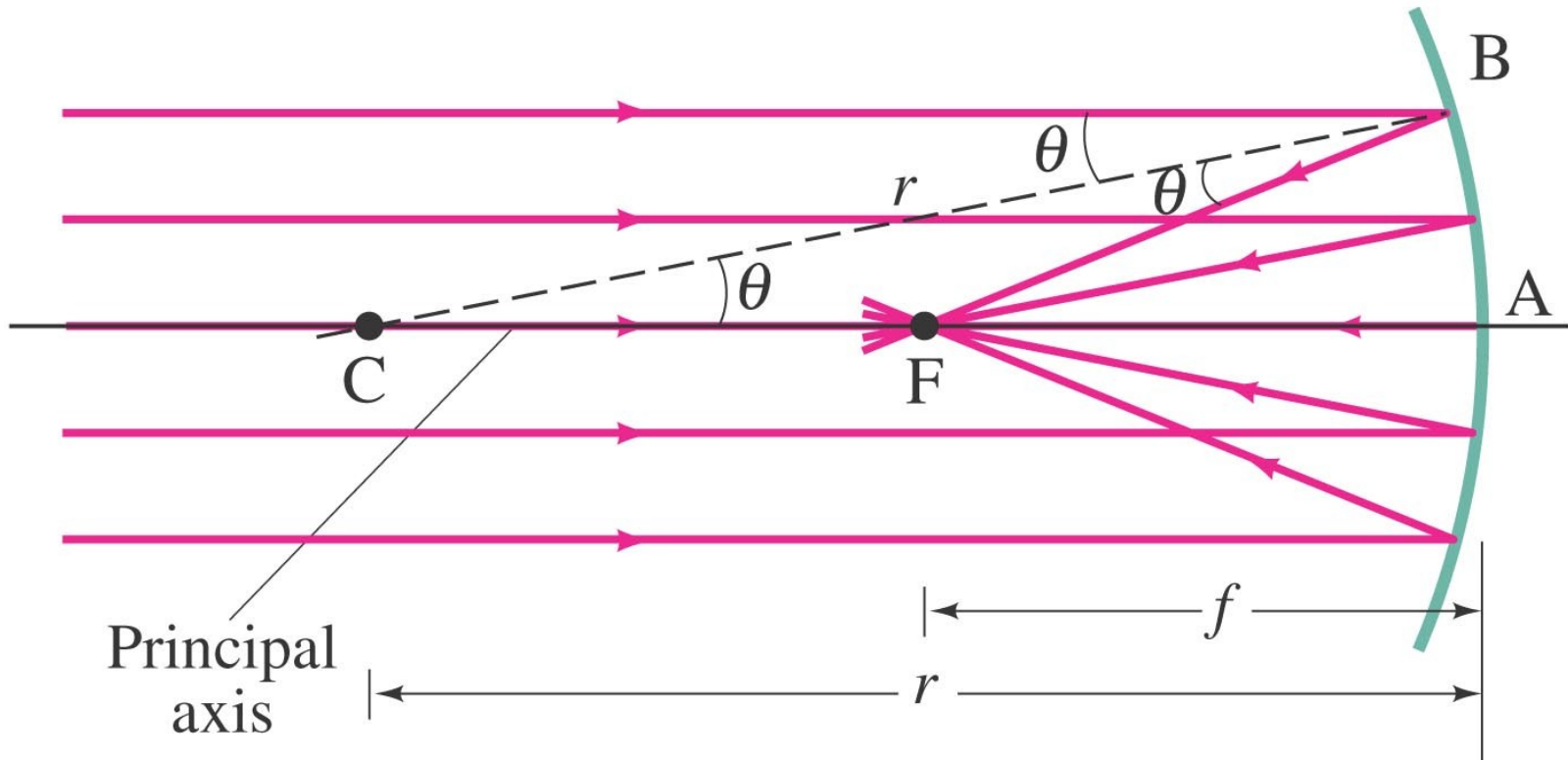
**Parallel rays striking a spherical mirror do not all converge at exactly the same place if the curvature of the mirror is large; this is called spherical aberration.**





# Formation of Images by Spherical Mirrors

If the curvature is small (small  $\theta$ ), the focus is much more precise; the focal point is where the rays converge.



# Formation of Images by Spherical Mirrors

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

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

[spherical mirror]

Spherical aberration can be avoided by using a parabolic reflector; these are more difficult and expensive to make, and so are used only when necessary, such as in research telescopes.

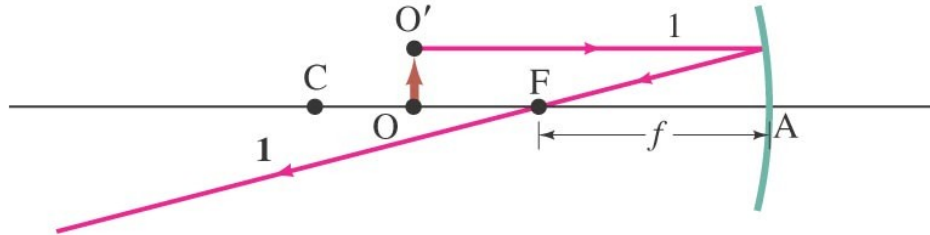
# Formation of Images by Spherical Mirrors

**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:**

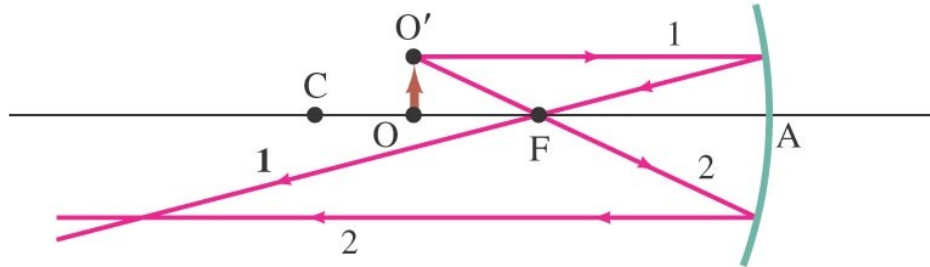
- 1. A ray parallel to the axis; after reflection it passes through the focal point.**
- 2. A ray through the focal point; after reflection it is parallel to the axis.**
- 3. A ray perpendicular to the mirror; it reflects back on itself.**

# Formation of Images by Spherical Mirrors

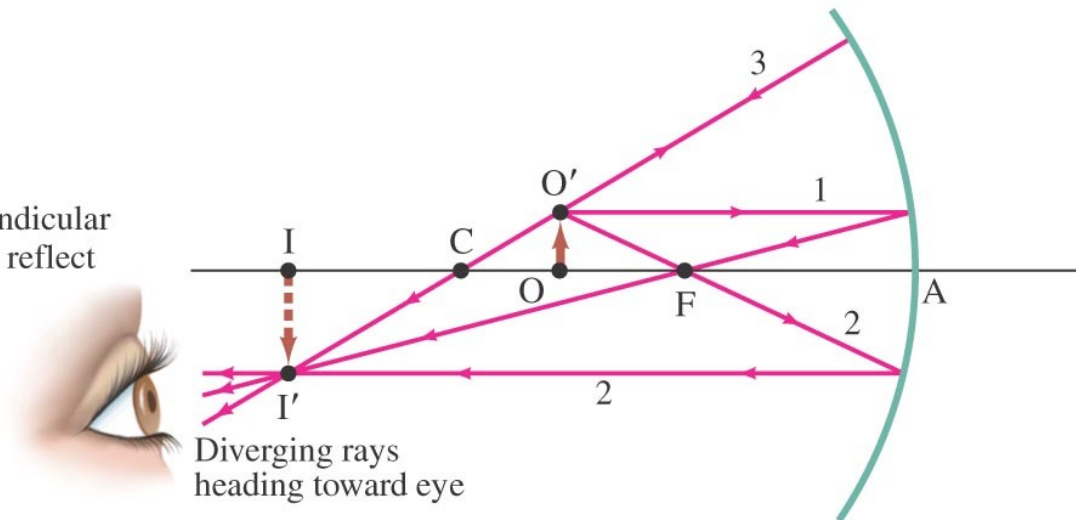
Ray 1 goes out from  $O'$  parallel to the axis and reflects through  $F$ .



Ray 2 goes through  $F$  and then reflects back parallel to the axis.



Ray 3 is chosen perpendicular to mirror, and so must reflect back on itself and go through  $C$  (center of curvature).



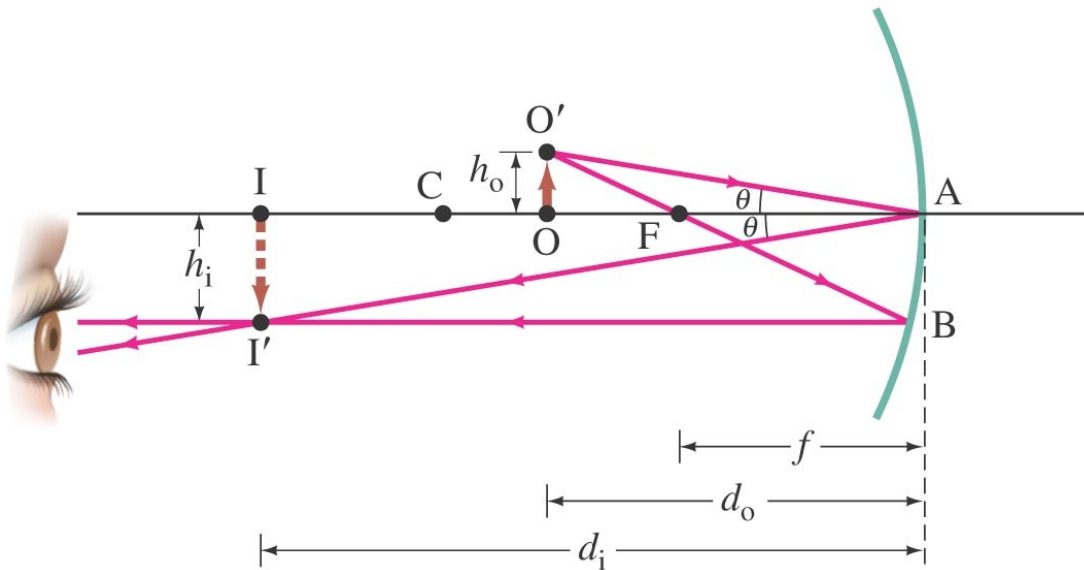
# Formation of Images by Spherical Mirrors

**The intersection of these three rays gives the position of the image of that point on the object.**

**Usually only two of these three rays are needed, the third can be used as a check.**

# Formation of Images by Spherical Mirrors

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



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

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

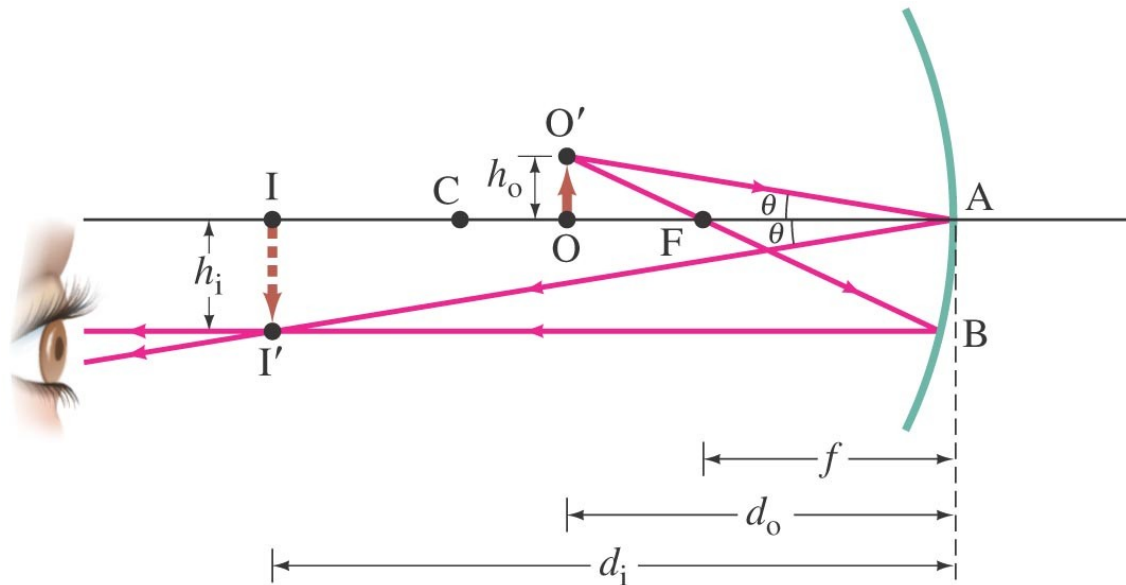
# Formation of Images by Spherical Mirrors

We can also find the magnification (ratio of image height to object height):

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

When the image is inverted,  $m$  will be negative.

In this case, the object is between the center of curvature and the focal point, and its image is larger, inverted, and real.

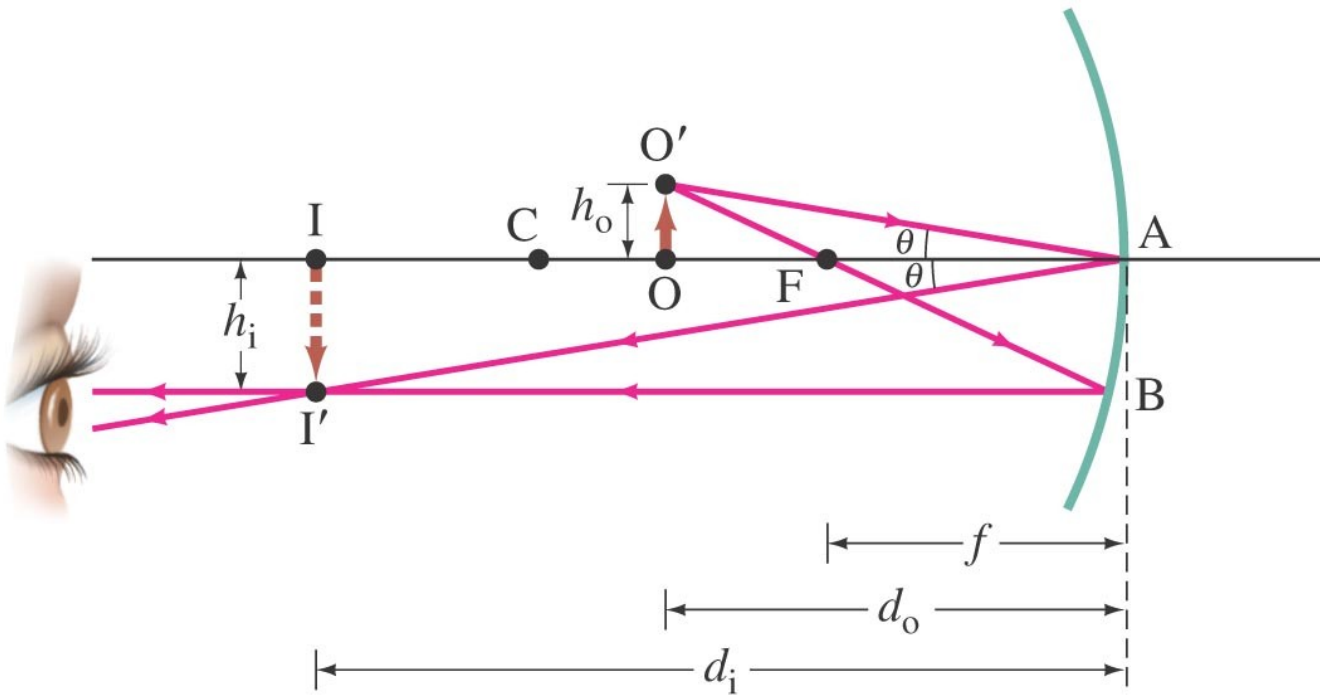


# Formation of Images by Spherical Mirrors

**Example: Image in a concave mirror.**

**A 1.50-cm-high diamond ring is placed 20.0 cm from a concave mirror with radius of curvature 30.0 cm. Determine (a) the position of the image, and (b) its size.**





## Conceptual Example: Reversible rays.

If the object in this figure is placed where the image is, where will the new image be?

Are light rays reversible?

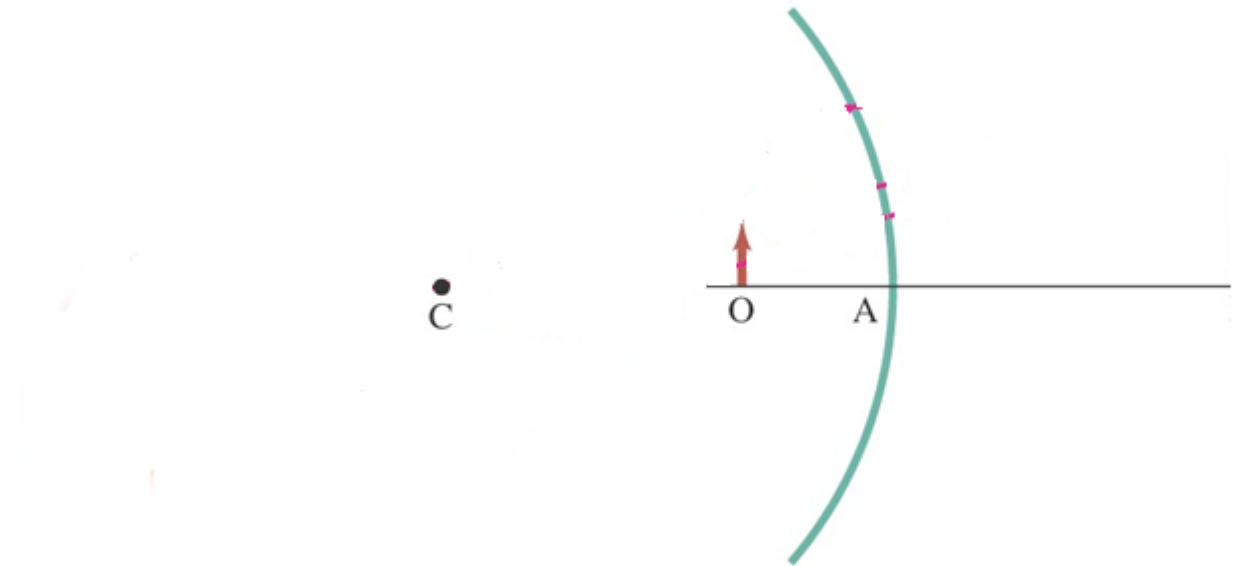
A) Yes.

B) No.

# Formation of Images by Spherical Mirrors

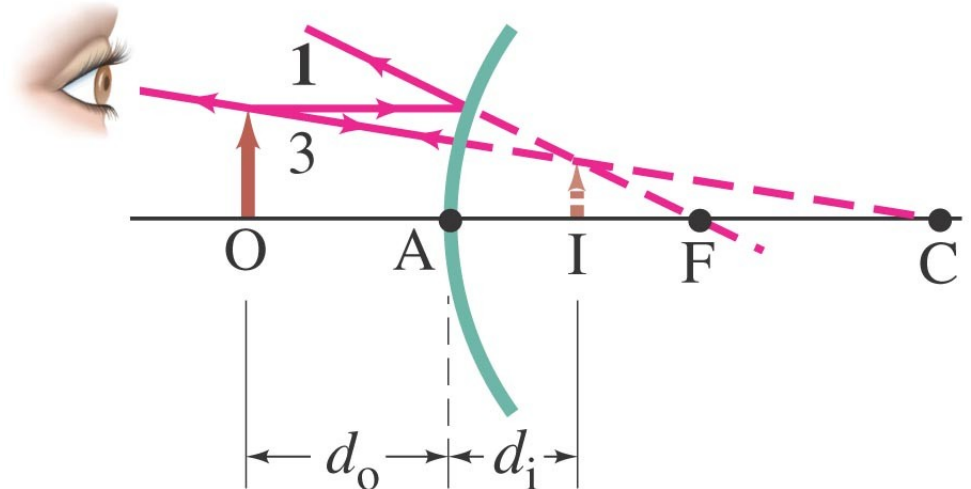
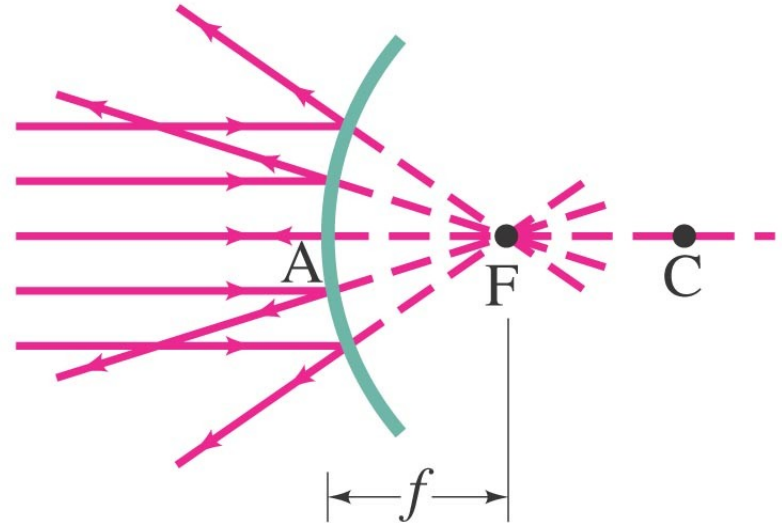
**Example: Object closer to concave mirror.**

**A 1.00-cm-high object is placed 10.0 cm from a concave mirror whose radius of curvature is 30.0 cm. (a) Draw a ray diagram to locate (approximately) the position of the image. (b) Determine the position of the image and the magnification analytically.**



# Formation of Images by Spherical Mirrors

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



# 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.

# Formation of Images by Spherical Mirrors

**Example: Convex rearview mirror.**

**An external rearview car mirror is convex with a radius of curvature of 16.0 m. Determine the location of the image and its magnification for an object 10.0 m from the mirror.**



# 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:

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

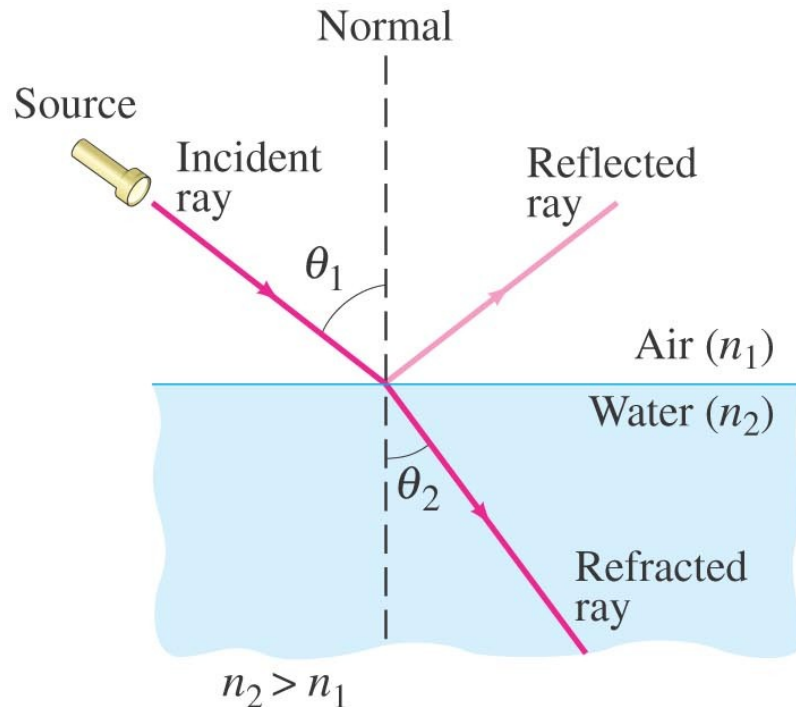
**TABLE 32–1 Indices of Refraction<sup>†</sup>**

Material	$n = \frac{c}{v}$
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 flin	.58
Lucite or Plexiglas	1.51
Sodium chloride	1.53
Diamond	2.42

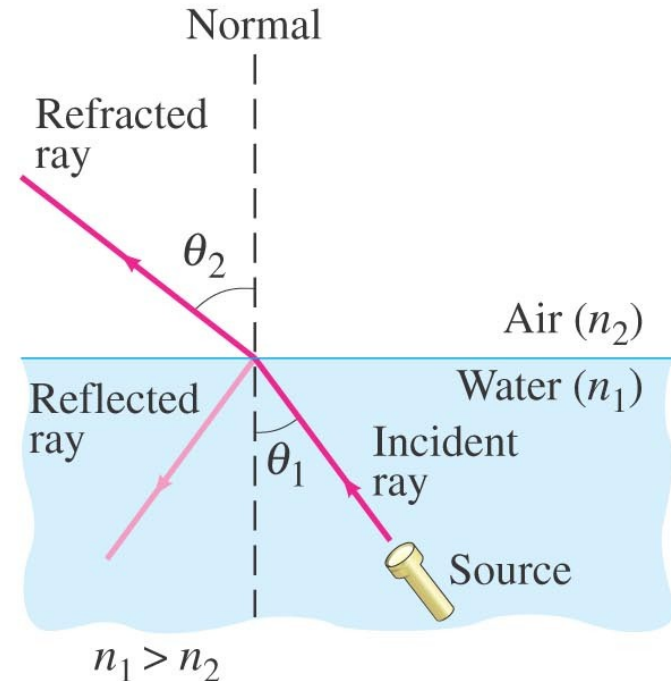
<sup>†</sup>  $\lambda = 589 \text{ nm}$ .

# Refraction: Snell's Law

Light changes direction when crossing a boundary from one medium to another. This is called refraction, and the angle the outgoing ray makes with the normal is called the angle of refraction.



(a) Ray bends toward  $\perp$

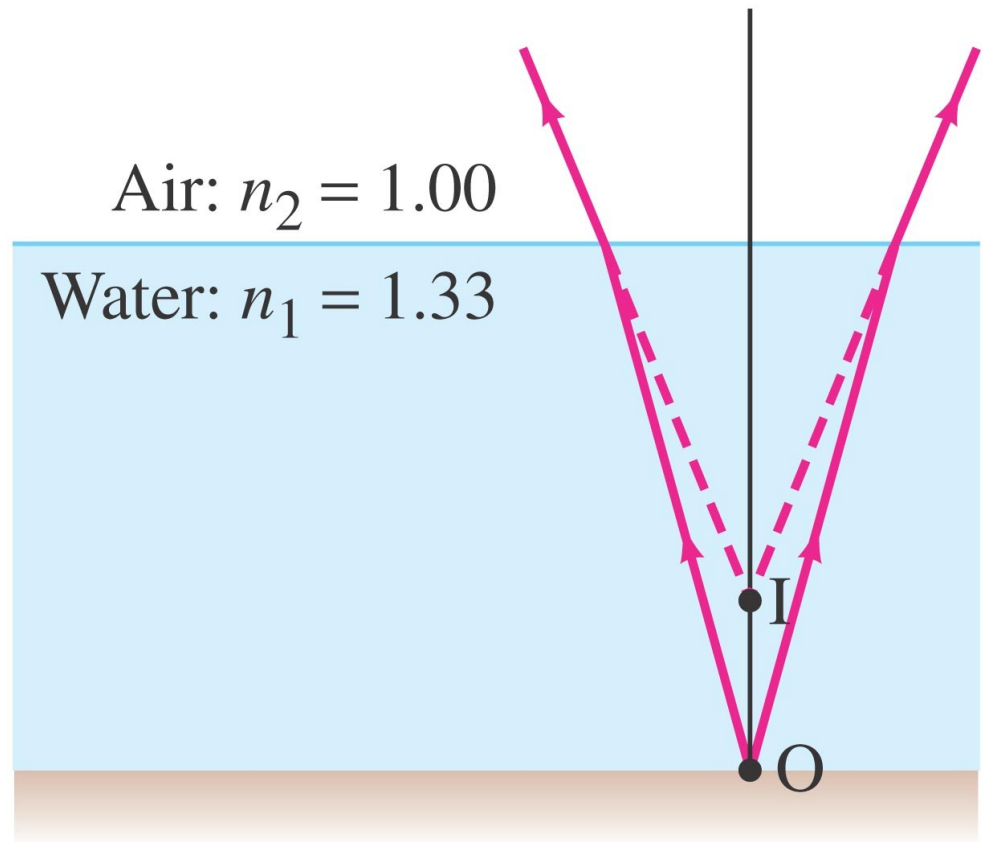


(b) Ray bends away from  $\perp$

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

## Example 32-9: Apparent depth of a pool.

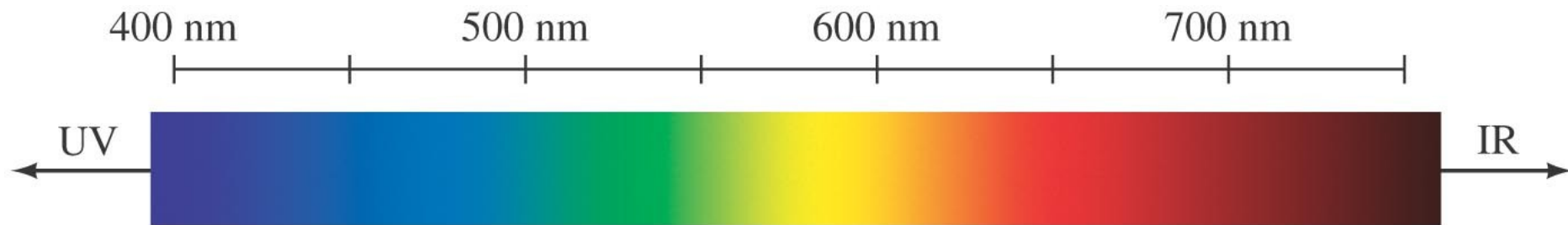
A swimmer has dropped her goggles to the bottom of a pool at the shallow end, marked as 1.0 m deep. But the goggles don't look that deep. Why? How deep do the goggles appear to be when you look straight down into the water?





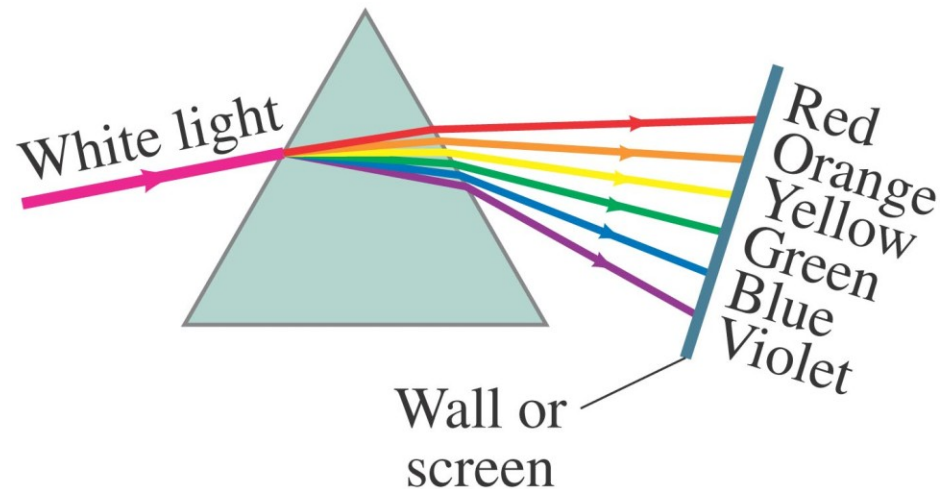
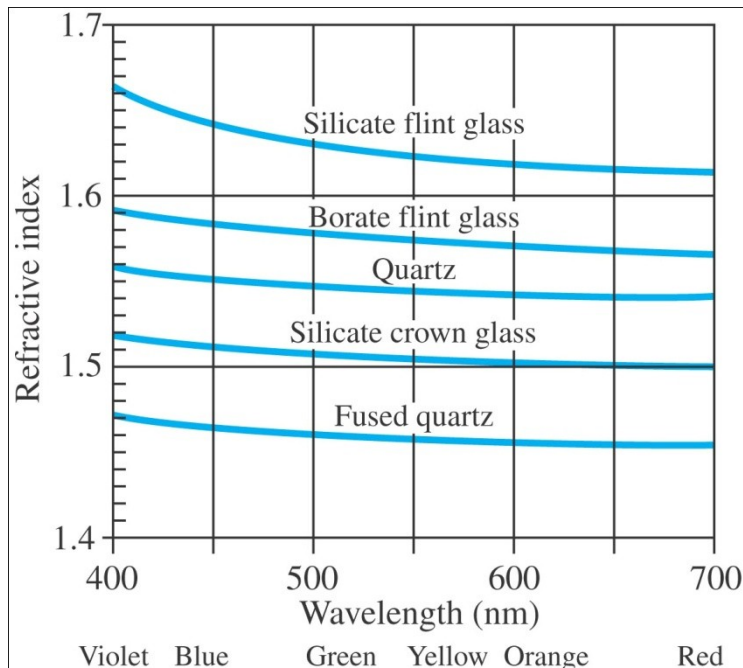
# Visible Spectrum and Dispersion

The visible spectrum contains the full range of wavelengths of light that are visible to the human eye.



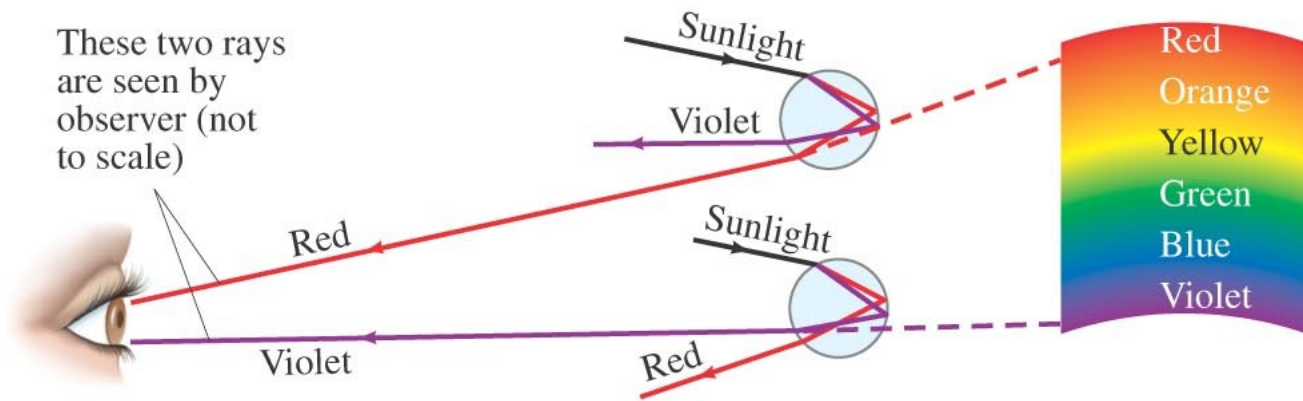
# Visible Spectrum and Dispersion

The index of refraction of many transparent materials, such as glass and water, varies slightly with wavelength. This is how prisms and water droplets create rainbows from sunlight.



# Visible Spectrum and Dispersion

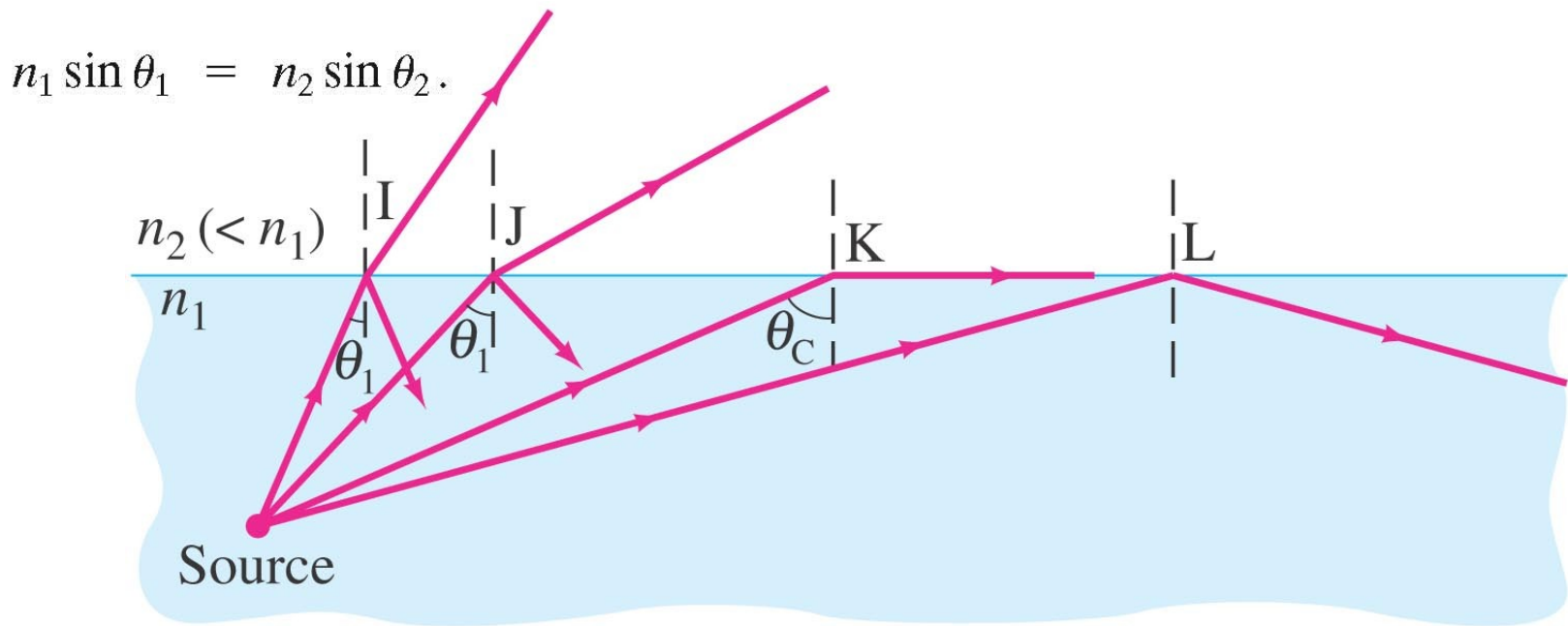
This spreading of light into the full spectrum is called dispersion.



# 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  $90^\circ$ ; this is called the critical angle:

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



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

# Total Internal Reflection; Fiber Optics

Optical fibers also depend on total internal reflection; they are therefore able to transmit light signals with very small losses.

