

PHYSICS 1442-003

Fall 2011

Lecture 19

MIRRORS AND LENSES

# Notation for Lenses

- The *object distance* is the distance from the object to the lens
  - Denoted by  $p$
- The *image distance* is the distance from the image to the lens
  - Denoted by  $q$
- The *lateral magnification* of the lens is the ratio of the image height to the object height
  - Denoted by  $M$

# Types of Images for Lenses

- A *real image* is one in which light actually passes through the image point
  - Real images can be displayed on screens
- A *virtual image* is one in which the light does not pass through the image point
  - The light appears to diverge from that point
  - Virtual images cannot be displayed on screens

# More About Images

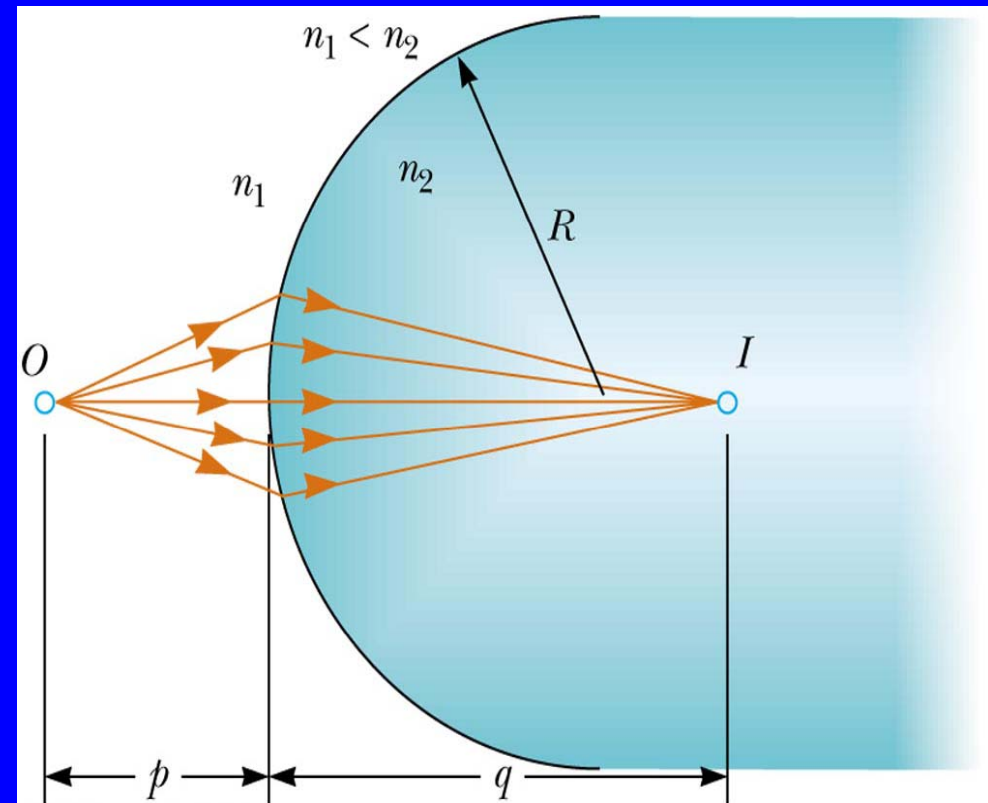
- To find where an image is formed, it is always necessary to follow at least two rays of light as they pass through the lens

# Images Formed by Refraction

- Rays originate from the object point,  $O$ , and pass through the image point,  $I$
- When  $n_2 > n_1$ ,

$$M = \frac{h'}{h} = -\frac{n_1 q}{n_2 p}$$

- Real images are formed on the side opposite from the object

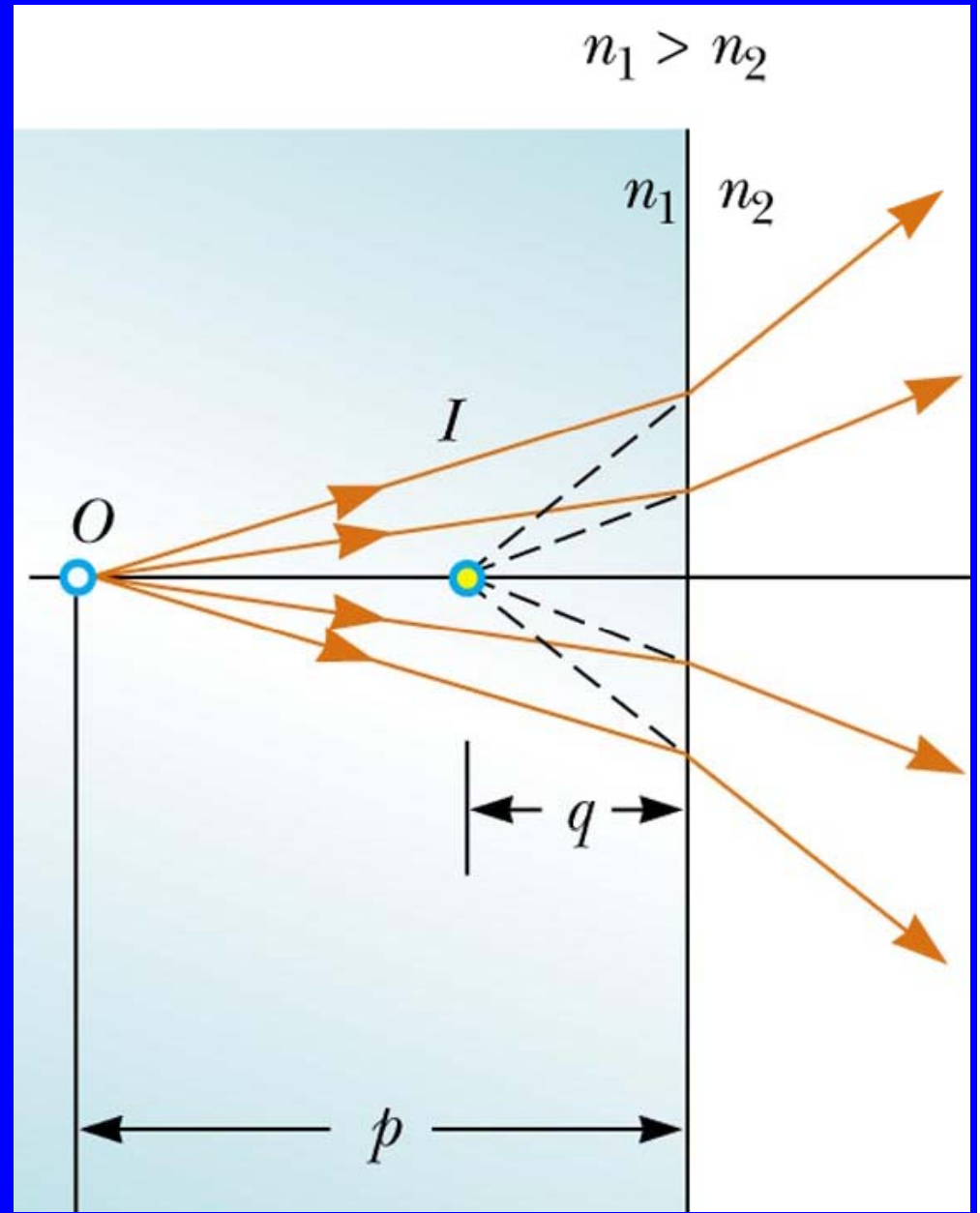


# Sign Conventions for Refracting Surfaces

<i>Quantity</i>	<i>Positive When</i>	<i>Negative When</i>
Object location ( $p$ )	Object is in front of surface	Object is in back of surface
Image location ( $q$ )	Image is in back of surface	Image is in front of surface
Image height ( $h'$ )	Image is upright	Image is inverted
Radius ( $R$ )	Center of curvature is in back of surface	Center of curvature is in front of surface

# Flat Refracting Surface

- The image formed by a flat refracting surface is on the *same* side of the surface as the object
  - The image is *virtual*
  - The image forms between the object and the surface
  - The rays bend away from the normal since  $n_1 > n_2$



## QUICK QUIZ 2

A person spear fishing from a boat sees a fish located 3 m from the boat at an apparent depth of 1 m. To spear the fish, should the person aim (a) at, (b) above, or (c) below the image of the fish?

# QUICK QUIZ 2 ANSWER

(c). Since  $n_{water} > n_{air}$ , the virtual image of the fish formed by refraction at the flat water surface is closer to the surface than is the fish.

## QUICK QUIZ 3

True or false? (a) The image of an object placed in front of a concave mirror is always upright. (b) The height of the image of an object placed in front of a concave mirror must be smaller than or equal to the height of the object. (c) The image of an object placed in front of a convex mirror is always upright and smaller than the object.

# QUICK QUIZ 3 ANSWER

(a) False. A concave mirror forms an inverted image when the object distance is greater than the focal length.

(b) False. The magnitude of the magnification produced by a concave mirror is greater than 1 if the object distance is less than the radius of curvature.

(c) True

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# More About Images

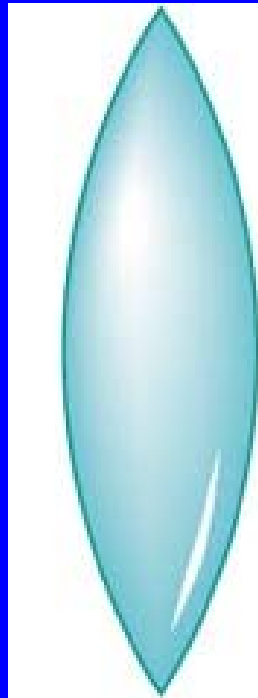
- To find where an image is formed, it is always necessary to follow at least two rays of light as they pass through the lens

# Thin Lenses

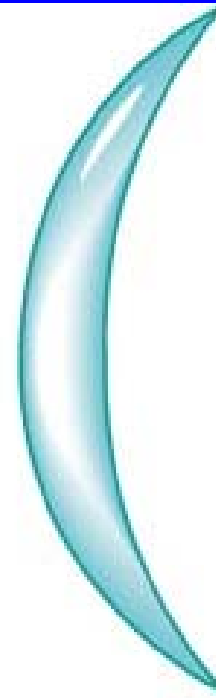
- A thin lens consists of a piece of glass or plastic, ground so that each of its two refracting surfaces is a segment of either a sphere or a plane
- Lenses are commonly used to form images by refraction in optical instruments

# Thin Lens Shapes

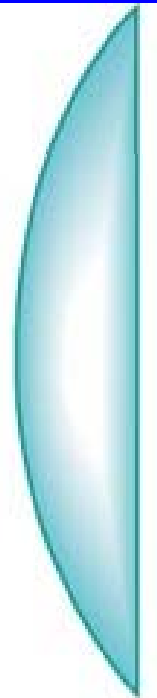
- These are examples of *converging* lenses
- They have positive focal lengths
- They are thickest in the middle



Biconvex

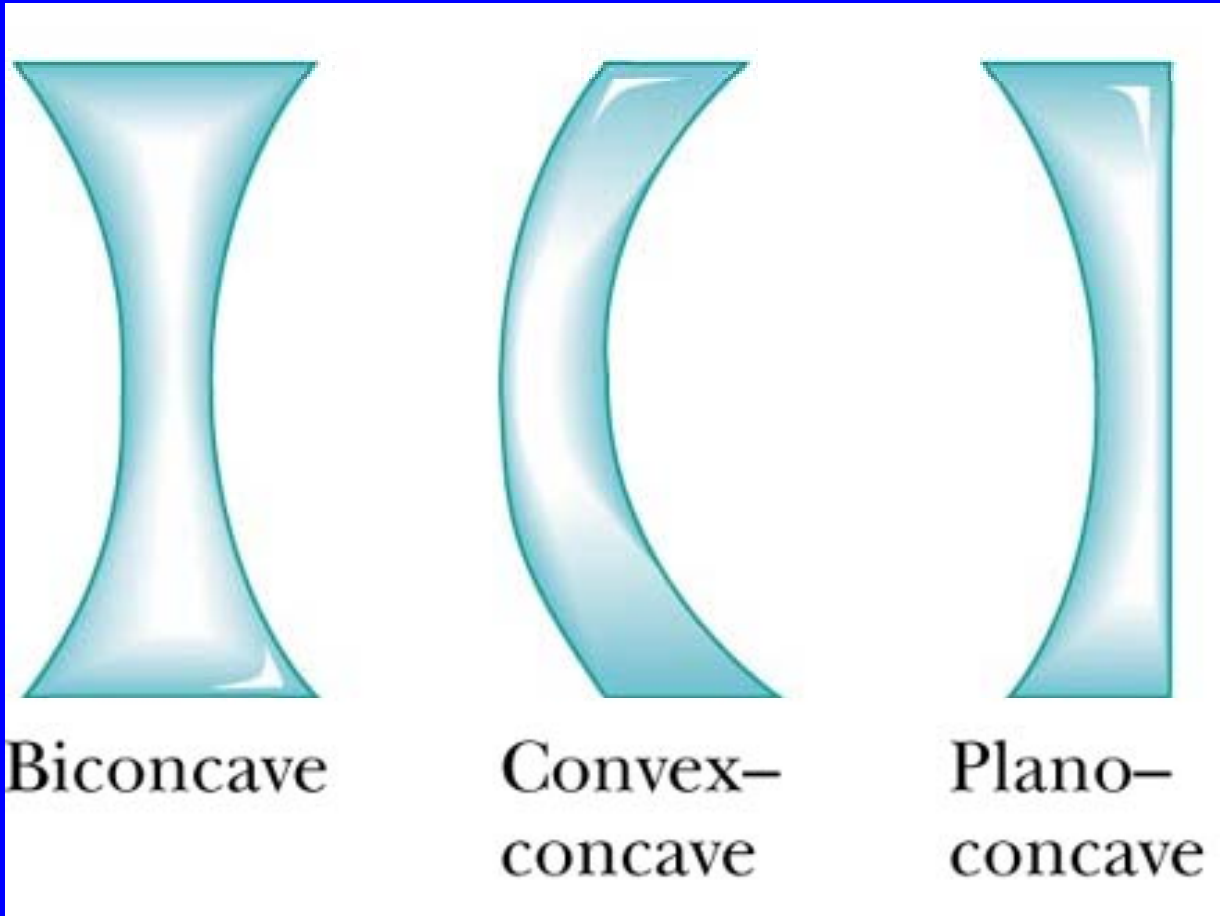


Convex-  
concave



Plano-  
convex

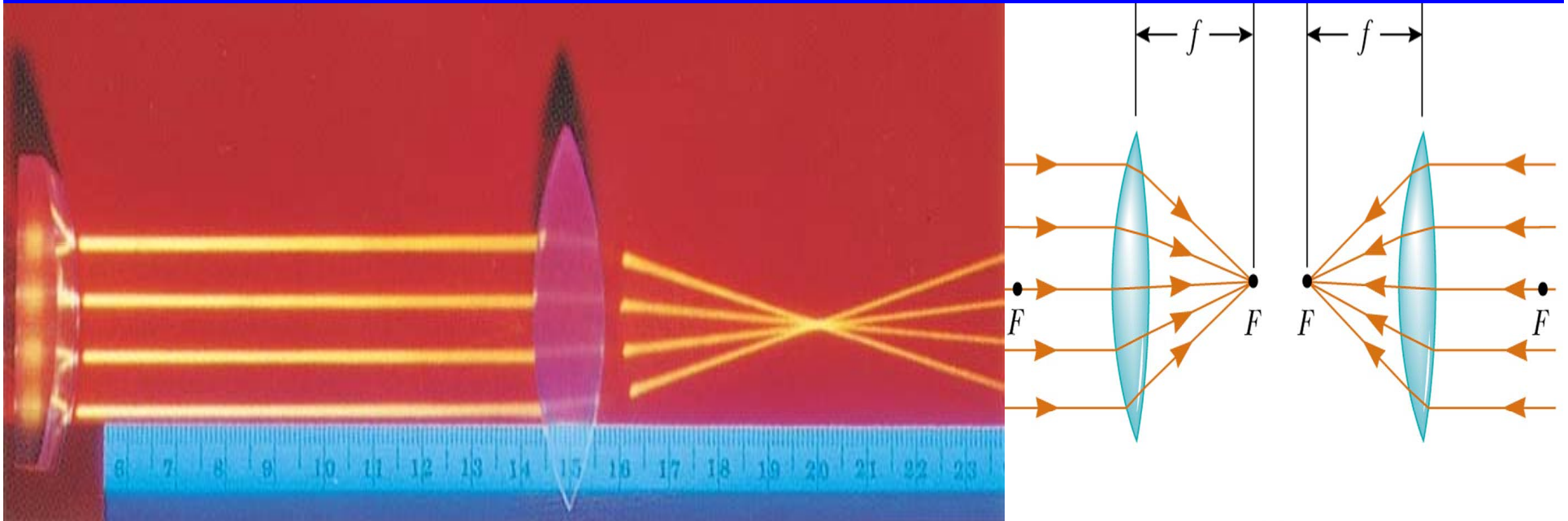
- These are examples of *diverging* lenses
- They have negative focal lengths
- They are thickest at the edges



# Focal Length of Lenses

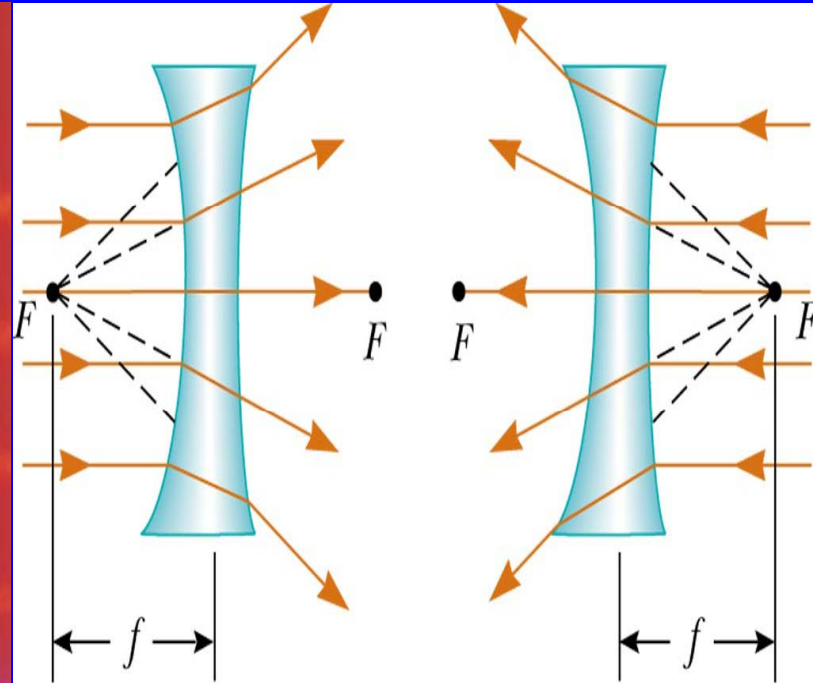
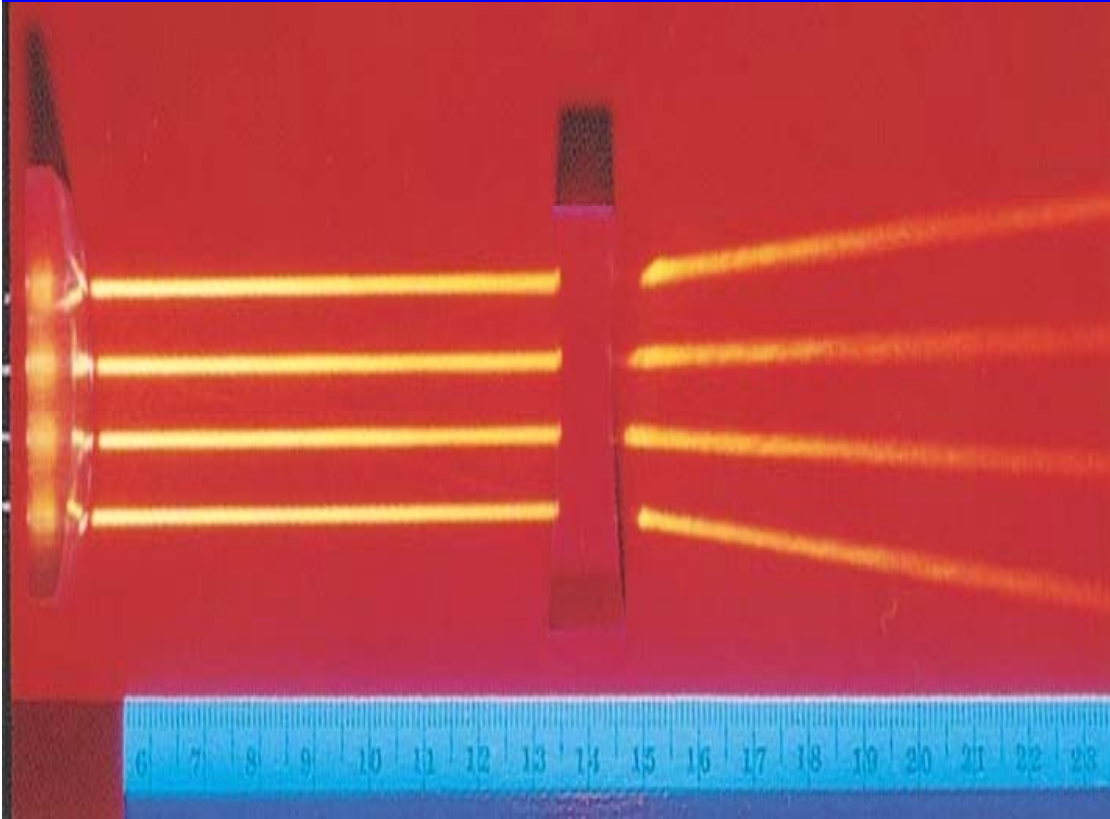
- The focal length,  $f$ , is the image distance that corresponds to an infinite object distance
  - This is the same as for mirrors
- A thin lens has two focal points, corresponding to parallel rays from the left and from the right
  - A thin lens is one in which the distance between the surface of the lens and the center of the lens is negligible

# Focal Length of a Converging Lens



- The parallel rays pass through the lens and converge at the focal point
- The parallel rays can come from the left or right of the lens

# Focal Length of a Diverging Lens

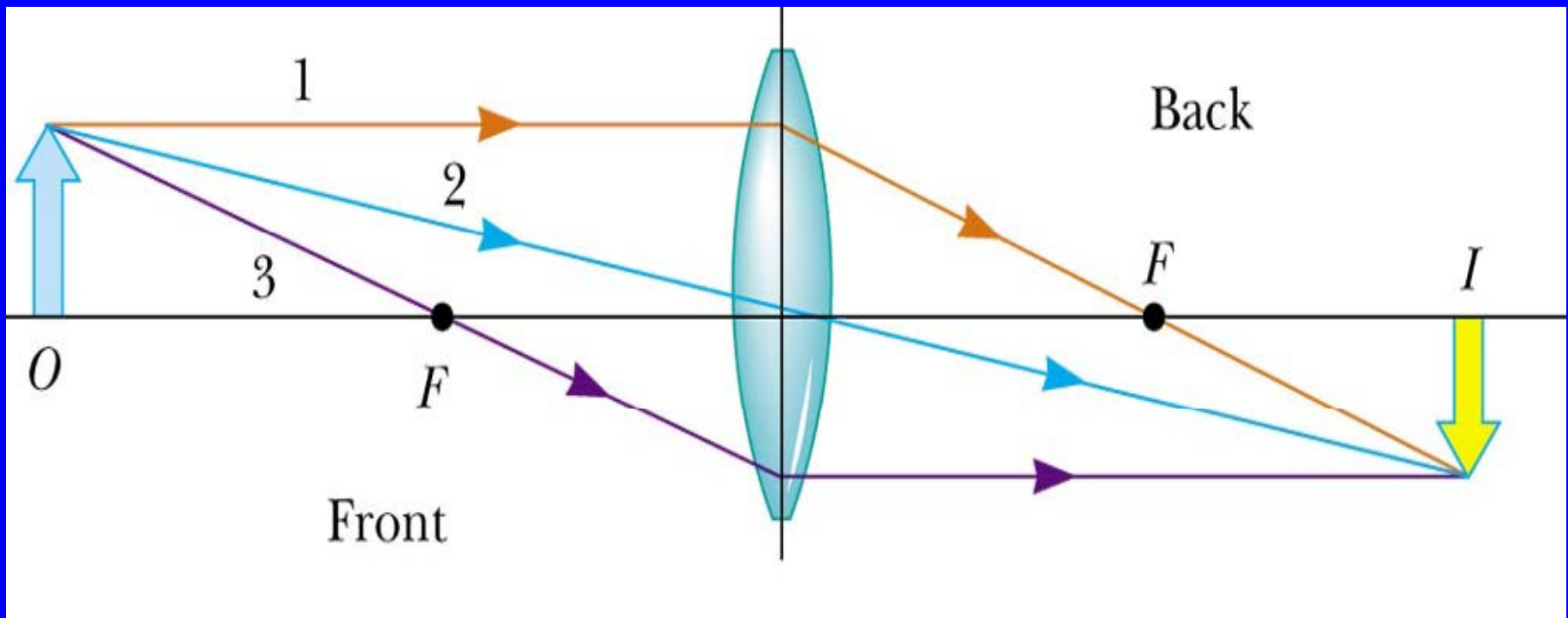


- The parallel rays diverge after passing through the diverging lens
- The focal point is the point where the rays appear to have originated

# Ray Diagrams for Thin Lenses

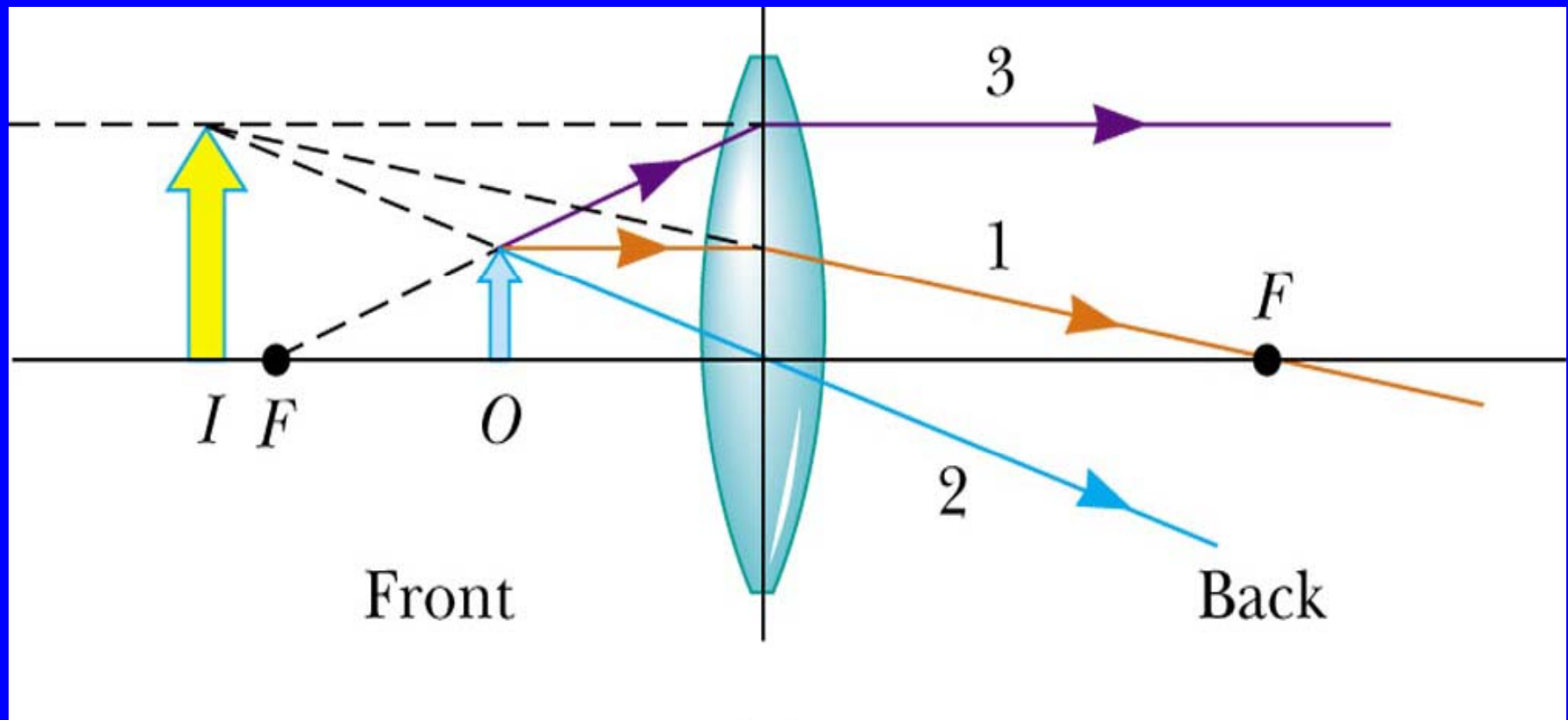
- Ray diagrams are essential for understanding the overall image formation
- Three rays are drawn
  - The first ray is drawn parallel to the first principle axis and then passes through (or appears to come from) one of the focal lengths
  - The second ray is drawn through the center of the lens and continues in a straight line
  - The third ray is drawn from the other focal point and emerges from the lens parallel to the principle axis
- There are an infinite number of rays, these are convenient

# Ray Diagram for Converging Lens, $p > f$



- The image is real
- The image is inverted

# Ray Diagram for Converging Lens, $p < f$



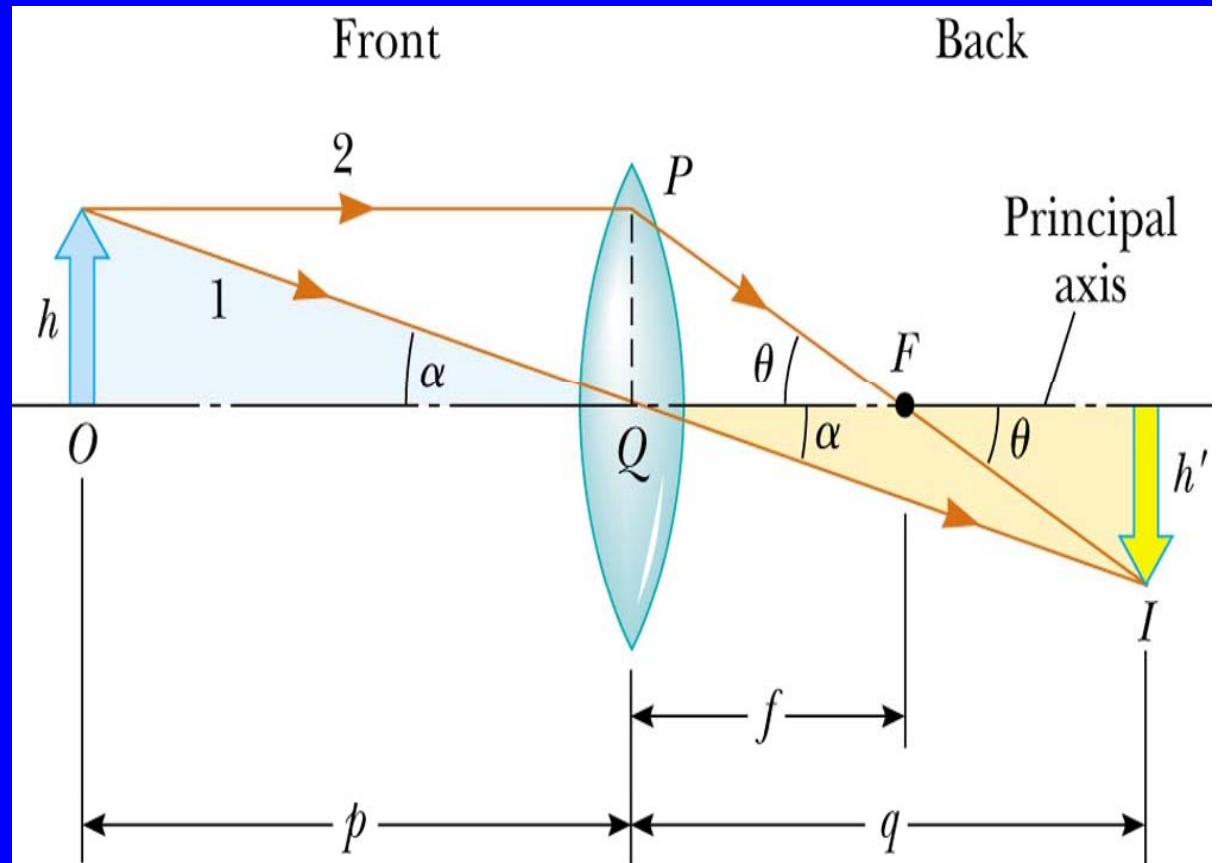
- The image is virtual
- The image is upright

# Lens Equations

- The geometric derivation of the equations is very similar to that of mirrors

$$M = \frac{h'}{h} = -\frac{q}{p}$$

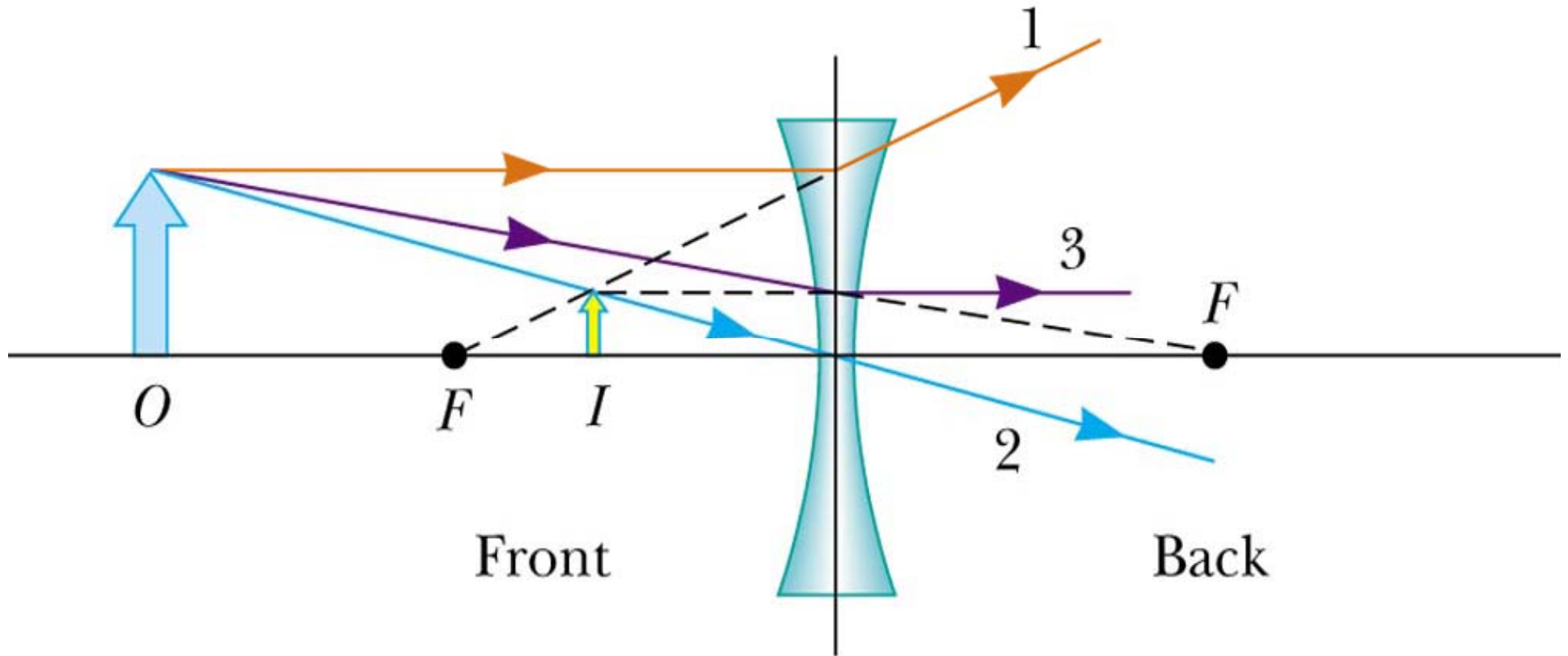
$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$



# Lens Equations

- The equations can be used for both converging and diverging lenses
  - A converging lens has a positive focal length
  - A diverging lens has a negative focal length

# Ray Diagram for Diverging Lens



- The image is virtual
- The image is upright

# Focal Length for a Lens

- The focal length of a lens is related to the curvature of its front and back surfaces and the index of refraction of the material

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

- This is called the *lens maker's equation*

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# Sign Conventions for Thin Lenses

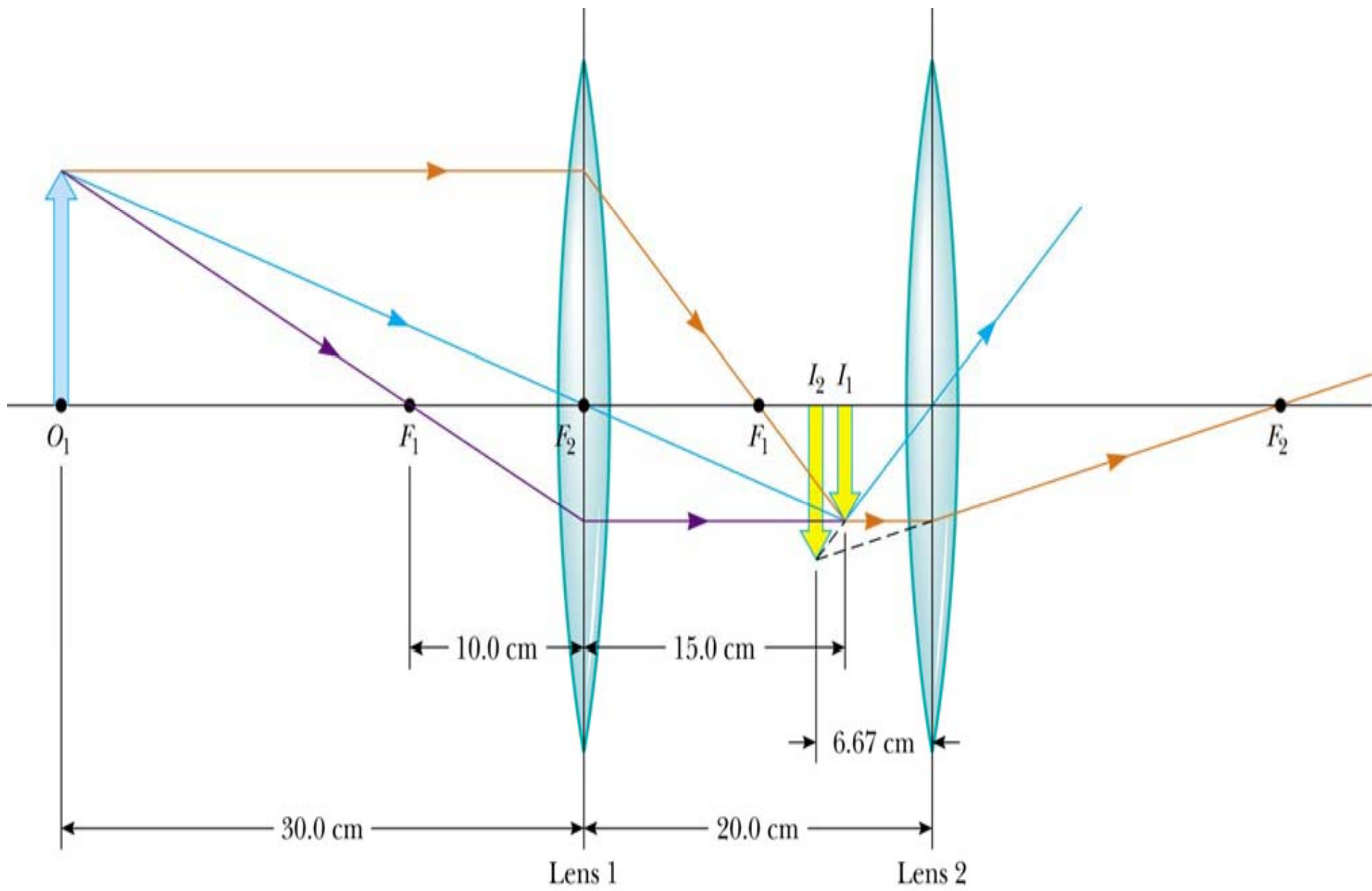
<i>Quantity</i>	<i>Positive When</i>	<i>Negative When</i>
Object location ( $p$ )	Object is in front of the lens	Object is in back of the lens
Image location ( $q$ )	Image is in back of the lens	Image is in front of the lens
Image height ( $h'$ )	Image is upright	Image is inverted
$R_1$ and $R_2$	Center of curvature is in back of the lens	Center of curvature is in front of the lens
Focal length ( $f$ )	Converging lens	Diverging lens

# Combinations of Thin Lenses

- The image produced by the first lens is calculated as though the second lens were not present
- The light then approaches the second lens as if it had come from the image of the first lens
- *The image of the first lens is treated as the object of the second lens*
- The image formed by the second lens is the final image of the system

# Combination of Thin Lenses

- If the image formed by the first lens lies on the back side of the second lens, then the image is treated as a *virtual object* for the second lens
  - $p$  will be negative
- The overall *magnification* is the product of the magnification of the separate lenses

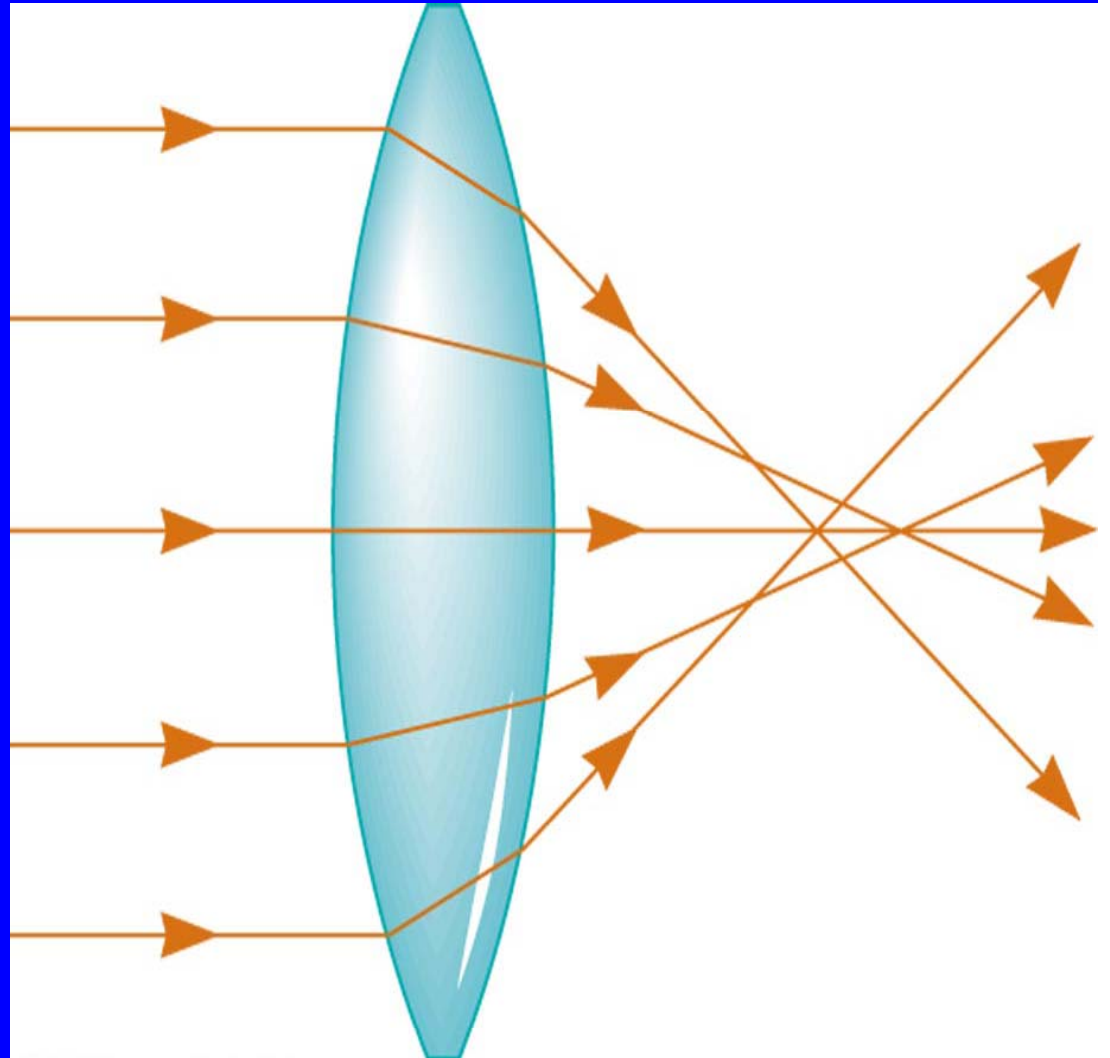


# Lens and Mirror Aberrations

- One of the basic problems is the imperfect quality of the images
  - Largely the result of defects in shape and form
- Two common types of aberrations exist
  - Spherical aberration
  - Chromatic aberration

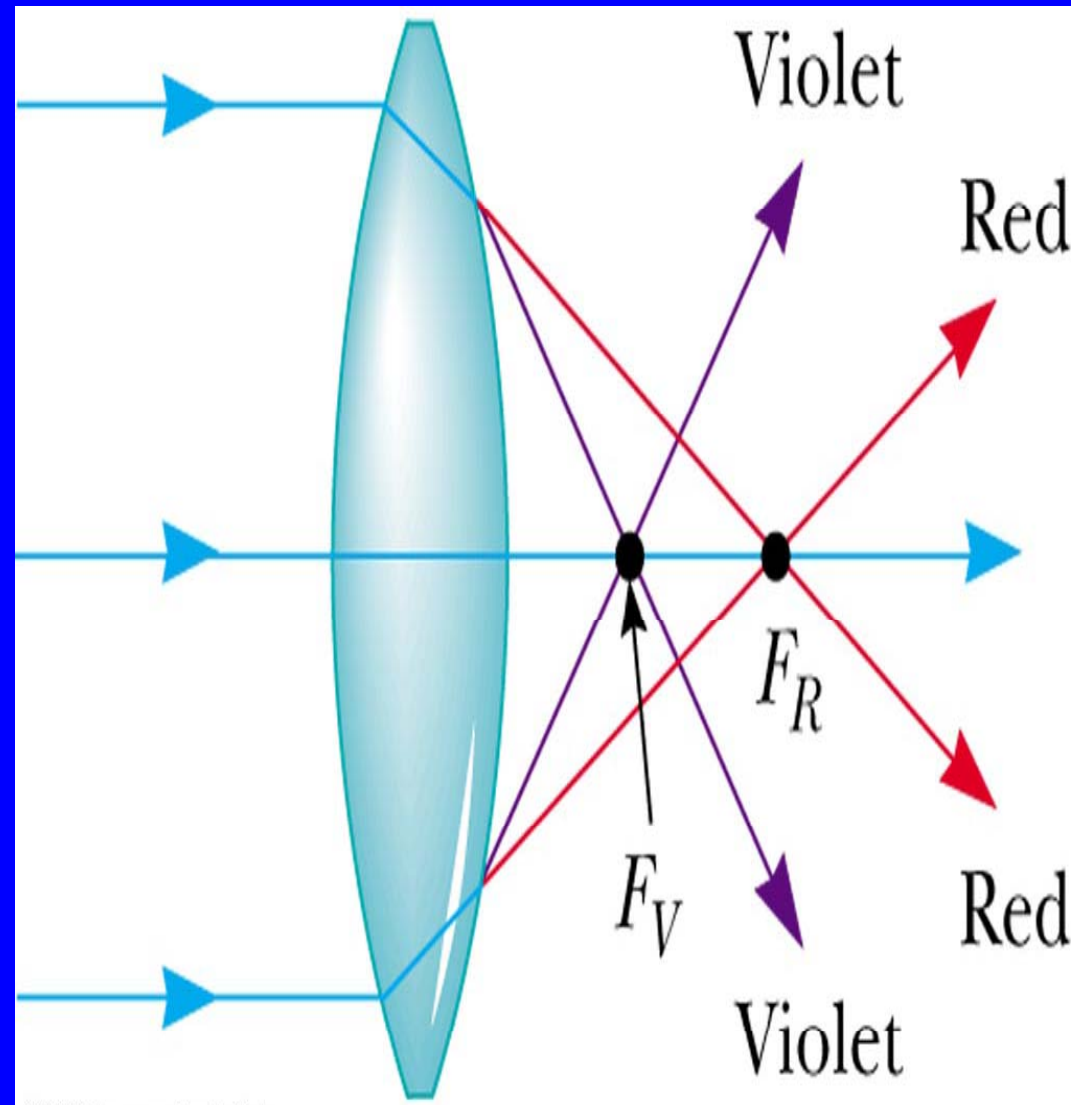
# Spherical Aberration

- Results from the focal points of light rays far from the principle axis are different from the focal points of rays passing near the axis
- For a mirror, parabolic shapes can be used to correct for spherical aberration



# Chromatic Aberration

- Different wavelengths of light refracted by a lens focus at different points
  - Violet rays are refracted more than red rays
  - The focal length for red light is greater than the focal length for violet light
- Chromatic aberration can be minimized by the use of a combination of converging and diverging lenses

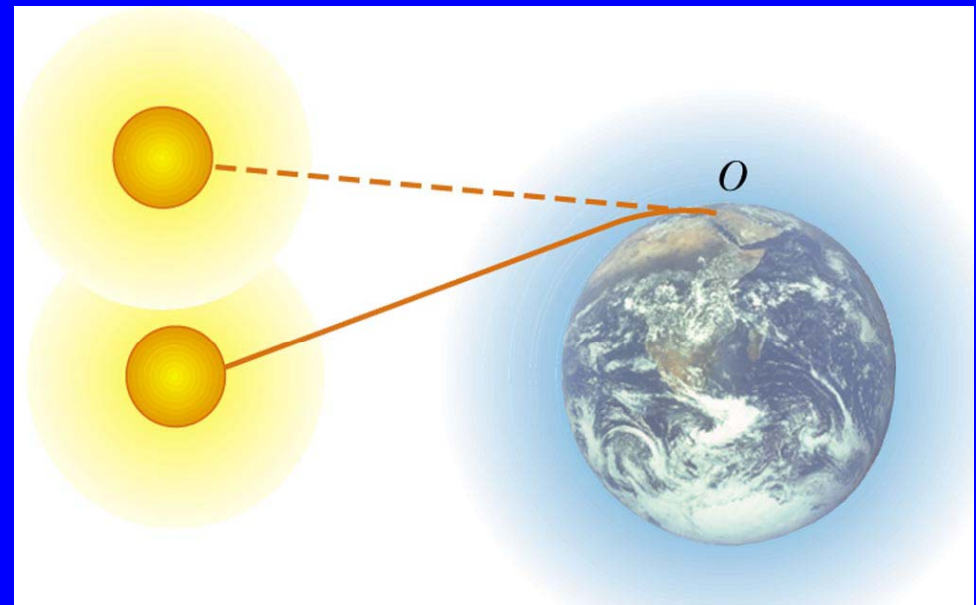


# Atmospheric Refraction

- There are many interesting results of refraction in the atmosphere
  - Sunsets
  - Mirages

# Atmospheric Refraction and Sunsets

- Light rays from the sun are bent as they pass into the atmosphere
- It is a gradual bend because the light passes through layers of the atmosphere
  - Each layer has a slightly different index of refraction
- The Sun is seen to be above the horizon even after it has fallen below it



# Atmospheric Refraction and Mirages

- A mirage can be observed when the air above the ground is warmer than the air at higher elevations
- The rays in path B are directed toward the ground and then bent by refraction
- The observer sees both an upright and an inverted image

