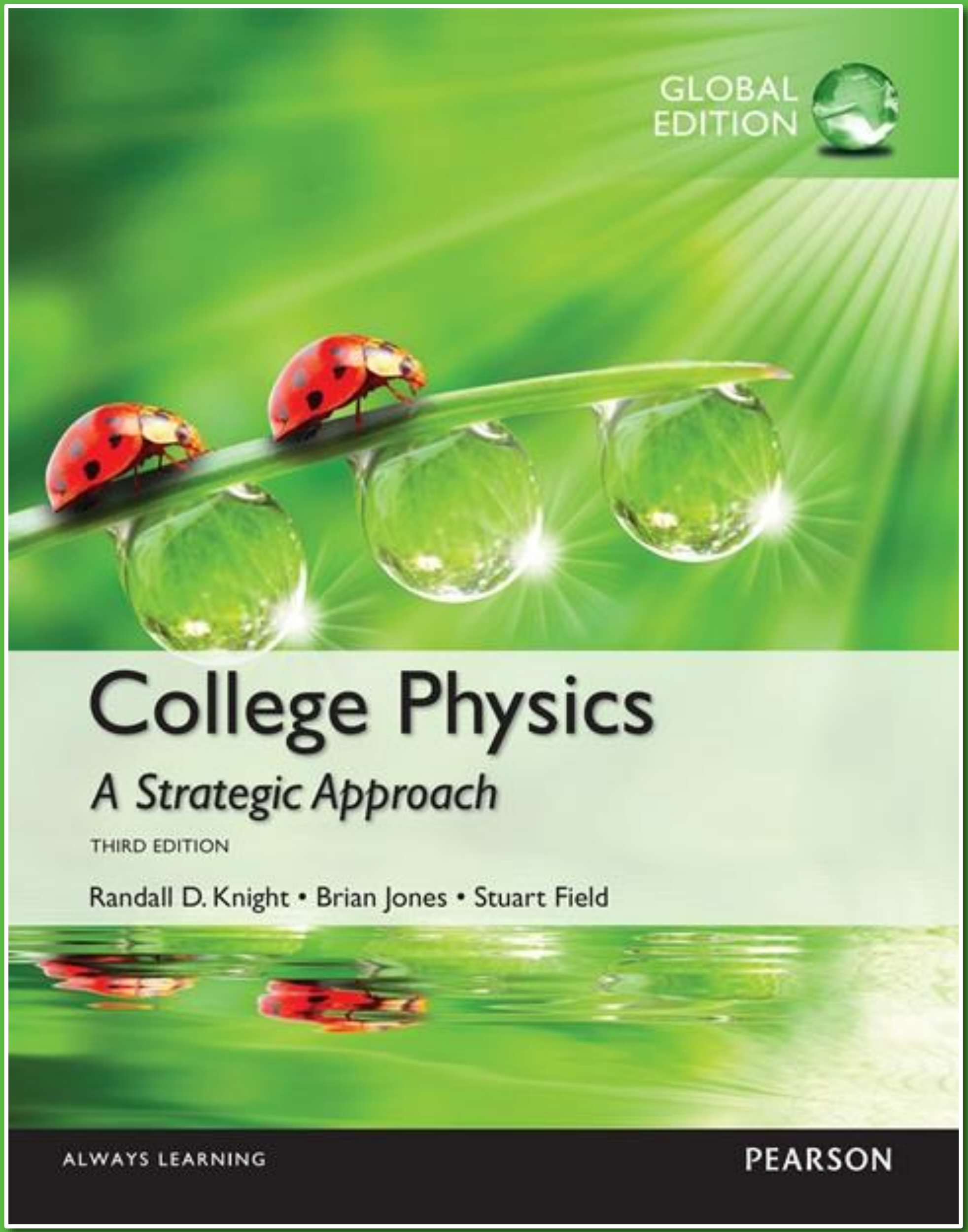


Lecture Presentation

Chapter 18

Ray Optics

Chapter 18 Ray Optics

Section 18.2 Reflection
Section 18.3 Refraction
Section 18.5 Thin Lenses: Ray Tracing
Section 18.7 The Thin-Lens Equation

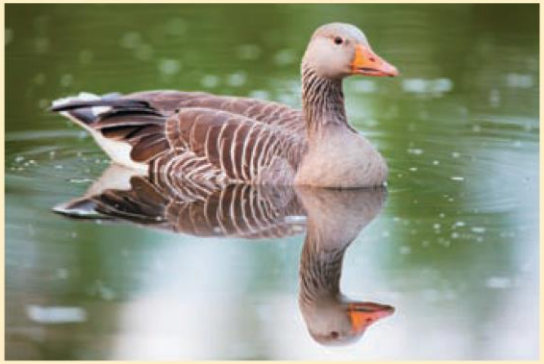
Chapter 18 Ray Optics

Chapter Goal: To understand and apply the ray model of light.

Chapter 18 Preview
Looking Ahead

Reflection

Light rays can bounce, or **reflect,** off a surface. Rays from the bird's head reflect from the water, forming an upside-down image.



You'll learn how the **law of reflection** can be used to understand image formation by mirrors.

Refraction

The two images of the turtle are due to **refraction,** the bending of light rays as they travel from one material into another.

You'll learn **Snell's law** for refraction and how images can be formed by refraction.

Lenses and Mirrors

Rays refracting at the surfaces of this lens form a magnified **image** of the girl behind it.

You'll learn how to locate and characterize the images formed by lenses and mirrors.

Optics

- In the ray model, the assumption is made that light moves along straight lines while travelling within a homogeneous medium.

- It may change its direction when reflected by and/or passing through an interface into another medium according to the laws of reflection and refraction derived from Huygens' principle.

Section 18.2 Reflection

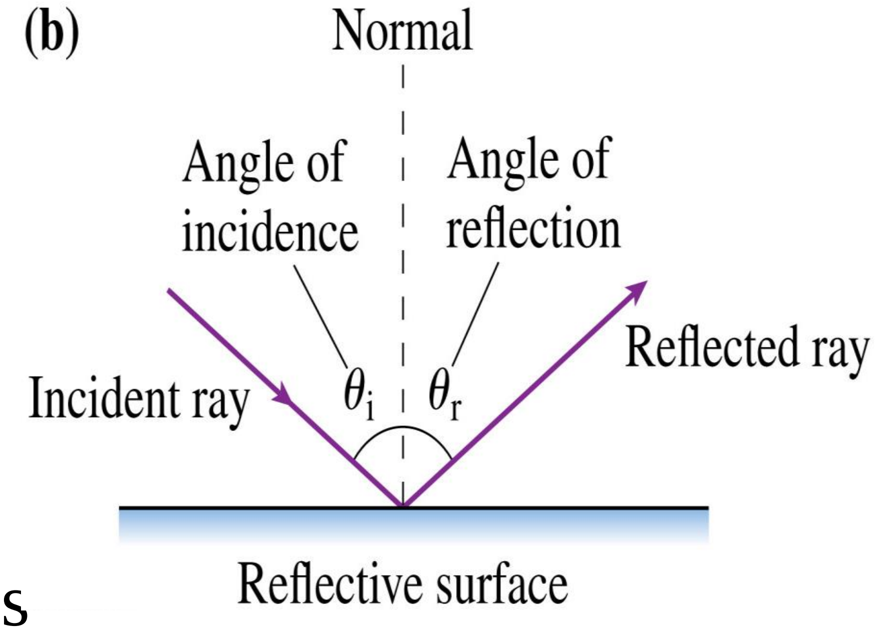
Reflection

The **law of reflection** states:

1. The incident ray and the reflected ray are both in the same plane.

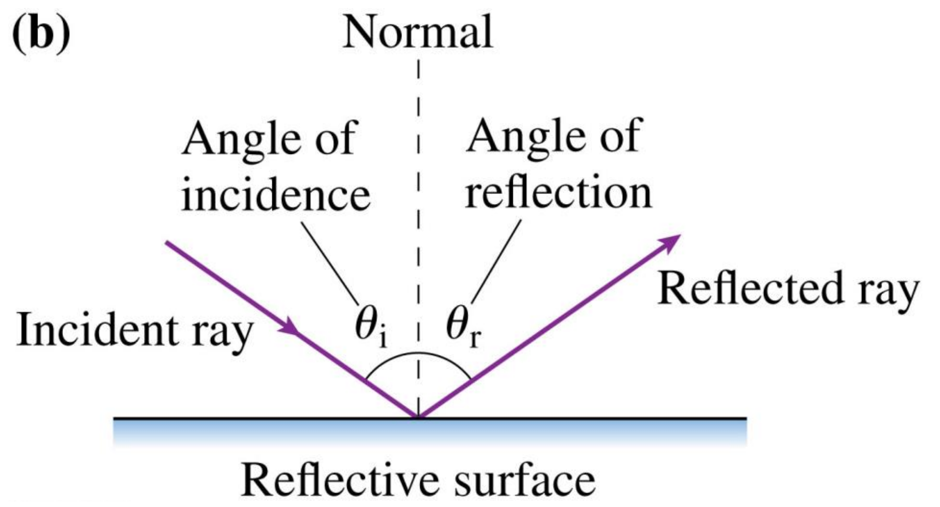
2. The angle of reflection equals the angle of incidence:

$$\theta_r = \theta_i$$



Reflection

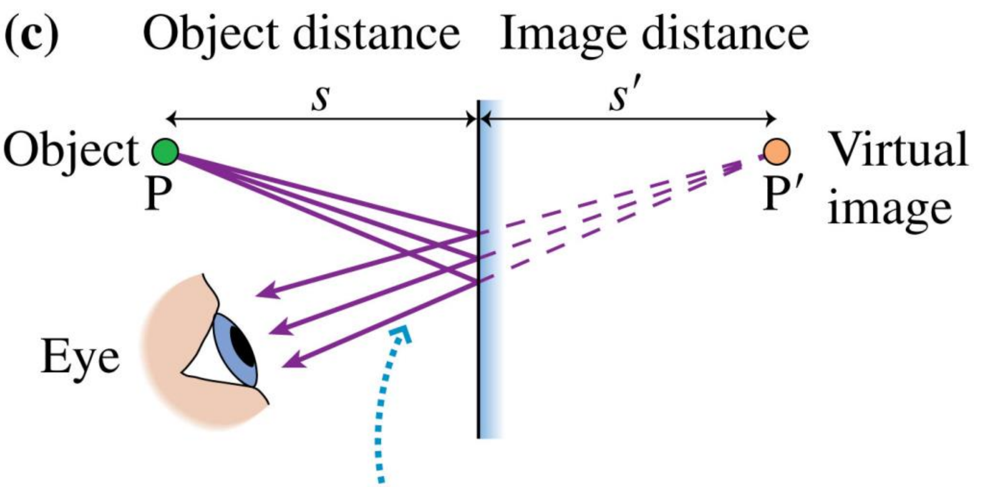
- The angle of incidence, θ_i, is the angle between the incident ray and the line perpendicular to the surface.
- The angle of reflection, θ_r, is the angle between the reflected ray and the normal to the surface.



The Plane (flat) Mirror

- Point P′, from which the reflected rays diverge, is called the virtual image of P.
- The image is virtual because no rays actually leave point P′
- The image distance s' is equal to the object distance s:

$$s' = s$$



The reflected rays *all* diverge from P′, which appears to be the source of the reflected rays. Your eye collects the bundle of diverging rays and "sees" the light coming from P′.

Section 18.3 Refraction

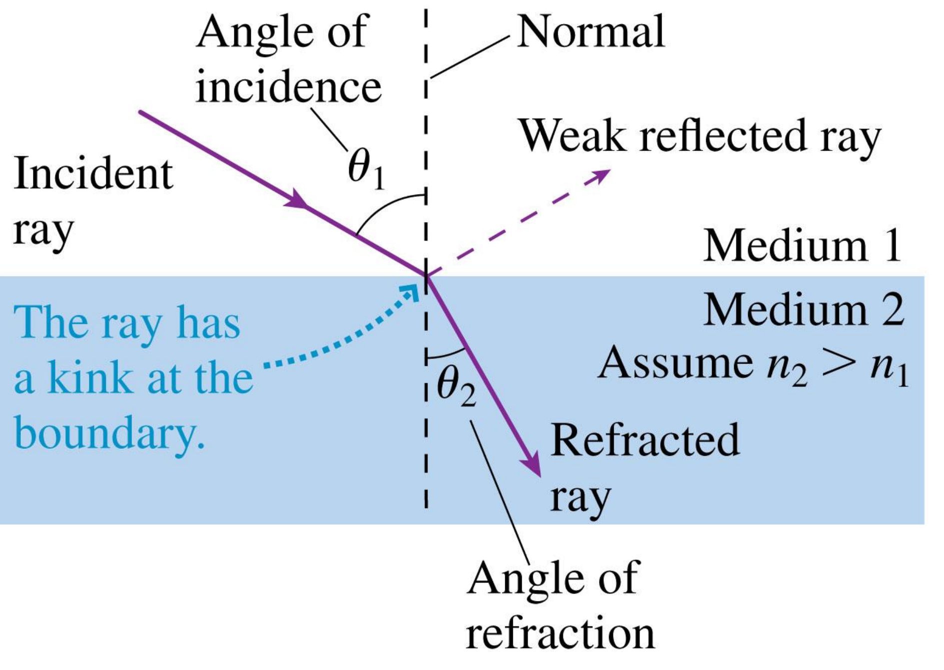
Refraction

- Refraction is the change in the direction of light when it crosses a boundary between two media.
- Occurs when the speed of light changes in different media.

- The angle between the incident ray and the normal is the angle of incidence.

- The angle on the transmitted side, measured from the normal, is called the **angle of refraction.**

(b) Refraction from lower-index medium to higher-index medium



Index of Refraction n

$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}} = \frac{c}{v}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

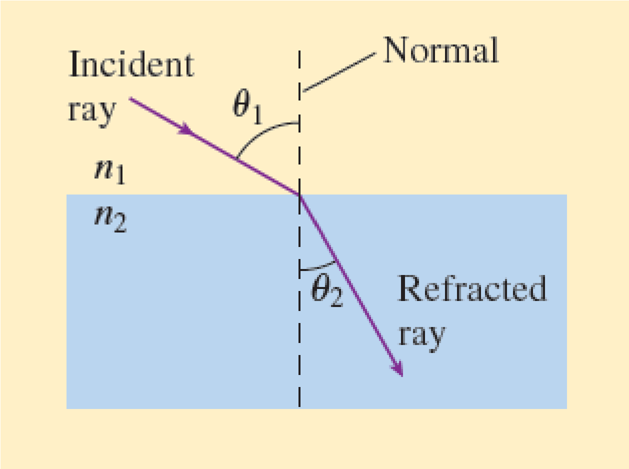
Medium	***n***
Vacuum	1 exactly
Air (actual)	1.0003
Air (accepted)*	1.00
Water	1.33
Ethyl alcohol	1.36
Oil	1.46
Glass (typical)	1.50
Polystyrene plastic	1.59
Cubic zirconia	2.18
Diamond	2.42
Silicon (infrared)	3.50

Refraction

The law of refraction:

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

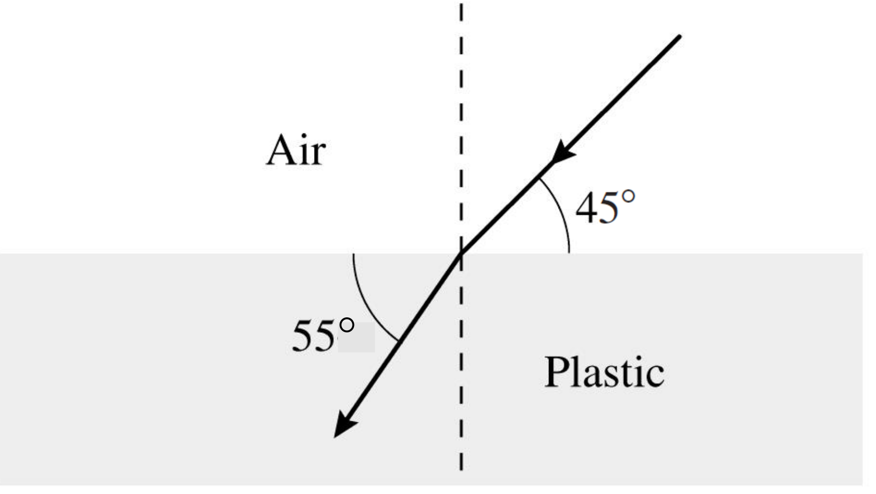
Snell's law for refraction between two media



- When a ray is transmitted into a material with a higher index of refraction, it bends to make a smaller angle with the normal.
- When a ray is transmitted into a material with a lower index of refraction, it bends to make a larger angle with the normal.

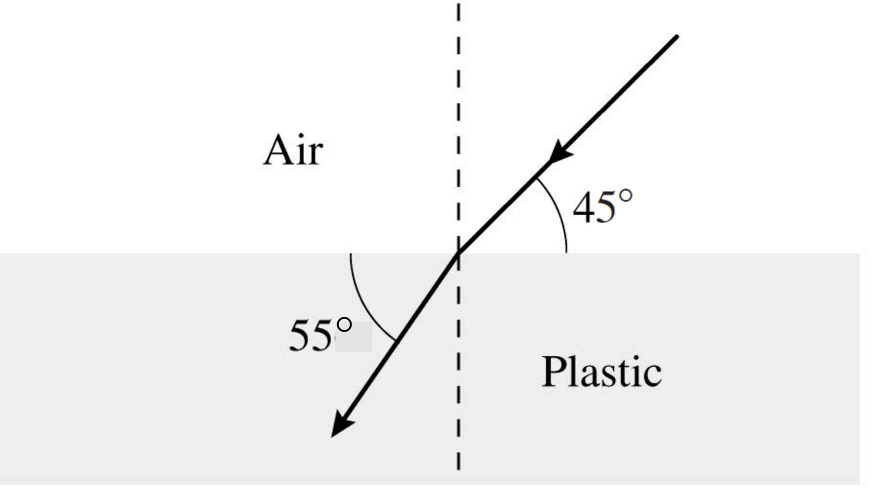
Example Problem

What is the index of refraction of the plastic if a ray is refracted as in the figure?



Example Problem

What is the index of refraction of the plastic if a ray is refracted as in the figure?



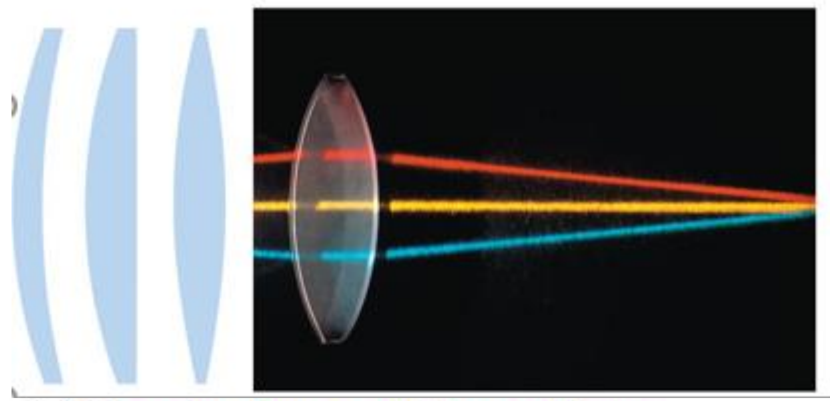
The angle of incidence (in air) is 45 degrees, and the angle of refractions is 35 degrees (90-55). Thus n_1*sin(45) = n_2*sin(35) where n_1 = 1 for air. so n_2 = sin(45)/sin(35) = 1.23.

Section 18.5 Thin Lenses: Ray Tracing

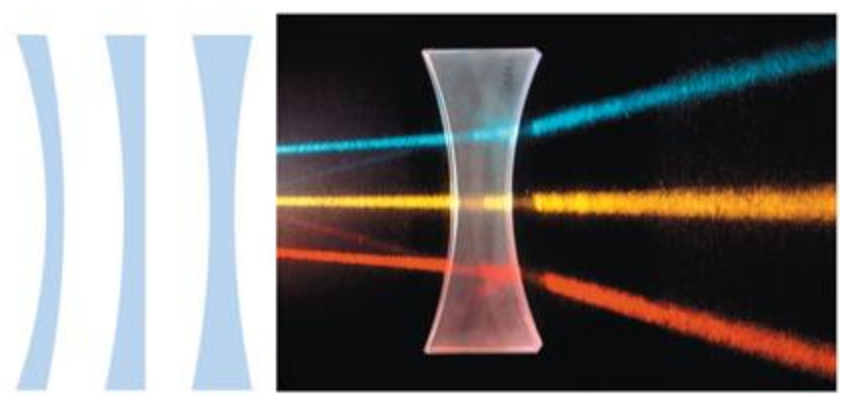
Thin Lenses:

- Lenses are usually used to converge or diverge the light rays.

(a) Converging lenses, which are thicker in the center than at the edges, refract parallel rays toward the optical axis.



(b) Diverging lenses, which are thinner in the center than at the edges, refract parallel rays away from the optical axis.



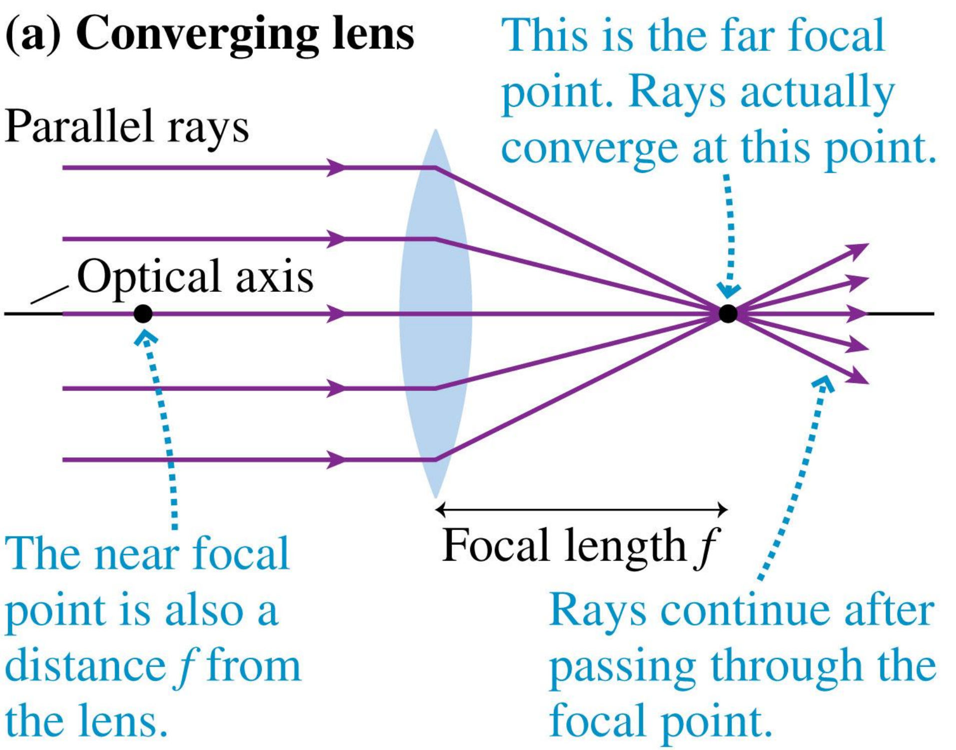
Lens classification:

- A <u>converging lens</u> refract the light rays toward its axis.

- A <u>diverging lens</u> refract the light rays outward from its axis.

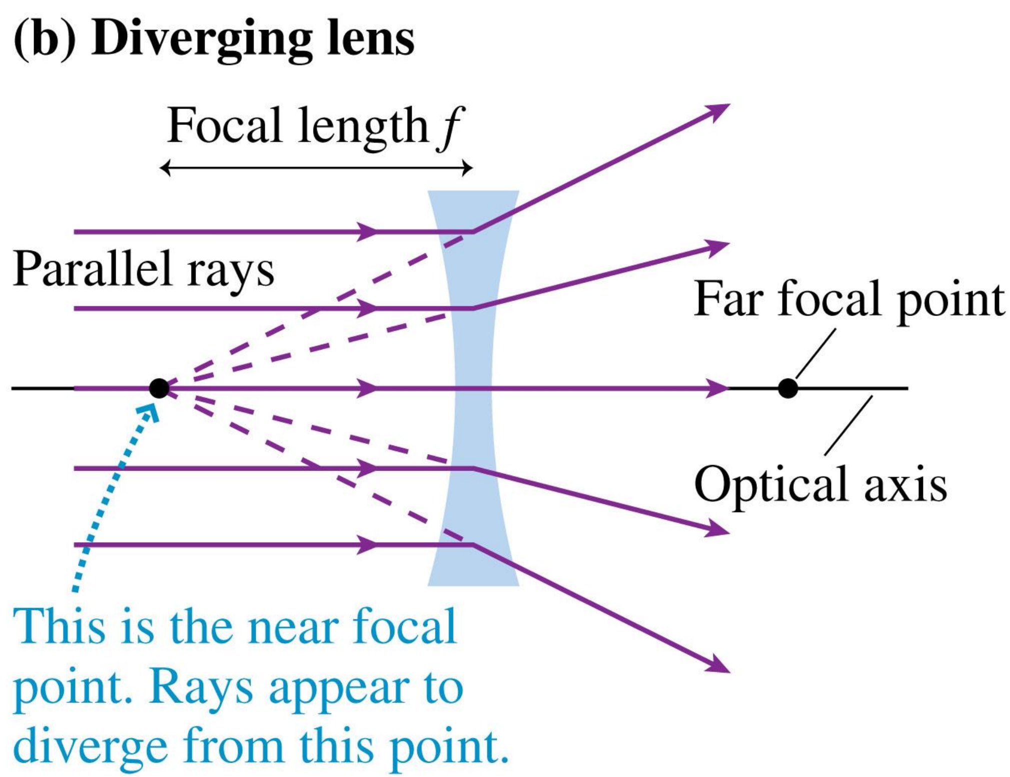
Lenses and Images

- Light rays that enter a converging lens parallel to its axis bend to meet at a point called the focal point.
- The distance from the center of the lens to the focal point is called the focal length.
- The optical axis usually gets through the center of the lens.



Lenses and Images

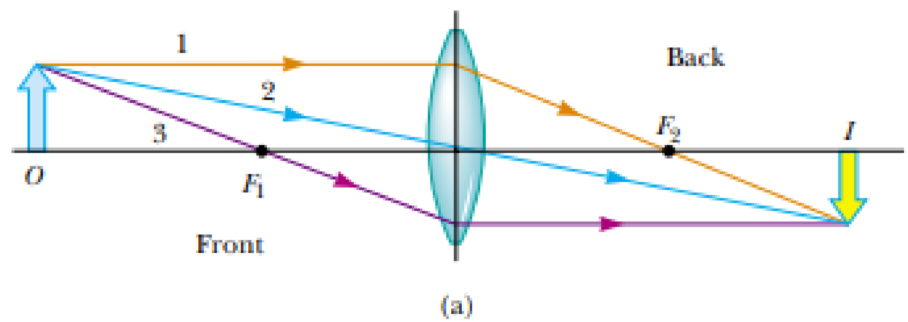
- For a diverging lens, the focal length is the distance from the lens to the point at which rays parallel to the optical axis converge or from which they appear to diverge.



The image formed by a lens

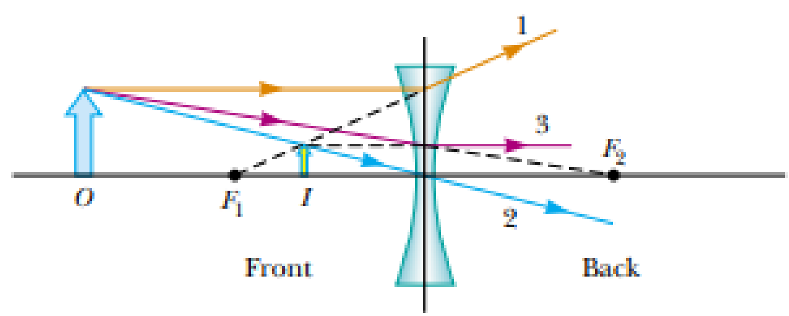
Real Image: Image is made from "real" light rays that converge at a real focal point so the image is REAL.

It is an **inverted image**



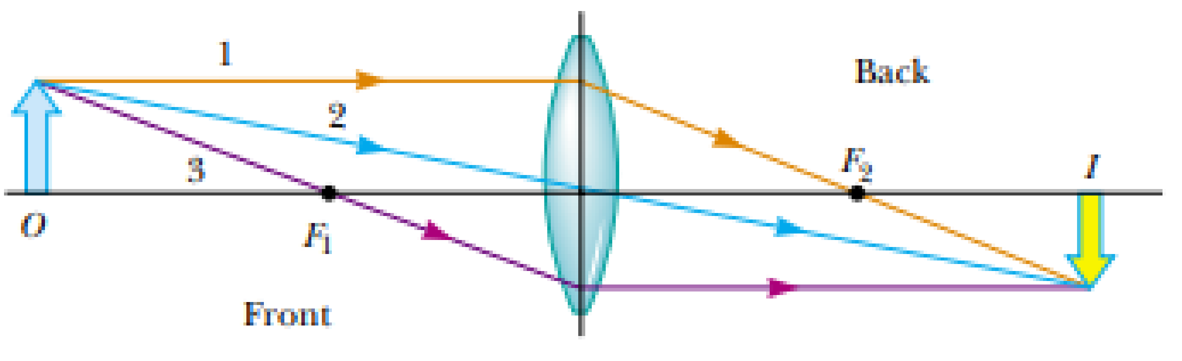
Virtual image: is the collection of focus points made by extensions of diverging rays.

It is an **upright image**.



There are three kind of light rays:

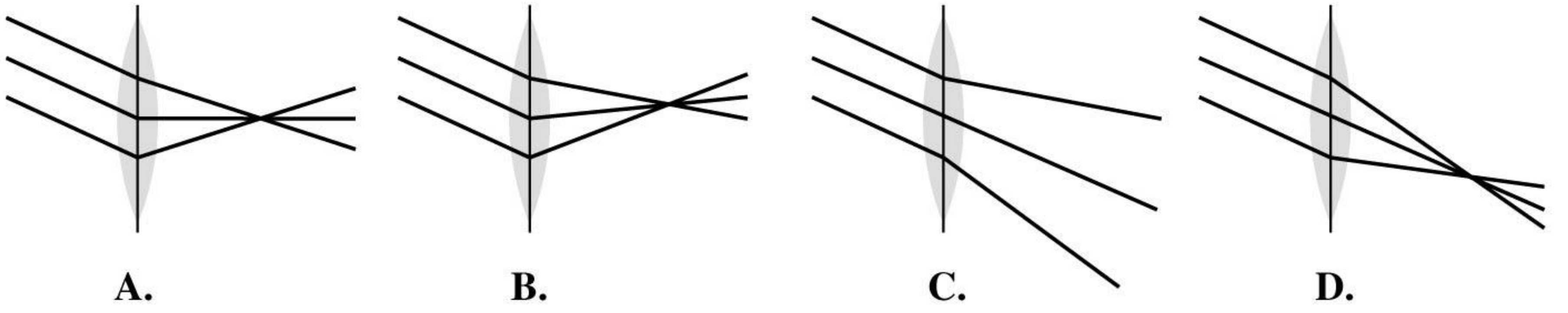
- A light ray parallel to the axis passes through the far focal point.
- A light ray that passing through the center of the lens is not deflected at all.
- Alight ray passing through the near focal point emerges parallel to the axis.



(a)

QuickCheck 18.13

- Which of these ray diagrams is possibly correct?



Thin Lenses Magnification

- The **magnification** m describes the orientation of the image relative to the object and its size.
- The absolute value of *m* fives the ratio of image height to object height: $h'/h = |m|$.

$$m = -\frac{s'}{s} = \frac{h'}{h}$$

- A positive value of *m* indicates that the image is upright relative to the object.
- A negative value of *m* indicates that the image is inverted.

Sign conventions for thin lenses

s	(+) if the object is in front of the lens. (-) if the object is behind the lens.
s'	(+) if the image is behind the lens. (-) if the image is in front of the lens.
f	(+) Converging lens. (-) Diverging lens.

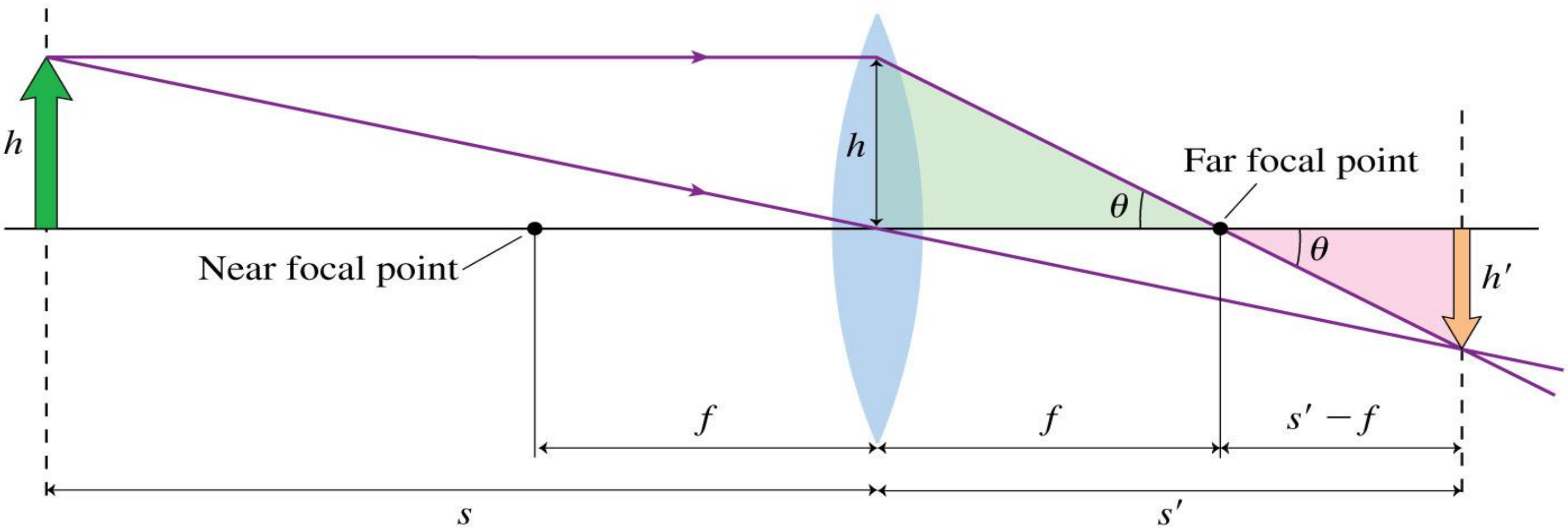
Section 18.7 The Thin-Lens Equation

The Thin-Lens Equation

The relation between focal, object, and image lengths for thin lenses.

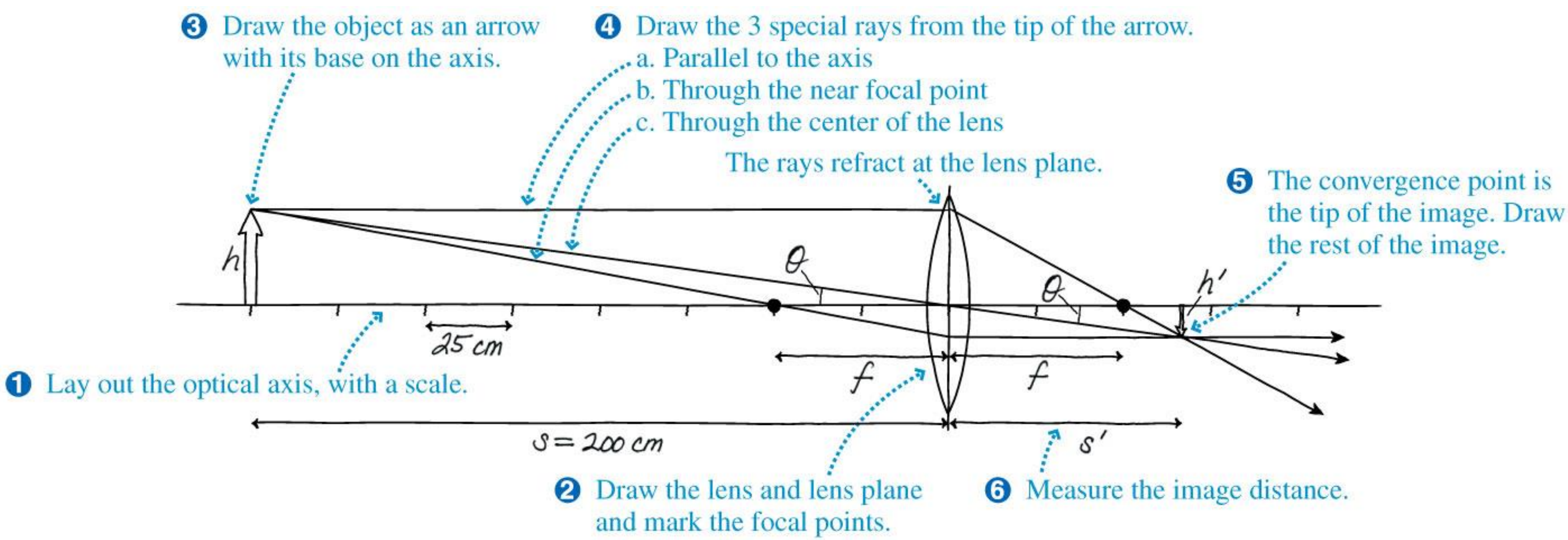
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

Thin-lens equation (also works for mirrors) relating object and image distances to focal length



Example 18.7 Finding the image of a flower

A 4.0-cm-height flower is 200 cm from the 50-cm-focal-length lens of a camera. How far should the plane of the camera's light detector be placed behind the lens to record a well-focused image? What is the height of the image on the detector?



Example 18.7 Finding the image of a flower (cont.)

SOLVE

$$h = 4\ cm \quad s = 200\ cm \qquad f = 50\ cm$$

$$s' = ? \quad h' = ?$$

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{50} - \frac{1}{200} = 0.015\ cm^{-1}$$

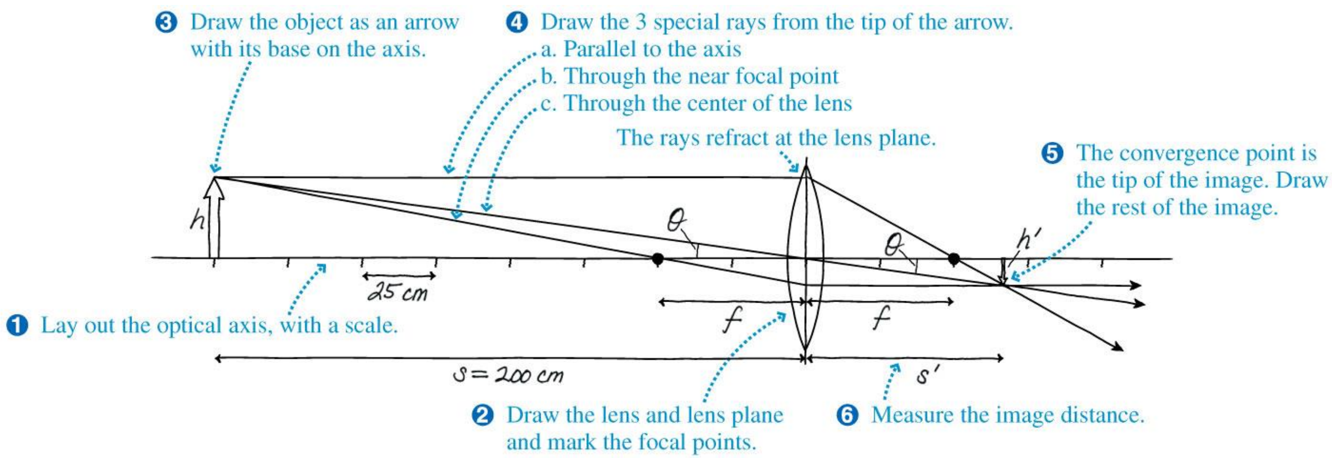
$$s' = 66.7 \text{ cm}$$

Example 18.7 Finding the image of a flower (cont.)

Solving for h' gives $\because m = -\frac{s\prime}{s} = \frac{h\prime}{h}$

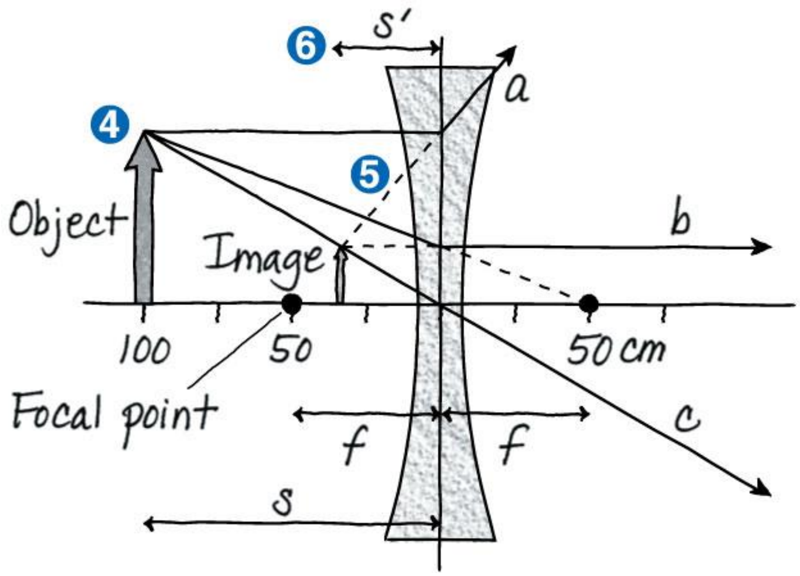
$$h' = -\frac{s'h}{s} = -\frac{66.7 * 4}{200} = -1.3\ cm$$

The flower's image has a height of 1.3 cm.



Example 18.9 Demagnifying a flower

A diverging lens with a focal length of 50 cm is placed 100 cm from a flower. Where is the image? What is its magnification?



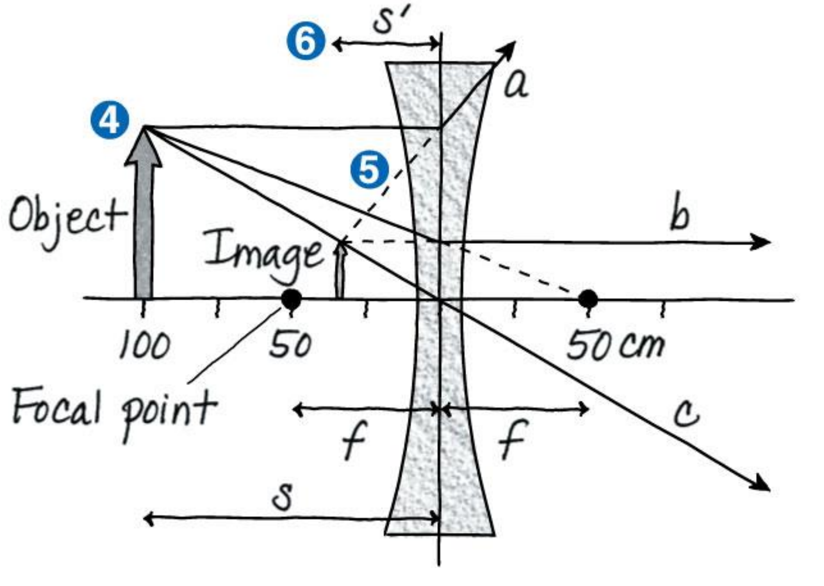
Example 18.9 Demagnifying a flower (cont.)

SOLVE The Figure shows the ray-tracing diagram. The three special rays (labeled a, b, and c to match the Figure) do not converge. However, they can be traced backward to an intersection ≈33 cm to the left of the lens.

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = -0.03\ cm^{-1}$$

$$s' = -33.3 \text{ cm}$$

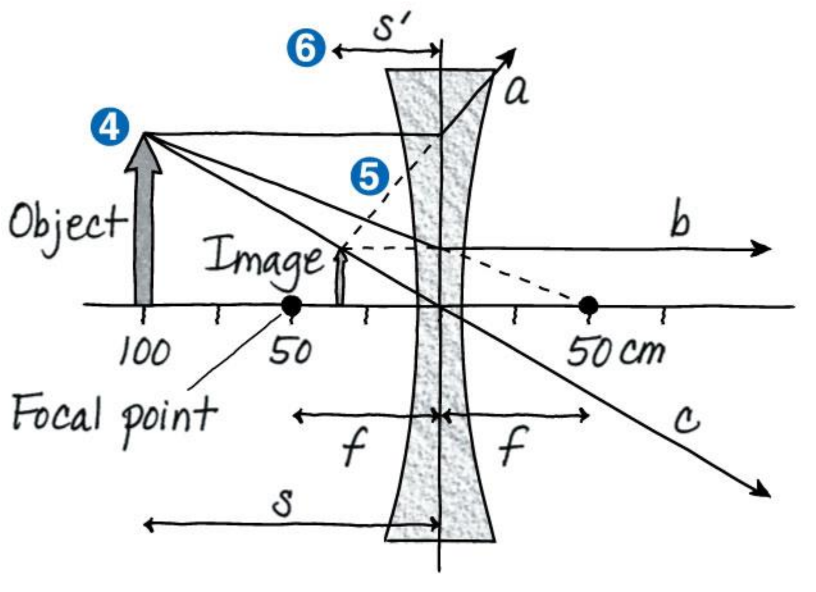


Example 18.9 Demagnifying a flower (cont.)

Because the rays appear to diverge from the image, this is a virtual image and s' is < 0. The magnification is

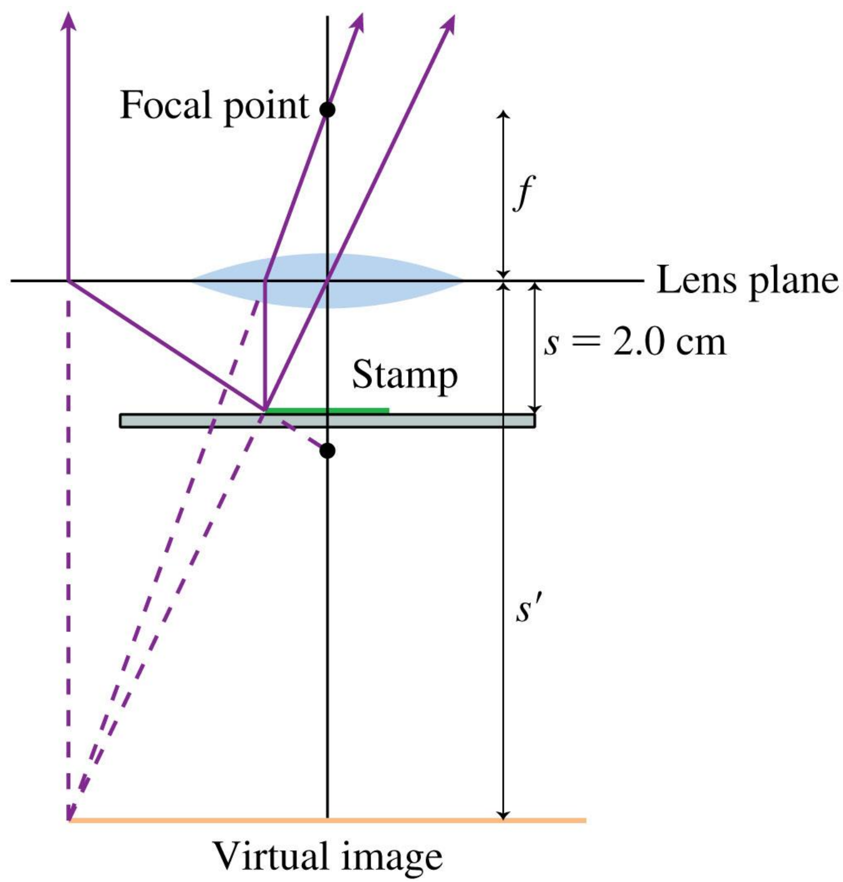
$$m = -\frac{s'}{s} = -\frac{-33\text{ cm}}{100\text{ cm}} = 0.33$$

The image, which can be seen by looking *through* the lens, is one-third the size of the object and upright.



Example 18.12 Analyzing a magnifying lens

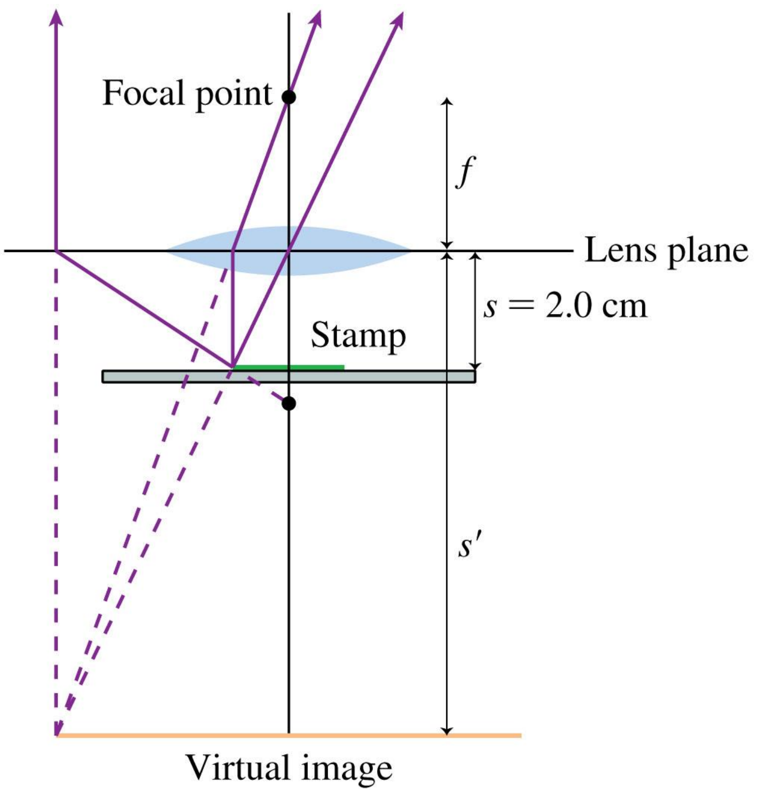
A stamp collector uses a magnifying lens that sits 2.0 cm above the stamp. The magnification is 4. What is the focal length of the lens?



Example 18.12 Analyzing a magnifying lens (cont.)

SOLVE A virtual image is upright, so $m = +4$. The magnification is $m = -s'/s$; thus

$$s' = -4s = -4(2.0\text{ cm}) = -8.0\text{ cm}$$



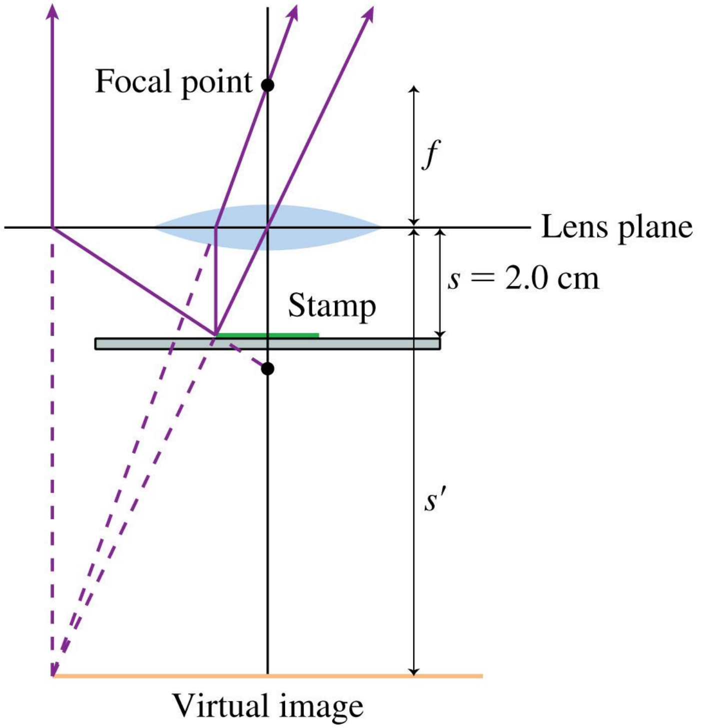
Example 18.12 Analyzing a magnifying lens (cont.)

We can use s and s' in the thin-lens equation to find the focal length:

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} = \frac{1}{2.0\text{ cm}} + \frac{1}{-8.0\text{ cm}} = 0.375\text{ cm}^{-1}$$

Thus

$$f = \frac{1}{0.375\text{ cm}^{-1}} = 2.7\text{ cm}$$



Reading Question 18.2

The image seen in a plane mirror is located

A. In front of the mirror.
B. Behind the mirror.
C. At the surface of the mirror.
D. At the position of the object.

Reading Question 18.3

A light ray can change direction when going from one material into another. That phenomenon is known as

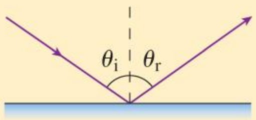
A. Reflection.
B. Absorption.
C. Refraction.
D. Scattering.

Summary

GENERAL PRINCIPLES

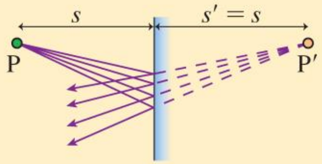
Reflection

Law of reflection: $\theta_r = \theta_i$



Reflection can be **specular** (mirror-like) or **diffuse** (from rough surfaces).

Plane mirrors: A virtual image is formed at P′ with $s' = s$, where s is the **object distance** and s' is the **image distance.**

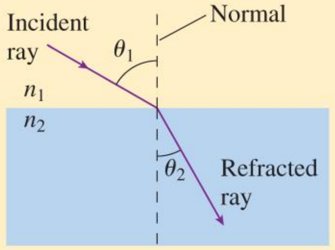


Refraction

Snell's law of refraction:

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

Index of refraction is $n = c/v$. The ray is closer to the normal on the side with the larger index of refraction.

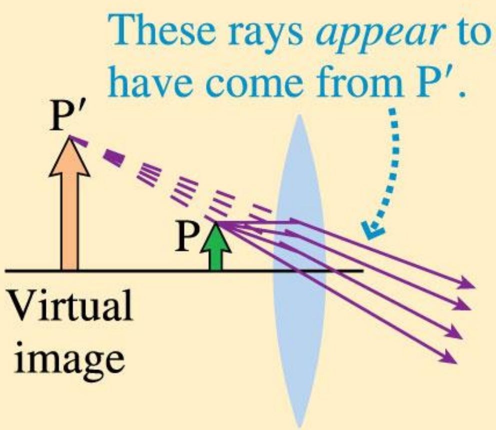


Text: p. 627

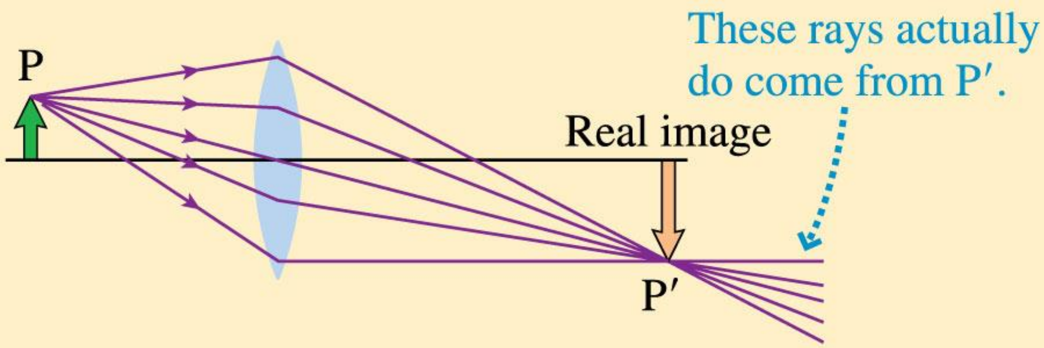
Summary: Important Concepts

Image formation

If rays diverge from P and, after interacting with a lens or mirror, *appear* to diverge from P′ without actually passing through P′, then P′ is a **virtual image** of P.



If rays diverge from P and interact with a lens or mirror so that the refracted rays *converge* at P′, then P′ is a **real image** of P. Rays actually pass through a real image.

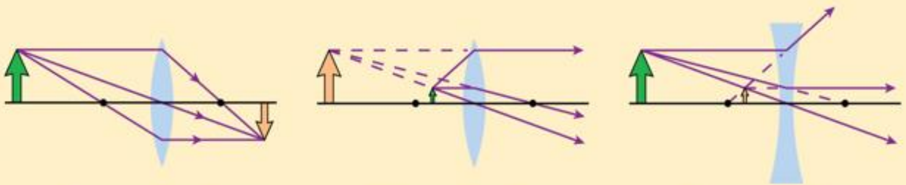


Text: p. 627

Summary: Applications

Ray tracing for lenses

Three special rays in three basic situations:



Converging lens
Real image

Converging lens
Virtual image

Diverging lens
Virtual image

The thin-lens equation

For a lens or curved mirror, the object distance s, the image distance s', and the focal length f are related by the thin-lens equation:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

The **magnification** of a lens or mirror is $m = -s'/s$.

Sign conventions for the thin-lens equation:

Quantity	Positive when	Negative when
s	Always	Not treated here
s'	*Real* image; on opposite side of a lens from object, or in front of a mirror	*Virtual* image; on same side of a lens as object, or behind a mirror
f	Converging lens or concave mirror	Diverging lens or convex mirror
m	Image is upright.	Image is inverted.

Text: p. 627