Lecture Outlines
Chapter 26
Chapter 26
Geometrical Optics
Objectives: After completing this module, you should be able to:

- Explain and discuss with diagrams, reflection and refraction of light rays.
- Illustrate graphically the reflection of light from plane, convex, and concave mirrors.
- Define and illustrate your understanding of real, virtual, erect, inverted, enlarged, and diminished as applied to images.
- Use Mirror equation to find distance.
- Use geometrical optics to draw images of an object at various distances from converging and diverging mirrors.
26-1 The Reflection of Light

If a stone is dropped into a pond, circular waves emanate from the point where it landed. Rays, perpendicular to the wave fronts, give the direction in which the waves propagate.

http://www.youtube.com/watch?v=Pot-S4koghk
26-1 The Reflection of Light

As one moves farther from a point wave source, the wave fronts become more nearly flat.
The law of reflection states that the angle of incidence equals the angle of reflection:

\[
\theta_r = \theta_i
\]
Reflection from a smooth surface is called specular reflection; if the surface is rough, it is diffuse reflection.
Example 1.

A laser beam is reflected by a plane mirror. It is observed that the angle between the incident and reflected beams is 38°. If the mirror is now rotated so that the angle of incidence increases by 5.0°, what is the new angle between the incident and reflected beams?
Example 2.

How many times does the light beam shown in the figure below reflect from (a) the top and (b) the bottom mirror?
26-2 Forming Images with a Plane Mirror

Light reflected from the flower and vase hits the mirror. Obeying the law of reflection, it enters the eye. The eye interprets the ray as having had a straight-line path, and sees the image behind the mirror (virtual image). Real image.
Example 3.

An observer is at table level, a distance $d$ in front of a flower of height $h$. The flower itself is a distance $d$ to the left of a mirror, as shown in the sketch. Note that a ray of light propagating from the top of the flower to the observer's eye reflects from the mirror at a height $y$ above the table. Find $y$ in terms of the height of the flower, $h$. 
Example 4.

A person whose eyes are 1.62 m above the floor stands 2.10 m in front of a vertical plane mirror whose bottom edge is 43 cm above the floor. What is the horizontal distance $x$ to the base of the wall supporting the mirror of the nearest point on the floor that can be seen reflected in the mirror?
Conceptual checkpoint

To save expenses, you would like to buy the shortest mirror that will allow you to see your entire body. Should the mirror be

1. Half your height 0%
2. Two-thirds your height 0%
3. Equal to your height 0%
Example 5: Work at Home: 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.
Home Problem Example 6.

You hold a small mirror 0.5 m in front of your eyes, as shown below. The mirror is 0.32 m high, and in it you see the image of a tall building behind you. (a) If the building is 95 m behind you, what vertical height of the building, $H$, can be seen in the mirror at any one time? (b) If you move the mirror closer to your eyes, does your answer to part (a) increase, decrease, or stay the same? Explain.
26-2 Forming Images with a Plane Mirror

Properties of Mirror Images Produced by Plane Mirrors:

• A mirror image is upright, but appears reversed right to left.

• A mirror image appears to be the same distance behind the mirror that the object is in front of the mirror.

• A mirror image is the same size as the object.

http://www.youtube.com/watch?v=3oDNNzb7tyl
Reflection

When watching the Moon over the ocean, you often see a long streak of light on the surface of the water. This occurs because:

1) the Moon is very large
2) atmospheric conditions are just right
3) the ocean is calm
4) the ocean is wavy
5) motion of the Moon
Reflection

When watching the Moon over the ocean, you often see a long streak of light on the surface of the water. This occurs because:

When the water surface changes, the angle of incidence also changes. Thus, different spots on the water can reflect the Moon into your eyes at different times.

1) the Moon is very large
2) atmospheric conditions are just right
3) the ocean is calm
4) the ocean is wavy
5) motion of the Moon

Follow-up: Where else does this occur?
An observer at point O is facing a mirror and observes a light source $S$. Where does the observer perceive the mirror image of the source to be located?
Mirror I

An observer at point O is facing a mirror and observes a light source S. Where does the observer perceive the mirror image of the source to be located?

Trace the light rays from the object to the mirror to the eye. Since the brain assumes that light travels in a straight line, simply extend the rays back behind the mirror to locate the image.

Follow-up: What happens when the observer starts moving toward the mirror?
26-2 Forming Images with a Plane Mirror

A corner reflector reflects light parallel to the incident ray, no matter the incident angle.
26-3 Spherical Mirrors

A spherical mirror has the shape of a section of a sphere. If the outside is mirrored, it is convex; if the inside is mirrored, it is concave.
26-3 Spherical Mirrors

Spherical mirrors have a central axis (a radius of the sphere) and a center of curvature (the center of the sphere).
26-3 Spherical Mirrors

Parallel rays hitting a spherical mirror come together at the focal point (or appear to have come from the focal point, if the mirror is convex).
26-3 Spherical Mirrors

This is a ray diagram for finding the focal point of a concave mirror.
The Focal Length $f$ of a Mirror

The focal length, $f$

Incident parallel ray

Since $\theta_i = \theta_r$, we find that $F$ is mid-way between $B$ and $C$; we find:

The focal length $f$ is:

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

The focal length $f$ is equal to half the radius $R$
The Focus of a Concave Mirror

The focal point $F$ for a concave mirror is the point at which all parallel light rays converge. For objects located at infinity, the real image appears at the focal point since rays of light are almost parallel.
The Focus of a Convex Mirror

The **focal point** for a convex mirror is the point **F** from which all parallel light rays **diverge**.

Virtual focus; reflected rays diverge.

\[ f = -\frac{R}{2} \]
26-3 Spherical Mirrors

Focal Length for a Convex Mirror of Radius $R$

$$f = -\frac{1}{2} R$$

SI unit: m

For a convex mirror, the focal length is negative, as the rays do not go through the focal point. The opposite is true for a concave mirror.

Focal Length for a Concave Mirror of Radius $R$

$$f = \frac{1}{2} R$$

SI unit: m
Conceptual checkpoint
Suppose you would like to use the Sun to start a fire in the wilderness. Which type of mirror,

1. concave or 0%
2. Convex 0%

Would work best 0%
26-3 Spherical Mirrors

We have made the assumption here that the rays do not hit the mirror very far from the principal axis. If they do, the image is blurred; this is called **spherical aberration**, and can be remedied by using a parabolic mirror instead.
26-3 Spherical Mirrors

When the Hubble Space Telescope was first launched, its optics were marred by spherical aberration. This was fixed with corrective optics.
Do it at Home Problem Example 7.

Sunlight reflects from a concave piece of broken glass, converging to a point 15 cm from the glass. What is the radius of curvature of the glass?
26-4 Ray Tracing and the Mirror Equation

We will find the orientation, size, and location of an image in a spherical mirror.

Two techniques:

Ray tracing and the mirror equation
26-4 Ray Tracing and the Mirror Equation

We use three principal rays in finding the image produced by a spherical mirror.

- The parallel ray ($P$ ray) reflects through the focal point.
- The focal ray ($F$ ray) reflects parallel to the axis.
- The center-of-curvature ray ($C$ ray) reflects back along its incoming path.
Image Construction:

**Ray 1:** A ray parallel to mirror axis passes through the focal point of a concave mirror or appears to come from the focal point of a convex mirror.
Ray 2: A ray passing through the focus of a concave mirror or proceeding toward the focus of a convex mirror is reflected parallel to the mirror axis.
Ray 3: A ray that proceeds along a radius is always reflected back along its original path.
An object is placed in front of a concave mirror. It is useful to trace the images as the object moves ever closer to the vertex of the mirror.

We will want to locate the image and answer three questions for the possible positions:

1. Is the image erect or inverted?
2. Is the image real or virtual?
3. Is it enlarged, diminished, or the same size?
1. The image is **inverted**; i.e., opposite of the object orientation.

2. The image is **real**; i.e., formed by actual light rays in front of mirror.

3. The image is **diminished** in size; i.e., smaller than the object.
Object at the Center C

1. The image is **inverted**; i.e., opposite of the object orientation.
2. The image is **real**; i.e., formed by actual light rays in front of mirror.
3. The image is **the same size** as the object.

Image is located at C, inverted.
Object Between C and F

1. The image is **inverted**; i.e., opposite of the object orientation.

2. The image is **real**; i.e., formed by actual light rays in front of mirror.

3. The image is **enlarged** in size; i.e., larger than the object.

Image is outside of the center C
Object at Focal Point

When the object is located at the focal point of the mirror, the image is **not formed** (or it is located at infinity).

The parallel reflected rays **never cross**.

Image is located at infinity (not formed).
1. The image is **erect**; i.e., same orientation as the object.

2. The image is **virtual**; that is, it seems to be located behind mirror.

3. The image is **enlarged**; bigger than the object.
Observe the Images as Object Moves Closer to Mirror

Erect and enlarged

Virtual image
Convex Mirror Imaging

Convex mirror

Convex mirror

All images are **erect**, **virtual**, and **diminished**. Images get larger as object approaches.
Converging and Diverging Mirrors

**Concave mirrors and converging parallel rays will be called converging mirrors from this point onward.**

**Convex mirrors and diverging parallel rays will be called diverging mirrors from this point onward.**
26-4 Ray Tracing and the Mirror Equation

This image shows how these three rays are used to find the image formed by a convex mirror. The image is located where the projections of the three rays cross. The size of the image can also be determined.
26-4 Ray Tracing and the Mirror Equation

The process is similar for a concave mirror, although there are different results depending on where the object is placed.
Conceptual checkpoint
The passenger-side rear-view mirrors in newer cars often have a warning label that reads, “OBJECTS IN MIRROR ARE CLOSER THAN THEY APPEAR” Are these rear-view mirrors
1. Concave
2. Convex
26-4 Ray Tracing and the Mirror Equation

We derive the mirror equation using the ray diagrams:
Using the similar triangles and the fact that $f = \frac{1}{2} R$, we get the mirror equation:

\[
\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}
\]

Here, $d_o$ is the distance from the mirror to the object, $d_i$ is the distance from the mirror to the image, and $f$ is the focal length.
26-4 Ray Tracing and the Mirror Equation

<table>
<thead>
<tr>
<th>Convex Mirror</th>
<th>Concave Mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Object location</strong></td>
<td><strong>Image orientation</strong></td>
</tr>
<tr>
<td>Arbitrary</td>
<td>Upright</td>
</tr>
<tr>
<td>Beyond C</td>
<td>Inverted</td>
</tr>
<tr>
<td>C</td>
<td>Inverted</td>
</tr>
<tr>
<td>Between F and C</td>
<td>Inverted</td>
</tr>
<tr>
<td>Just beyond F</td>
<td>Inverted</td>
</tr>
<tr>
<td>Just inside F</td>
<td>Upright</td>
</tr>
<tr>
<td>Between mirror and F</td>
<td>Upright</td>
</tr>
</tbody>
</table>

Copyright © 2007 Pearson Prentice Hall, Inc.
26-4 Ray Tracing and the Mirror Equation

We can also find the magnification:

\[
m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}
\]
Here are the sign conventions for concave and convex mirrors:

**Focal Length**
- $f$ is positive for concave mirrors.
- $f$ is negative for convex mirrors.

**Magnification**
- $m$ is positive for upright images.
- $m$ is negative for inverted images.

**Image Distance**
- $d_i$ is positive for images in front of a mirror (real images).
- $d_i$ is negative for images behind a mirror (virtual images).

**Object Distance**
- $d_o$ is positive for objects in front of a mirror (real objects).
- $d_o$ is negative for objects behind a mirror (virtual objects).
Problem Example 8.

Image in a concave mirror

A 2.0-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.
Problem Example 9.

Object closer to concave mirror

A 1.0-cm-high object is placed 10.0 cm from a concave mirror with radius of curvature 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.
HOME Problem Example 10.

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.
CONCLUSION:
That’s all for today
(geometrical)