FINAL EXAM INFO: 12-3 May 10, on Busch
Exam review in class next Monday May 1

Congrats on 4/4:
Alison Bansil, Cho, Hong, Huang, Kamara, Komatreddy, Pohane, S. Shah, Stephen, Uchil

Come and play with the demos

Spherical mirrors: how does the image change as you bring the object (ball, mallet) in from far away?

Different shapes: how do parallel incoming rays get bent? Where do the outgoing rays intersect?
Chapter 34

Images
TODAY
Study images formed by mirrors and thin lenses

Plane mirror
Convex spherical mirror
Concave spherical mirror

Converging lens
Diverging lens
To see an object, an eye intercepts some of the light rays spreading from the object.

The brain extrapolates the rays arriving from a point on the object back to their intersection point to get the apparent position of the point.

This is done simultaneously for all points on the object and the brain constructs an image of the object.

If the light rays are not bent, the image of the object is exactly the same as the object (position, size, orientation) – this information about the object is useful to the brain!

If there is light emanating from the intersection point, the image is “real.” An image that is not real is called “virtual”.

Question: if the light rays are not bent, as in the figure on this page, is the image “real”, or “virtual”? 
For an extended object, image of each point on object follows the rule “Straight to the mirror and equal distance on other side”

Is this image real, or virtual?
Why do mirrors reverse left and right, but not top and bottom?

Object: ring is on left hand
Image: ring is on “right hand”

If I were to lie horizontal, ring would still change hands
Why do mirrors reverse left and right, but not top and bottom?

Answer:
Mirror DOES NOT reverse left and right
It reverses front and back
GOAL
Given a mirror or thin lens, and an object a distance $p$ away
be able to describe the image: $i, m$

How far from the mirror/lens? On which side?
This information is contained in “$i$”
magnitude of $i$ is the distance of the image from the mirror/lens
sign of $i$: positive if image is on same side as outgoing light
Is it real or virtual?
positive $i$ -> real image; negative $i$ -> virtual image

orientation and size: “$m$”
Magnitude of $m$ is ratio of image height to object height
Positive $m$ -> upright; negative $m$-> inverted
SIMPLEST CASE
Given a PLANE MIRROR and an object a distance $p$ away
be able to describe the image: $i$, $m$

How far from the mirror/lens? On which side?
magnitude of $i$ is the distance of the image from the mirror/lens
sign of $i$: positive if on same side as outgoing light
Is it real or virtual?
negative $i$ -> virtual image
$i = -p$

orientation and size: “$m$”
$m=1$
Magnitude of $m$ is ratio of image height to object height
Positive $m$ -> upright
GOAL
Given a spherical mirror or thin lens, and object at distance \( p \) be able to describe the image: \( i, m \)

How far from the mirror/lens? On which side?
This information is contained in “\( i \)”
magnitude of \( i \) is the distance of the image from the mirror/lens
sign of \( i \): positive if image is on same side as outgoing light
Is it real or virtual?
positive \( i \) -> real image; negative \( i \) -> virtual image

orientation and size: “\( m \)”
Magnitude of \( m \) is ratio of image height to object height
Positive \( m \) -> upright; negative \( m \) -> inverted
i and m are functions of p and a property of the mirror/lens called the focal length “f”

\[ \frac{1}{p} + \frac{1}{i} = \frac{1}{f} \]

\[ i = \frac{pf}{(p-f)} \]
\[ m = -\frac{i}{p} = \frac{(-f)}{(p-f)} \]

The same functional form for both spherical mirrors and lenses! – just need to know f
Determining f

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

as \( p \to \infty \), \( i = f \)

as \( p \to \infty \), rays from a point become parallel

So, shine parallel rays onto the mirror/lens and locate the intersection of the outgoing rays

Magnitude of \( f \) is the distance of the intersection from the mirror/lens

Sign of \( f \) is positive if intersection is on the same side as the outgoing light

Sign of \( f \) is negative if intersection is on the side opposite to the outgoing light
spherical mirrors

Specify the radius $r$ of the sphere
$r$ is called the “radius of curvature”
The center of the sphere is called the “center of curvature” $C$
$C$ is at distance $r$ from the mirror

Convex spherical mirror: object is on side opposite to $C$
Concave spherical mirror: object is on same side as $C$
Convex spherical mirror
\[ f = -\frac{r}{2} < 0 \]

Concave spherical mirror
\[ f = \frac{r}{2} > 0 \]
Image in a convex mirror

\[ i = \frac{pf}{(p-f)} \text{ and } m = -\frac{i}{p} \]

\[ f = -\frac{r}{2} \]

\( i \) is always negative, \( m \) is always positive

magnitude of \( i \) is always less than \( p \)

A convex mirror makes an image that is always virtual, always upright, always smaller.
Image in a concave mirror: $f = \frac{r}{2} > 0$
Have to consider several cases for $p$

**FIRST CASE: $p < f$**

$$i = \frac{pf}{(p-f)} \text{ and } m = -\frac{i}{p}$$
$i$ is always negative, $m$ is always positive

**Image is virtual, upright**
magnitude of $i$ is always greater than $p$
**Image is bigger and farther than object**
Image in a concave mirror: $f = r/2 > 0$
SECOND CASE: $2f > p > f$

$i = pf/(p-f)$ and $m = -i/p$
i is always positive, $m$ is always negative
Image is real, inverted
magnitude of $i$ is always greater than $p$
image is larger and farther than object
Image in a concave mirror: $f = \frac{r}{2} > 0$

THIRD AND LAST CASE: $p$ is greater than $2f$

$i = \frac{pf}{(p-f)}$ and $m = -\frac{i}{p}$

$i$ is always positive, $m$ is always negative

magnitude of $i$ is always less than $p$
Clicker

Take a concave mirror with \( f = +1.0 \text{ cm} \). The image of an object at \( p = 3.0 \text{ cm} \) is

a) On the same side as the object and closer to the mirror
b) On the same side as the object and farther from the mirror
c) On the opposite side from the object and closer to the mirror
d) On the opposite side from the object and farther from the mirror
e) I have no idea how to answer this
Clicker

Take a concave mirror with $f = +1.0$ cm. The image of an object at $p = 3.0$ cm is

a) On the same side as the object and closer to the mirror
b) On the same side as the object and farther from the mirror
c) On the opposite side from the object and closer to the mirror
d) On the opposite side from the object and farther from the mirror
e) I have no idea how to answer this
34.7: Thin Lenses:

**Lens**: piece of glass whose two sides are ground and polished to form smooth surfaces.

**CURVED SURFACE BENDS LIGHT AS IT GOES THROUGH**

**DEMO: LENS WITH ONE CURVED AND ONE FLAT SURFACE**

Focal length $f$ of lens depends on curvatures of its two sides, and on index of refraction.

\[
\frac{1}{f} = \frac{1}{p} + \frac{1}{i} \quad \text{ (thin lens),} \\
\]

\[
m = -\frac{i}{p}
\]

$f$, $i$ are positive if on the same side as the outgoing light
Diverging lens
\( f < 0 \)

Converging lens
\( f > 0 \)

If you intercept these rays, they seem to come from \( F_2 \).

To find the focus, send in rays parallel to the central axis.
Clicker

Take a lens with \( f = -1.0 \) cm. The image of an object at \( p = 2.0 \) cm is

a) On the same side as the object and closer to the lens
b) On the same side as the object and farther from the lens
c) On the opposite side from the object and closer to the lens
d) On the opposite side from the object and farther from the lens
e) I have no idea how to answer this
Clicker

Take a lens with \( f = -1.0 \) cm. The image of an object at \( p = 2.0 \) cm is

a) On the same side as the object and closer to the lens
b) On the same side as the object and farther from the lens
c) On the opposite side from the object and closer to the lens
d) On the opposite side from the object and farther from the lens
e) I have no idea how
Confirm image position by ray tracing

Rules for special rays for lenses
When \( f \) is negative (diverging lens)

i is always negative

Image is
Always same side of lens as the object
Always upright
Always smaller
Clicker

Take a lens with \( f = +1.0 \) cm. The image of an object at \( p = 3.0 \) cm is

a) On the same side as the object and closer to the lens  
b) On the same side as the object and farther from the lens  
c) On the opposite side from the object and closer to the lens  
d) On the opposite side from the object and farther from the lens  
e) I have no idea how to answer this
Clicker

Take a lens with \( f = +1.0 \text{ cm} \). The image of an object at \( p = 3.0 \text{ cm} \) is

a) On the same side as the object and closer to the lens
b) On the same side as the object and farther from the lens
c) On the opposite side from the object and closer to the lens
d) On the opposite side from the object and farther from the lens
e) I have no idea how to answer this
When $f$ is positive (converging lens) and $p$ is greater than $f$

$i$ is always positive

Image is
Always opposite side from the object
Always inverted
Either further and bigger (if $2f > p > f$)
OR closer and smaller (if $p > 2f$)

Confirm by ray tracing
Clicker

Take a lens with $f = +1.0$ cm. The image of an object at $p = 0.5$ cm is

a) On the same side as the object and closer to the lens
b) On the same side as the object and farther from the lens
c) On the opposite side from the object and closer to the lens
d) On the opposite side from the object and farther from the lens
e) I have no idea how to answer this
Clicker

Take a lens with $f = +1.0$ cm. The image of an object at $p = 0.5$ cm is

a) On the same side as the object and closer to the lens
b) **On the same side as the object and farther from the lens**
c) On the opposite side from the object and closer to the lens
d) On the opposite side from the object and farther from the lens
e) I have no idea how to answer this
When $f$ is positive (converging lens) and $p$ is less than $f$

$i$ is always negative

Image is
Always same side as the object
Always upright
Always further and larger
Confirm image position by ray tracing
f for lens with index of refraction \( n \) in air: “lensmaker’s equation”

\[
\frac{1}{f} = (n - 1) \left( \frac{1}{r_1} - \frac{1}{r_2} \right)
\]

\( r \) is the “signed” radius of curvature of the surface
positive if surface faced by the object is convex
negative if surface faced by the object is concave

1 for the surface nearer the object, 2 for the far surface
i-clicker:
A lens makes an image of an object. Suppose we cover the right half of the lens. What happens to the image?

a) Right half of image disappears.
b) Left half of image disappears.
c) Entire image disappears.
d) Entire image remains, but it is fainter.
A lens makes an image of an object. Suppose we cover the right half of the lens. What happens to the image?

a) Right half of image disappears.

b) Left half of image disappears.

c) Entire image disappears.

d) Entire image remains, but it is fainter.

Answer: d

Light from all parts of the object still go through the half-lens. But less light will go through than before.