Lecture 37: Lenses and mirrors

- Spherical lenses: converging, diverging
- Plane mirrors
- Spherical mirrors: concave, convex

The animated ray diagrams were created by Dr. Alan Pringle.
Terms and sign conventions for lenses and mirrors

- **object distance** $s$, positive

- **image distance** $s'$, positive if image is on side of outgoing light, i.e., same side of mirror, opposite side of lens: real image
  - $s'$ negative if image is on same side of lens/behind mirror: virtual image

- **focal length** $f$
  - positive for concave mirror and converging lens
  - negative for convex mirror and diverging lens

- **object height** $h$, positive

- **image height** $h'$
  - positive if the image is upright
  - negative if image is inverted

- **magnification** $m = h'/h$, positive if upright, negative if inverted
Lens equation

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}
\]

\[
m = -\frac{s'}{s} = \frac{h'}{h}
\]

ew magnification

\[
s' = \frac{fs}{s - f}
\]
Converging and diverging lenses

- Rays refract towards optical axis (thicker in the center)
- Rays refract away from optical axis (thinner in the center)
- There are focal points on both sides of each lens
- Focal length f on both sides is the same
Ray 1 is parallel to the axis and refracts through F.
Ray 2 passes through F’ before refracting parallel to the axis.
Ray 3 passes straight through the center of the lens.

- **Object between f and 2f**: Image is real, inverted, enlarged
- **Object outside of 2f**: Image is real, inverted, reduced
- **Object inside of f**: Image is virtual, upright, enlarged
Ray 1 is parallel to the axis and refracts as if from F.

Ray 2 heads towards F' before refracting parallel to the axis.

Ray 3 passes straight through the center of the lens.

image is always virtual, upright and reduced
- point object A, source of light

- reflected rays appear to come from A' \(\rightarrow\) A' is image of A

- image appears to be located behind the mirror \(\rightarrow\) image is virtual
• every point of the object acts as light source
• every point has an image
• collection of image points form image of the object
• image is upright, virtual, same size as object ($h' = h$), $s' = s$
• made from (polished) sections cut from a spherical surface

• **center of curvature** $C$ is center of original sphere

• **vertex** $V$ is center of mirror segment

• **radius of curvature** $R$ is radius of sphere, or the distance from $V$ to $C$.

• **principal axis** (or **optical axis**) is line passing through $C$ and $V$
Rays parallel to the axis get reflected through a common point the **focal point** or **focus** F.
Focal length $f$ is distance from V to F.
Concave and convex mirror
Ray 1 is parallel to the axis and reflects through F.

Ray 2 passes through F before reflecting parallel to the axis.

Ray 3 passes through C and reflects back on itself.

Ray 4 goes to the vertex V and reflects under the same angle below the optical axis.
Ray Diagrams for Concave Mirrors

- image is formed where the outgoing rays cross
- two principal rays are sufficient to find image, use third and fourth to check your diagram

Example:

- object outside center ($s > 2f$) → image is **real, inverted, and smaller** than object ("telescope")

- object between $f$ and $2f$ → image is **real, inverted, and larger** than object ("microscope")

Real image: outgoing rays do cross. Can be captured on screen or by camera.
• object inside the focal point (s<f)
  → image is **virtual**, **upright**, and **larger** than object (makeup mirror)

Ray 1: parallel to the axis then through F.

Ray 2: through F then parallel to the axis.

Ray 3: “through” C.
Ray 1: parallel to the axis then from F.

Ray 3: from C.

Ray 2: Vertex.

Ray 4: towards F, then parallel.

• image is **virtual**, **upright**, and **smaller** than object
Concave mirrors:

- Shaving and makeup mirrors
- Solar cookers
- Satellite dishes (for EM waves)

Convex mirrors:

- Passenger side rear-view mirrors
- Anti-shoplifting (surveillance) mirrors
- Christmas tree ornaments
# Image formation for mirrors and lenses

<table>
<thead>
<tr>
<th>Type</th>
<th>Focal length $f$</th>
<th>Object distance $s$</th>
<th>Image distance $s'$</th>
<th>Character</th>
<th>Orientation</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave mirror/Converging lens</td>
<td>$f &gt; 0$</td>
<td>$s &gt; 2f$</td>
<td>$f &lt; s' &lt; 2f$</td>
<td>real</td>
<td>inverted</td>
<td>reduced</td>
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<tr>
<td></td>
<td>$f &lt; s &lt; 2f$</td>
<td>$s' &gt; 2f$</td>
<td>real</td>
<td>inverted</td>
<td>enlarged</td>
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</tr>
<tr>
<td></td>
<td>$s &lt; f$</td>
<td>$s' &lt; 0$</td>
<td>virtual</td>
<td>upright</td>
<td>enlarged</td>
<td></td>
</tr>
<tr>
<td>Convex mirror/diverging lens</td>
<td>$f &lt; 0$</td>
<td>$s &gt; 0$</td>
<td>$s' &lt; 0$</td>
<td>virtual</td>
<td>upright</td>
<td>reduced</td>
</tr>
</tbody>
</table>

Do not memorize! We can easily get this from the equation!