November 19th

Interference

Chapter 36
Schedule

- **HW set #11** will open Tues. Nov. 18th and is due on **Tues. Nov. 25th at noon**.
  - Third mid-term is Nov. 25th at 6pm
- **HW set #12** will open Wed. Nov. 26th and is due on Wed. Dec. 3rd at 7am.
- **Corrections for the third exam** will open Wed. Nov. 26th at 5pm and are due Mon. Dec. 8th at 7am.
  - Final exam is Dec. 8th at 5:45-7:45pm.
Midterm Exam #3

- Last mid-term is **Tues. Nov. 25th at 6pm.**
  - Section 1 in N100 BCC (Business College)
  - Section 2 in 158 NR (Natural Resources)
- Covers homework sets #9, 10 and 11!
  - Chapters 32-35 in textbook
- Allowed one page (both sides) of notes and calculator.
- Bring photo id.
- Email Prof. Tollefson (tollefson@pa.msu.edu) if need make-up exam and explain why.
  - Make-up exam will be Wed. Nov. 26th at 8am
- Review in class on Monday.
Review – Mirrors (Fig. 35-6)

- **Plane** – flat mirror
- **Concave** – caved in away from object
- **Convex** – flexed out toward object
- Real images on side where object is, virtual images on opposite side
- Plane and convex mirrors make only virtual images
- Concave mirrors can produce both real and virtual images
Review – mirrors (Fig. 35-7)

- Spherical mirrors have focal point, \( r \) is radius of curvature

\[
f = \frac{1}{2} r
\]

- Find focal length, \( f \) from

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

- Object distance \( p \) is +
- Image distance \( i \) is + for real images, - for virtual images
- \( f \) is + for concave, - for convex
Review - mirrors

- Ratio of image’s height $h'$ to object’s height $h$ is called lateral magnification, $m$
  
  $$|m| = \frac{h'}{h}$$

- Magnification also equal to
  
  $$m = -\frac{i}{p}$$

- $m$ is $+$ if image has same orientation as object
- $m$ is $-$ if image is inverted from object
- Plane mirror $m = +1$
Review - Thin lenses (Fig. 35-12)

- Light rays bent by refraction form an image
- **Converging** – lens with convex refracting sides
- **Diverging** – lens with concave sides
Real images form on opposite side of lens from object, virtual images on same side.

Diverging lens only produces smaller, same orientation, virtual images (like convex mirror).

Converging lens (like concave mirror) can produce both real and virtual images depending on where the object is in relation to the lens’ focal point.

**Review - Thin lenses (Fig. 35-13)**
Review - Thin lenses (Fig. 35-12)

- Thin lenses have a focal point on each side of lens
- Focal length, $f$ same as mirror

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

- **Lens maker’s equation** – for lens in air, $r_2$ is radius of lens surface nearest the object, $r_2$ is other surface
  - $r$ is + for convex surface, - for concave surface

$$\frac{1}{f} = (n - 1) \left( \frac{1}{r_1} - \frac{1}{r_2} \right)$$
Review - Thin lenses (Fig. 35-4)

- Lateral magnification $m$ same as for mirror
  \[ |m| = \frac{h'}{h} \quad m = -\frac{i}{p} \]

- For a system of lenses or mirrors the total magnification $M$ is product of each $m$
  \[ M = m_1 m_2 m_3 \ldots \]

- Work through system of lenses one by one – use image from one lens as object for next lens
# Review - Thin lenses

**Converging lens** = concave mirror  
**Diverging lens** = convex mirror

<table>
<thead>
<tr>
<th>Thin Lens Type</th>
<th>Object Location</th>
<th>Image Location</th>
<th>Image Size</th>
<th>Image Type</th>
<th>Image Orientation</th>
<th>Sign of ( f )</th>
<th>Sign of ( i )</th>
<th>Sign of ( m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converging</td>
<td>( p &lt; f )</td>
<td>Anywhere</td>
<td>Bigger</td>
<td>Virtual</td>
<td>Same</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Converging</td>
<td>( f &lt; p &lt; 2f )</td>
<td>( i &gt; 2f )</td>
<td>Bigger</td>
<td>Real</td>
<td>Invert</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Converging</td>
<td>( p = 2f )</td>
<td>( i = 2f )</td>
<td>Equal</td>
<td>Real</td>
<td>Invert</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Converging</td>
<td>( p &gt; 2f )</td>
<td>( 2f &gt; i &gt; f )</td>
<td>Smaller</td>
<td>Real</td>
<td>Invert</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Diverging</td>
<td>Anywhere</td>
<td>(</td>
<td>i</td>
<td>&lt;</td>
<td>f</td>
<td>)</td>
<td>Smaller</td>
<td>Virtual</td>
</tr>
</tbody>
</table>
Human Eye

- Has a converging lens which makes real, **inverted** images at the retina
- **Near point** is the closest distance which our lens can focus light on the retina
  - Distance increases with age
  - Typically at age 10 is 18cm, at 20 is 25cm, at 40 is 50cm, at 60 is 500cm or more
  - For problems will use 25cm for human eye
- Nearsighted – correct with a diverging lens
- Farsighted – correct with a converging lens
Magnifying Lenses (Fig. 35-16)

- Object closer than near point: image blurred
- Use magnifying lenses
- Angular magnification:
  \[ m = -\frac{\theta'}{\theta} \]
  \[ \theta \approx \frac{h}{25 \text{ cm}} \]
  \[ \theta' \approx \frac{h}{f} \]

- Simple magnifier:
  \[ m \approx -\frac{25 \text{ cm}}{f} \]
Compound microscope (Fig. 35-17)

- Lateral magnification
  \[ m = -i / p = -s / f_{ob} \]

- \( s \) is length of tube

- Microscope
  \[ M = m_0 m = - \frac{s}{f_{ob}} \frac{25 \text{ cm}}{f_{ey}} \]
Telescope (Fig. 35-18)

- **Refracting telescope**
  - Two lenses - objective and eyepiece
  
  \[
  m = -\frac{\theta_{ey}}{\theta_{ob}}
  \]

  \[
  \theta_{ob} \approx \frac{h'}{f_{ob}} \quad \theta_{ey} \approx \frac{h'}{f_{ey}}
  \]

  \[
  m = -\frac{f_{ob}}{f_{ey}}
  \]

- **Reflecting telescope**
  - Mirror and lens
  - \(f_{ob}\) is focal length of objective mirror
Light as a wave (Fig. 36-1)

- Light is an EM wave
- Interfering light waves combine to enhance or suppress colors in sunlight
  - Soap bubbles, oil slicks
- Interference best evidence that light is a wave
- Huygen’s principle – points on wavefront act as point sources of spherical wavelets, at time $t$ new position of wavefront is tangent to wavelets
Can use Huygen’s principle and geometry to prove Snell’s law (see section 36-2)

\[ n_2 \sin \theta_2 = n_1 \sin \theta_1 \]

Wavelength of light in two different media, 1 and 2, are proportional to

\[ \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1} \]
Index of refraction

\[
\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}
\]

- Frequency of light in medium is same as in vacuum
- Wavelength and velocity of light change in a medium and depend on its index of refraction, \( n \)
- Velocity of light in a medium is always smaller than speed of light in vacuum, \( c \)
- Wavelength of light in a medium, \( \lambda_n \) is smaller than in vacuum, \( \lambda \) and related by

\[
\lambda_n = \frac{\lambda}{n}
\]
Quiz 13

- **Focal length equation**
  - Image distance $i$ is + for real images, - for virtual images

- **Lateral magnification, $m$**

  \[
  m = -\frac{i}{p} \\
  |m| = \frac{h'}{h}
  \]

- $m$ is + if image has same orientation as object
- $m$ is – if image is inverted from object