About the Final Exam

- The exam will be on 7:25-9:42pm, Sunday, May 8th in:
  - 2103 Chamberlin, and Social Sci 6210 (Allocation in the email)
    - It will be exactly 120 minutes.
    - Distribution of tests starts at 7:15pm.
- Four (3+1) 8½ x 11” double sided sheets are allowed.
  - Put down whatever you like, prepare it **yourself**. (no photocopying, download-printing of lecture notes/exam solutions/examples. etc.)
- Any calculator is fine.
  - Do not use programming functionality.
  - Absolutely **no communication** functionality.
- A 2B pencil for Scantron.
- All special arrangements must be pre-approved.
About the Final Exam (2)

- The Exam is accumulative.
  - ~50% for new chapters (35, 36, 37, 38)
  - ~50% for old chapters (23-34)
- There will be 30 multiple-choice problems.
- New chapters since Exam 3
  - Chapter 35: Principles of Ray Optics
    - 35.1-35.8
  - Chapter 36: Image Formation (Mirrors and Lens)
    - 36.1-36.10 (36.5 Lens aberration: conception only)
  - Chapter 37: Waves Optics, interferences
    - 37.1-37.7
  - Chapter 38: Diffraction
    - 38.1-38.6
Review Lectures

- Review Lecture 1: Given on Feb 10 for Midterm 1.
- Review Lecture 2: Given on March 10 for Midterm 2.
- Review Lecture 3: Given on Apr 12 for midterm 3.

Those reviews won’t be repeated. Slides can be found on course web.

Exam Topics: Optics(1)

- Geometric optics:
  - Ray approximation.
  - Laws of reflection and refraction
  - Index of refraction and speed of light
  - Total internal reflection
  - Image formation, real and virtual image.
  - Basic properties of mirrors, lenses
    - use ray diagrams to find image
    - use of mirror equation and lens equation
    - simple sign conventions and their meanings.
  - Basic optic devices: camera/eye, magnifier, microscope, telescope.
Exam Topics: Optics (2)

- Wave Optics
  - Superposition Principle
  - General phase conditions for constructive and destructive interference.
  - Phase and path length.
  - Split beam interference
  - Diffraction
  - Intrinsic optical resolution
  - Polarization
Basic Techniques (1)

- Geometric Optics Fundamentals
  - Conversion between Index of Refraction (n) and speed of light in medium (v): n↔v (n=C/v)
  - Conversion using relationship λf=v
  - For a given ray with known incident angle, find out where the reflected and refracted rays go.
    - Law of reflection (θ_{reflected}=θ)
    - Law of refraction, Snell’s law. n_1\sinθ_1=n_2\sinθ_2
  - Understand the TIR (total internal reflection) conditions and be able to calculate the critical angle.
  - Understand the idea of image formation, real and virtual images.
Exercise/Quiz 1

When a light beam enters water from air, which of the followings is true:

A. Its wavelength remains unchanged but its frequency increases;
B. Its frequency remains unchanged but its wavelength increases;
C. Its wavelength remains unchanged but its frequency decreases;
D. Its frequency remains unchanged but its wavelength decreases;

Answer: D
Exercise 2: Reflection and Refraction

Given incoming ray 1, which rays are not possible? \( n_{\text{water}} = 1.33 \)

A. Rays 2,3  
B. Rays 3,4  
C. Ray 3 only  
D. Ray 4 only

Answer:  
B. Ray 3,4 are not possible

Reason:
Ray 3: obvious  
Ray 4: Check whether total internal reflection  
\[
\sin \theta_{\text{critical}} = \frac{n_{\text{air}}}{n_{\text{water}}} = \frac{1}{1.33} \rightarrow \theta_{\text{critical}} = 48.5^\circ < 70^\circ
\]
Basic Techniques (2)

- Geometric Optics: Lenses
  - Be able to do ray diagrams for single and compound lenses.
  - Be able to use mirror and lens equation with the help of sign convention table. (We will include a copy of the sign convention table in the test but you are expected to understand how to use them)
  - Have general idea how cameras, human eyes, simple magnifier, telescope, microscope work.
  - Understand the concept of psychological object size.
Reminder:
Master Equations for Lenses and Mirrors

Parameters
$d_o$: object distance
$d_i$: image distance
$h_o$: object height
$h_i$: image height
$M$: magnification
$f$: focal length

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

\[ d_i = \frac{fd_o}{d_o - f} \]

If $|M| < 1 \rightarrow \text{Image} < \text{Object}$
If $|M| > 1 \rightarrow \text{Image} > \text{Object}$
If $M < 0 \rightarrow \text{Image} \downarrow \uparrow \text{Object}$
If $M > 0 \rightarrow \text{Image} \uparrow \uparrow \text{Object}$
### Sign Conventions for Mirrors and Lenses

<table>
<thead>
<tr>
<th></th>
<th>&gt;0</th>
<th>&lt;0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f )</td>
<td>concave mirrors</td>
<td>convex mirrors</td>
</tr>
<tr>
<td></td>
<td>converging lens</td>
<td>diverging lens</td>
</tr>
<tr>
<td>( d_0 )</td>
<td>object side</td>
<td>the other side</td>
</tr>
<tr>
<td>( d_1 )</td>
<td>image side (real)</td>
<td>the other side (virtual)</td>
</tr>
<tr>
<td>( M = -\frac{d_1}{d_0} )</td>
<td>upright</td>
<td>inverted</td>
</tr>
</tbody>
</table>

### Object Side vs. Image Side

<table>
<thead>
<tr>
<th></th>
<th>Object Side</th>
<th>Image Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>mirrors</td>
<td>front</td>
<td>front</td>
</tr>
<tr>
<td>lenses</td>
<td>front</td>
<td>behind</td>
</tr>
<tr>
<td>refraction</td>
<td>opposite to</td>
<td>observer’s side</td>
</tr>
<tr>
<td>surface</td>
<td>observer’s side</td>
<td>observer’s side</td>
</tr>
</tbody>
</table>
Reminder: Ray Diagrams with Lenses

- If image can be formed, only two rays are necessary to determine an image point.

Useful rays:
- Object ray pointing to the center (C)
  - Image ray inline with the object ray
- Object ray parallel to principal axis
  - Image ray “pointing to” a focal point (F)
- Object ray passing through a focal point
  - Image ray parallel to principal axis.
Exercise 3: Where Is the Final Image

- As shown, two converging lenses, each with a focal length of 10cm, are separated by 15cm. An object of 2cm tall is 5cm in front of the first lens.

- Use lens equation to find the final image (where, real/virtual, upright/inverted, size?)
- Use ray diagram to find the final image.
- Tricky quiz: What is the path for ray 1?
Basic Techniques (3)

- Wave Optics: Interference of light waves
  - Understand the idea of superposition and interference.
  - Know the conditions for constructive and destructive interference of two light waves.
  - Be able to calculate phase difference from
    - Path length difference
    - Possible 180° shift in reflection.
  - Be able to deal with thin film interference
  - Have a general idea of double/multi-slit interference patterns
    - Where are dark/bright fringes?
    - How many 2nd order bright spots in between the main ones
Reminder

Interference of Two Light Waves

When two light waves meet at certain location, the resulting effect is determined by the superposition (i.e., sum) of the two individual waves.

- e.g. Two light waves with same color and amplitude.

\[ E_1 = E_0 \sin(\omega t-kx+\phi_1) = E_0 \sin(\omega t+\phi_1) \]
\[ E_2 = E_0 \sin(\omega t-kx+\phi_2) = E_0 \sin(\omega t+\phi_2) \]

\[ E = E_1 + E_2 = 2E_0 \cos(\Delta \phi/2) \sin(\omega t+ \phi) \]

\[ \Delta \phi = \phi_1 - \phi_2 \]
\[ \phi = (\phi_1 + \phi_2)/2 \]

\[ E_{\text{max}} = 2E_0 \cos(\Delta \phi/2) \]

- Constructive interference: \( \Delta \phi = 0, 2\pi, 4\pi, \ldots \) \( E_{\text{max}} = 2E_0 \)
- Destructive interference: \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \) \( E_{\text{max}} = 0 \)

The resulting light wave is highly dependent on \( \Delta \phi \)
Review: How to Calculate $\Delta \phi$?

For two interfering waves coming through different paths the phase difference:

$$\Delta\phi = \Delta\phi_{\text{at source}} + \Delta\phi_{\text{due to path}} + \Delta\phi_{\text{phase transition when reflected}}$$

- $=0$ in many cases
- $=k(r_2-r_1) = 2\pi/\lambda (r_2-r_1)$
- $n_1 < n_2? \pi:0$

where $r_1$ and $r_2$ are path lengths, $\Delta r = (r_1-r_2)$ is called path length difference.
Exercise 4: Thin Film Interference

Determine the minimum thickness of the film so gentleman A, who looks downwards near vertically, sees darkest. ($\lambda=550$ nm) (assuming normal incident angle)

Solution (see board):
A sees dark
→ 1 and 2 cancel each other (destructive interference)

\[ \Delta \phi_{12} = \frac{2\pi}{\lambda_n} \cdot 2t + 180^\circ = 3\pi \]

\[ \Rightarrow t = \frac{\lambda_n}{2} = \frac{\lambda}{n/2} = 189.6 \text{ nm.} \]

Note t is $\lambda$ dependent.

At which thickness B sees brightest?
Basic Techniques(4)

- Wave Optics: Diffractions
  - Understand general diffraction pattern
    - the size of central bright fringe
    - where are dark fringes.
  - Intrinsic optical resolution
  - Translate angular resolution to spatial resolution
Reminder:
Resolution of Single-slit and Circular Apparatus

Two separate beams each smeared due to diffraction

Rayleigh's Criterion

Single slit: \( \theta_{\text{min}} = \frac{\lambda}{D} \)
Circular opening: \( \theta_{\text{min}} = 1.22 \frac{\lambda}{D} \)

Intrinsic Resolutions!
Exercise 5: Resolution of Human Eye

- The typical pupil diameter of human eye at night time is $D=5\text{mm}$. The separation between head lights of a car is about 1.1m. In one evening, an observer is facing an approaching car 10 Km away. Can he distinguish the two head lights? Assume the wave length of the head light is 550nm.

- Solution: (see board)

\[
\theta_{\text{min}} = 1.22 \frac{\lambda}{D} = 1.22 \frac{550\text{nm}}{5\text{mm}} \approx 1.3 \times 10^{-4} \text{ Rad}
\]

\[
\Delta S_{\text{min}} \approx \theta_{\text{min}} \times L \approx 1.3 \times 10^{-4} \times 10000 \text{ m} = 1.3 \text{ m}
\]
Exercise 6: Laser Beam  
(Light as EM Wave)

- A uniform red ($\lambda=650\times10^{-9}$ m) laser beam in air has a diameter of 1mm and an average power of 10 mW.

$\Rightarrow$ What is the period of the laser light in air?  
$T=\frac{\lambda}{c} = \frac{650\times10^{-9}}{3\times10^{-8}} = 2.17 \times 10^{-15}$ s.

$\Rightarrow$ How much energy is delivered in one period of the beam?  
$U=PT = 10\times10^{-3} \times 2.17 \times 10^{-15} = 2.17 \times 10^{-17}$ J.

$\Rightarrow$ What is the magnitude of the Poynting vector of the beam?  
$S_{av}=I = \frac{p}{A} = \frac{10\text{mW}}{\pi (1\text{mm}/2)^2} = 1.3\times10^4 \text{W/m}^2$
Thank you and Good Luck !