Physics 11
Chapter 18: Ray Optics

"... Everything can be taken from a man but one thing; the last of the human freedoms — to choose one’s attitude in any given set of circumstances, to choose one’s own way."
Victor E. Frankl

"Your own mind is a sacred enclosure into which nothing harmful can enter except by your promotion." - Ralph Waldo Emerson

Reading: pages 574 – 602

Outline:

⇒ the ray model of light (PowerPoint)
⇒ reflection
  - specular and diffuse reflection
  - images from plane mirrors
⇒ refraction
  - Snell’s law
  - total internal reflection
⇒ image formation by refraction
⇒ thin lenses
  - ray tracing (PowerPoint)
  - focal point and focal length
  - magnification
  - real and virtual images
⇒ image formation with Spherical Mirrors
  - concave and convex mirrors
  - principle axis and radius of curvature
  - ray tracing for mirrors (PowerPoint)
⇒ the thin-lens / mirror equation and the magnification equation
  - sign conventions
  - lots of examples

Problem Solving

Whenever a light ray hits the interface between two transparent materials, generally some of the light is reflected (the angle of reflection equals the angle of incidence: $\theta_r = \theta_i$) and some of the light is transmitted or refracted. The angle of reflection equals the angle of incidence: $\theta_r = \theta_i$. The angle of the refracted ray is determined by Snell’s law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$ where $n$ is the index of refraction of the material which is given by $n = c/v$. Remember that in optics all angles are measured with respect to the normal.
When light hits the interface between a medium with a larger index of refraction and a medium with a smaller index of refraction (i.e. from water to air), it is possible for the light to be totally internally reflected. When this happens, no light at all escapes the medium with the larger index of refraction and 100% of the light is reflected. Total internal reflection will occur if the incident angle is greater than the critical angle, where $\theta_c$ is given by $\theta_c = \sin^{-1}(n_2/n_1)$.

You should know how to find the orientation, height and position of the image from a thin lens (both converging and diverging) and from a spherical mirror (both concave and convex) by using ray tracing. Ray tracing always involves drawing three light rays.

To find the orientation, height, and position of the image using a more mathematical approach, the thin-lens/mirror and magnification equations can be used.

The thin lens/mirror equation is 

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

where $s$ is the object distance, $s'$ is the image distance, and $f$ is the focal length.

The magnification equation is 

$$m = \frac{h'}{h} = -\frac{s'}{s}$$

where $h_i$ and $h_o$ are the image and object heights.

It is very important to know the sign conventions for thin lenses and spherical mirrors. They are listed below for your convenience.

$f$ is + for a concave mirror or converging lens
$f$ is - for a convex mirror or diverging lens

$s$ is + if the object is real
$s$ is - if the object is virtual (only possible with multiple lens/mirror systems)

$s'$ is + if the image is real
$s'$ is - if the image is virtual

$m$ is + for an image that is upright with respect to the object
$m$ is - for an image that is inverted with respect to the object
Example Problems from Chapter 18

Problem 1
At high noon, the sun is almost directly above (about 2.0° from the vertical) and a tall redwood tree casts a shadow that 10.0 ft long. How tall is the redwood tree?

Problem 2
You shine your laser pointer through the flat glass side of a rectangular aquarium at an angle of incidence of 45°. The index of refraction of this type of glass is 1.55.

(a) At what angle from the normal does the beam from the laser pointer enter the water inside the aquarium? (b) Does your answer to part a depend on the index of refraction of the glass?

Problem 3
A ray of light traveling through air encounters a 1.2-cm-thick sheet of glass at a 35° angle of incidence. How far does the light ray travel in the glass before emerging on the far side?
Problem 4
The glass core of an optical fiber has index of refraction 1.60. The index of refraction of the cladding is 1.48. What is the maximum angle between a light ray and the wall of the core if the ray is to remain inside the core?

Problem 5
An object is 15 cm in front of a converging lens with a focal length of 10 cm. Use ray tracing to determine the location of the image. What are the image characteristics: (i) real or virtual?, (ii) upright or inverted?, (iii) smaller, larger or same?, and (iv) the image location?

Problem 6
A light bulb is 60 cm from a concave mirror with a focal length of 40 cm. A 5-cm-long mascara brush is held upright 20 cm from the mirror. Use ray tracing to determine the location of the image. What are the image characteristics: (i) real or virtual?, (ii) upright or inverted?, (iii) smaller, larger or same?, and (iv) the image location?
Problem 7
A 2.0-cm tall object is 15 cm in front of a converging lens that has a 20 cm focal length. Where is the image located and what is the height of the image? What are the characteristics of the image (real or virtual, upright or inverted, enlarged or reduced)?

Problem 8
A 1.0-cm tall object is 60 cm in front of a diverging lens that has a -30 cm focal length. Where is the image located and what is the height of the image? What are the characteristics of the image (real or virtual, upright or inverted, enlarged or reduced)?
Problem 9
A 3.0-cm tall object is 15 cm in front of a convex mirror that has a -25 cm focal length. Where is the image located and what is the height of the image? What are the characteristics of the image (real or virtual, upright or inverted, enlarged or reduced)?

Problem 10
A 3.0-cm tall object is 45 cm in front of a concave mirror that has a 25 cm focal length. Where is the image located and what is the height of the image? What are the characteristics of the image (real or virtual, upright or inverted, enlarged or reduced)?