PHYS 1442 – Section 001
Lecture #15

Wednesday, August 5, 2009
Dr. Jaehoon Yu

- Chapter 23
  - Index of Refraction
  - Snell's Law of Refraction
  - Total Internal Reflection
  - Thin Lenses
  - The Thin Lens Equation

Today's homework is None!!

Announcements

- Final comprehensive exam
  - Date and time: 6 – 7:30pm, next Wednesday, Aug. 12
  - Covers from CH16 – CH23 + Appendix A.1 – A.8
  - There will be a help session Monday, Aug. 10
    - Be sure to bring your own problems
- Reading assignments
  - CH23.9 & 23.10
- Remember that the due for the planetarium extra credit is at the beginning of the exam next Wednesday, Aug. 12

Reminder: Special Projects

1. Derive the unit of speed from the product of the permitivity and permeability, starting from their original units. (5 points)
2. Derive and compute the speed of light in free space from the four Maxwell's equations. (20 points for derivation and 3 points for computation.)
3. Compute the speed of the EM waves in copper-oxide, water and one other material which is different from other students. (3 points each)

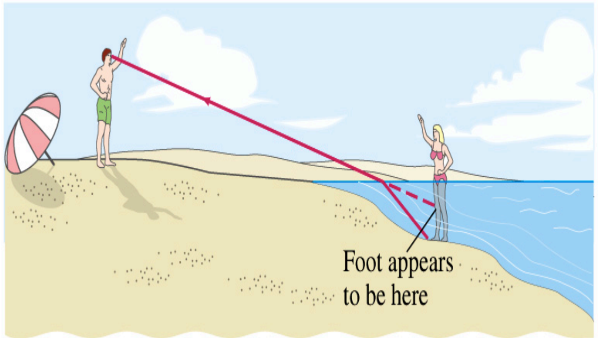
- Due for these projects are the start of the class next Monday, Aug. 10!

Index of Refraction

- Index of refraction of a material is defined as:
  - The inverse of the relative of speed light in a material
  - So mathematically, one would define it as

$$n = \frac{c}{v}$$

- What is the refraction?
  - The phenomena that the direction of light changes when it passes through the boundary of two transparent materials whose indices of refraction are different
  - How is this different than reflection?



Example 23 – 5

Speed of Light in Diamond. Calculate the speed of light in diamond.

What is the relationship between speed of light and the index of refraction?

$$n = \frac{c}{v}$$

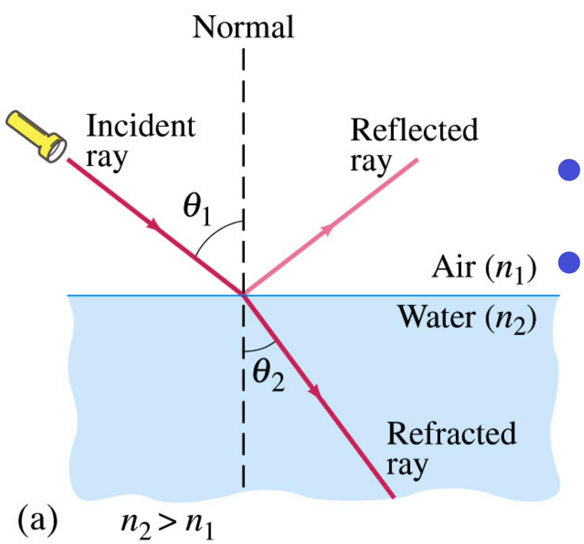
Index of refraction of diamond is, from table 23 -1 $n = 2.42$

So the speed of light in diamond is

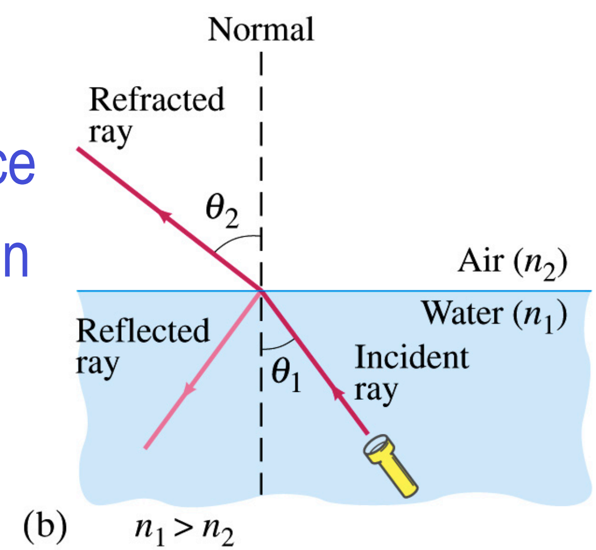
$$v = \frac{c}{n} = \frac{c}{2.42} = 0.413c = \frac{3\times 10^{8}}{2.42} = 1.24\times 10^{8}\ m/s$$

Refraction cont'd

- When refraction occurs, it normally comes with a partial reflection of the light
- The light bends towards the normal incident plane when the index of refraction changes from small to large
- The light bends away from the normal incident plane if the index of refraction changes from large to small



- θ_1: Angle of Incidence
- θ_2: Angle of refraction



Snell's Law of Refraction

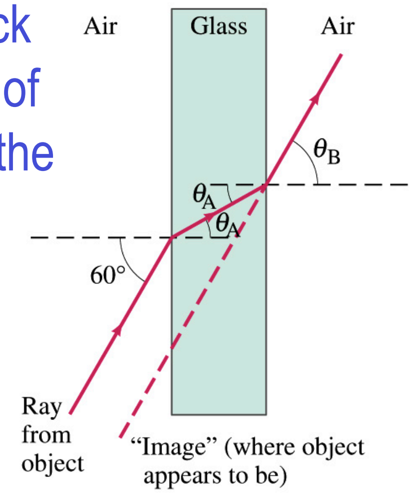
- The angle of refraction depends on the speed of light in the two media and the incident angle.
- Willebrord Snell analytically derived the relationship between the angle of incidence and refraction in 1621

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

- This is the basic Law of Refraction
- **Does this law explain the bend angles we discussed in the previous page?**

Example 23 – 6

Refraction through flat glass. Light travels through a uniformly thick glass at an incident angle of 60o as shown in the figure. If the index of refraction of the glass is 1.5, (a) what is the angle of refraction θ_A in the glass and (b) what is the light's emerging angle θ_B?



(a) From Snell's law, we obtain

$$n_1 \sin\theta_1 = n_A \sin\theta_A$$

$$\sin\theta_A = \frac{n_1 \sin\theta_1}{n_A} = \frac{1.0 \cdot \sin 60^\circ}{1.5} = 0.577$$

$$\theta_A = \sin^{-1}(0.577) = 35.2^\circ$$

(b) Again from Snell's law, we obtain

$$n_A \sin\theta_A = n_1 \sin\theta_B$$

$$\sin\theta_B = \frac{n_A \sin\theta_A}{n_1} = \frac{1.5 \cdot \sin 35.2^\circ}{1.0} = \frac{1.5 \cdot 0.577}{1.0} = 0.866$$

$$\theta_A = \sin^{-1}(0.866) = 60^\circ$$

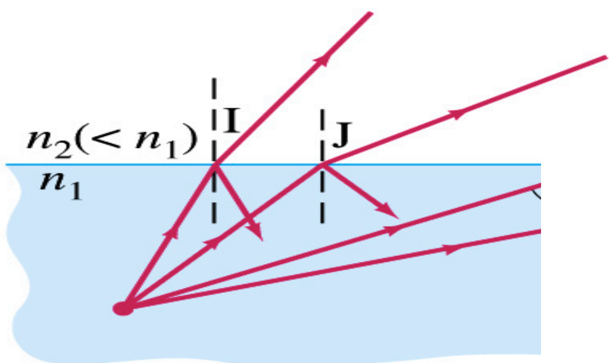
The lights comes out at the same angle as it went in. The image will look shifted slightly.

Total Internal Reflection

- What happens when the light passes through the boundary of two media from larger index of refraction to smaller one?
  - Right… It bends away from the normal incident plane
  - And has some partial reflections
- But when the incident angle is above certain value, the entire light reflects back into the first medium

$$\sin\theta_c = \frac{n_2}{n_1}\sin 90^o = \frac{n_2}{n_1}$$

- This phenomena is called the total internal reflection



Can total internal reflection happen in all cases? Nope. Then when can it?

When the light enters from larger to smaller index of refraction material.

Conceptual Problem Total Internal Refl.

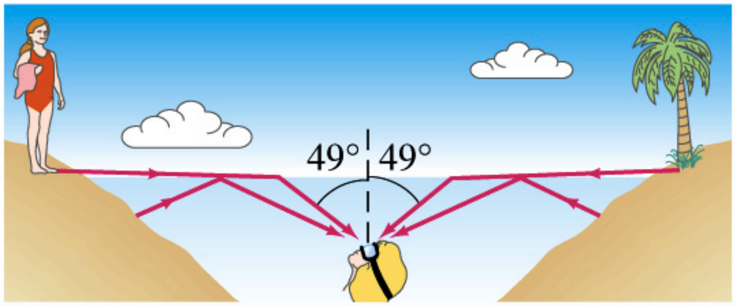
- View up from under water: What do you think a person would see if she looks up from beneath the undisturbed perfectly smooth surface of water?

What is the critical angle for air-water interface?

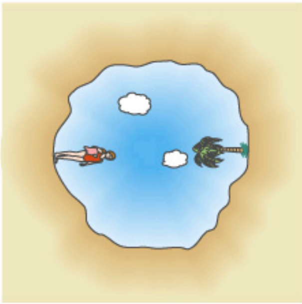
$$\sin\theta_c = \frac{n_2}{n_1} = \frac{1.0}{1.33} = 0.75$$

$$\theta_c = \sin^{-1}(0.75) = 49^\circ$$

The person will see the world compressed in a circle that forms a 49° angle relative to the eyes. Beyond that angle, she will see the bottom of the pool.

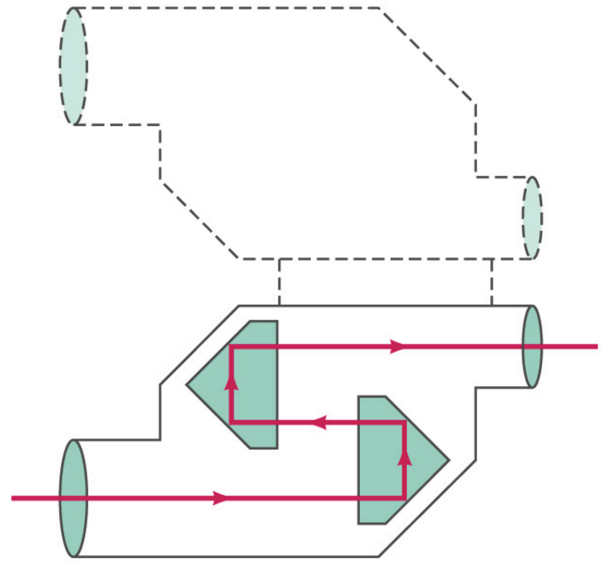


(a)


(b)

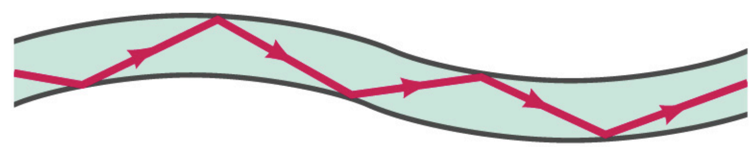
Total Internal Reflection Devices

- Glass Prisms: What should the angle of the prisms be for total internal reflection? 41.8°



- Fiber optic cables: glass or plastic fibers with a few μm diameter. How do you think it works?

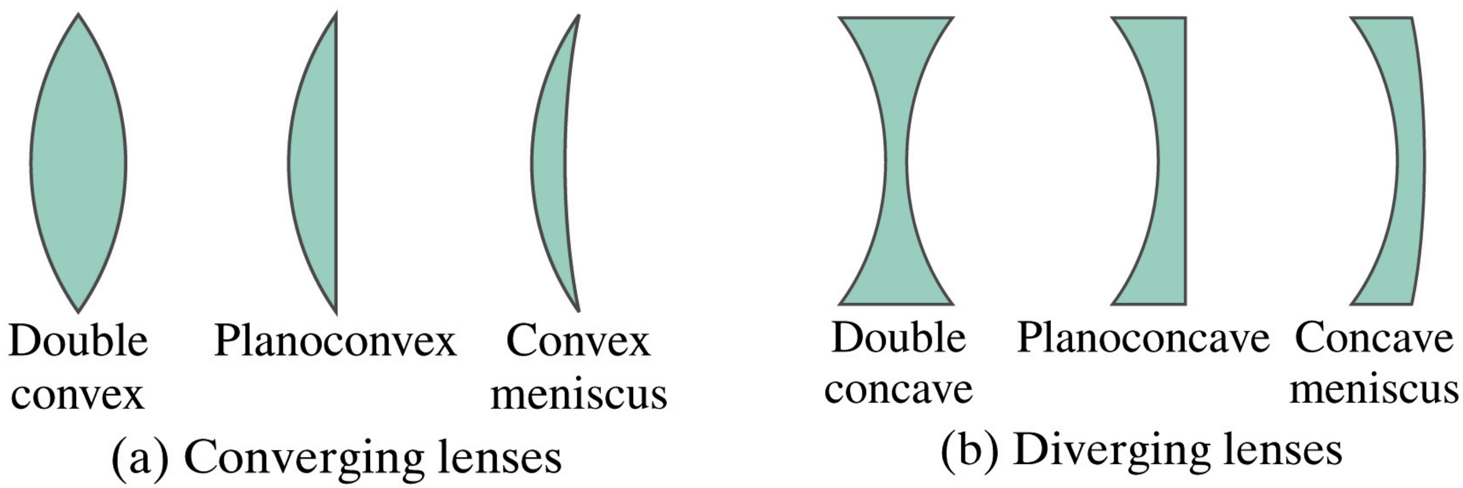
Light signal gets carried through the fiber with virtually no loss since the incident angle is larger than the critical angle!



Some cables can carry up to 1 Tera bit/sec information!!

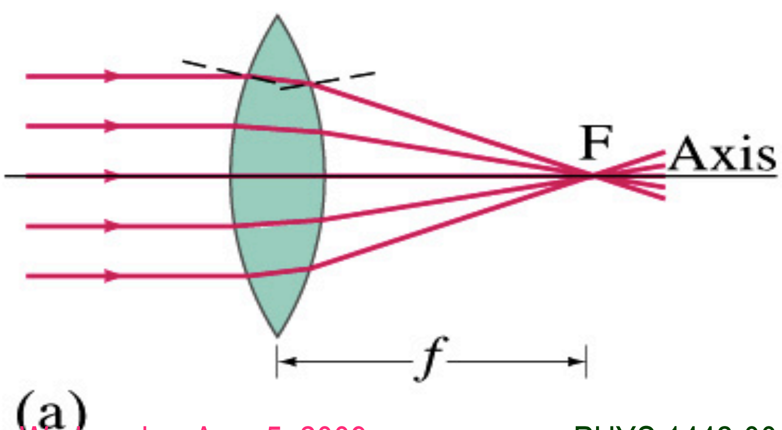
Thin Lenses

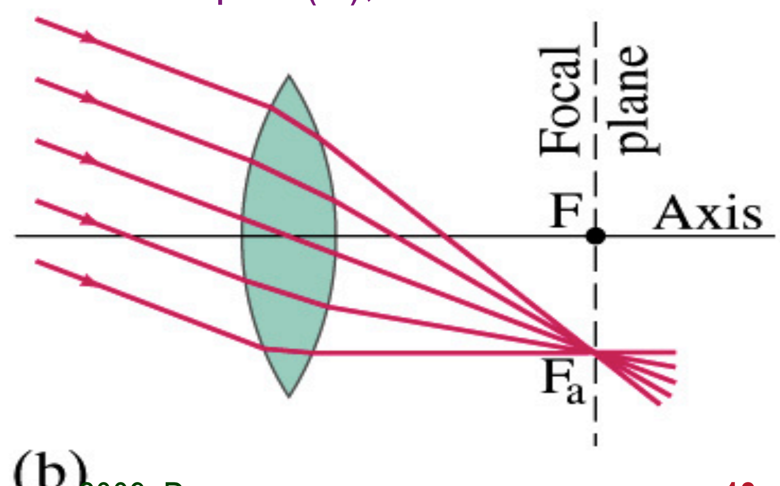
- What is the lens?
  - A simple optical device that transmits and and refracts the light either to converge or diverge the beam of light
  - Lenses have been used since as early as 13th century!!
  - Where are they used in?
    - Eye glasses, telescopes, cameras, medical imaging devices, etc
- Thin lenses are usually circular, and its two faces are usually portions of a sphere
  - Two styles: Convex and concave



Thin Lenses – Ray Tracing

- When performing ray tracing in lenses we assume that
  - The lenses are made of transparent glass or plastic so index of refraction is larger than the air.
  - The lenses are so thin that they refract the ray only at the center not at the surface. They are "thin" when the thickness is much smaller than the diameter.
  - If the ray parallel to the axis fall on a thin lens, they will be focused to a point called the "focal point", F.
  - The distance from the focal point to the center of the lens is called the focal length, f.
  - Lens power is called the power, $P=1/f$. Unit is diopter (D), 1/m

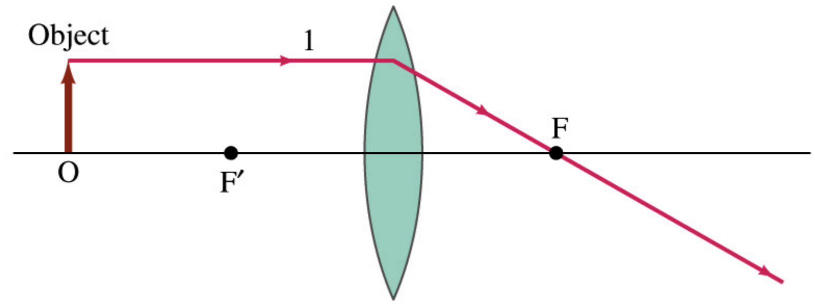


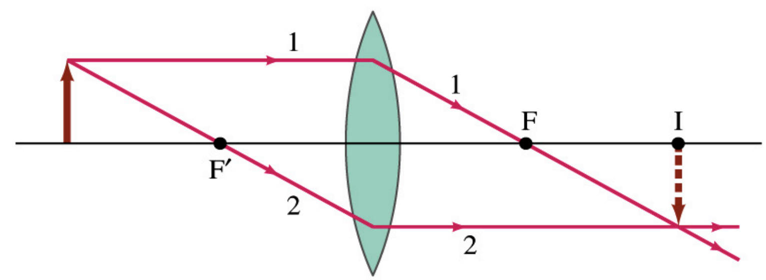


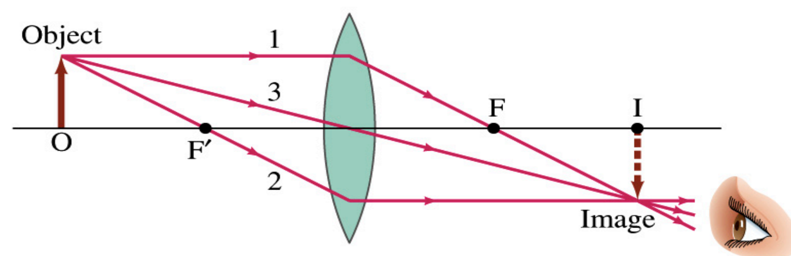
Thin Lenses – Ray Tracing

- Need at least two rays departing from a given point of an object to trace and find the image locations

1. A ray leaves one point on object, going parallel to the axis and refracts through focal point behind
2. A ray passes through F' in front of the lens and parallel to the axis behind the lens
3. A ray passes through the center of the lens



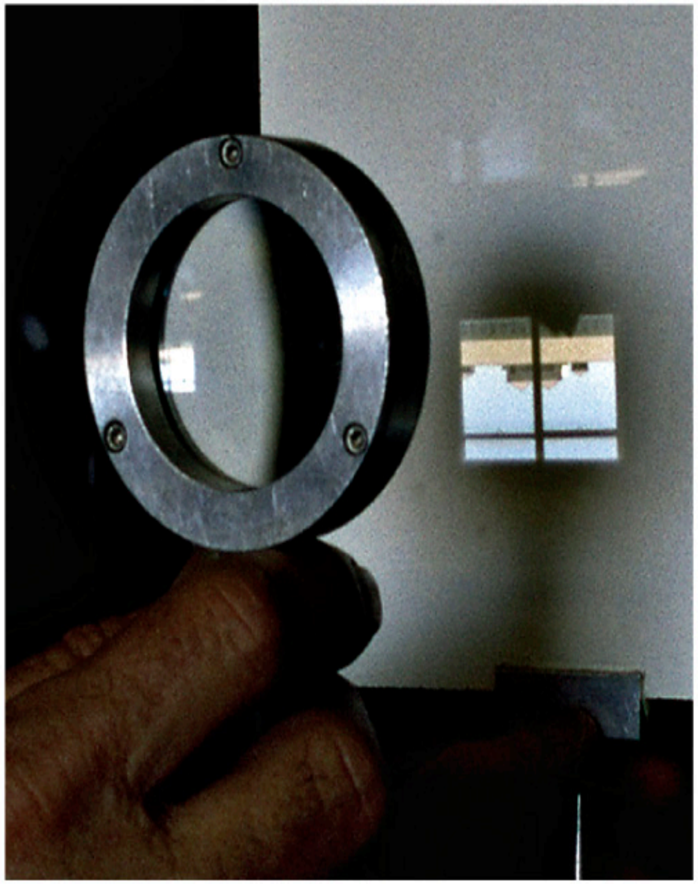




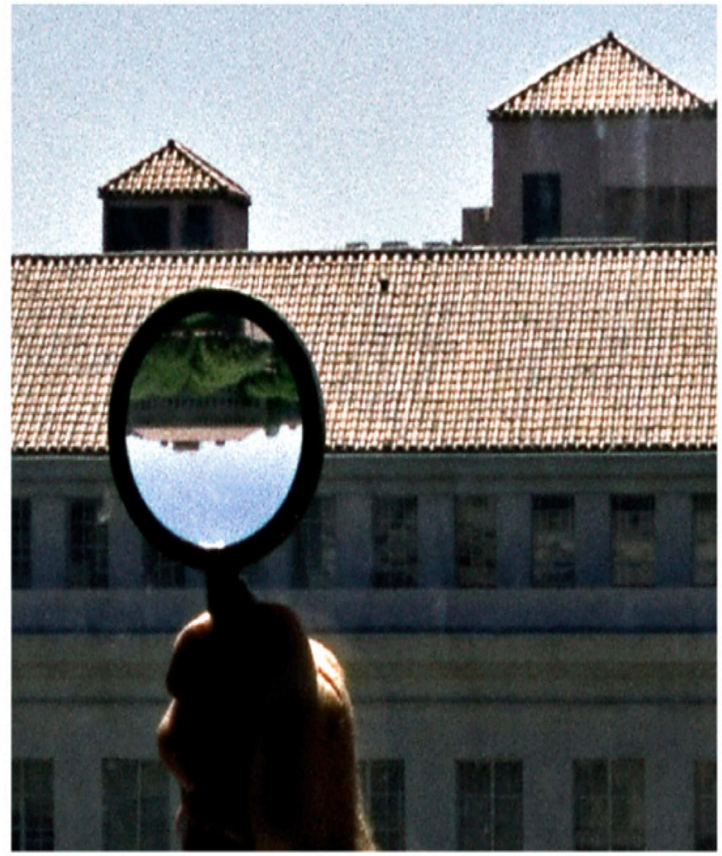
What does this tell you?

The image is real but will be inverted!!

How do images look through a convex lens?



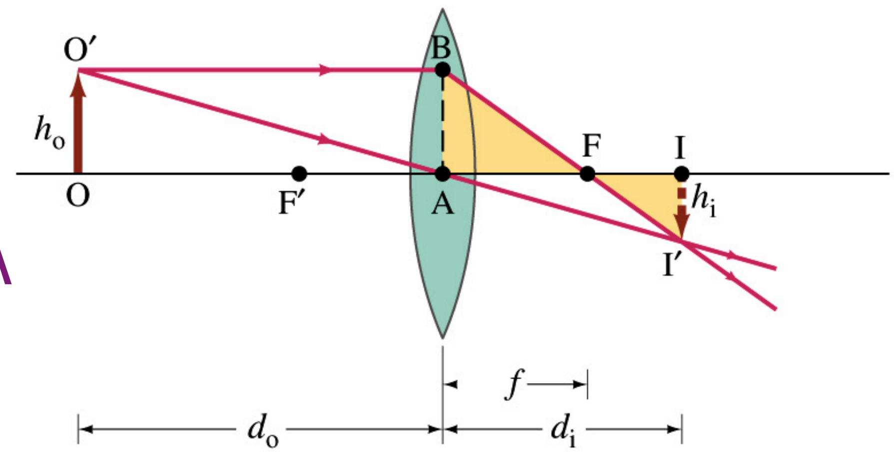
(a)



(b)

The Thin Lens Equation

- So what is the rule for image location and magnification for lenses?



- From the figure on the right
  - The right triangles FII' and FBA are similar since angles AFB and IFI' are the same, thus

$$\frac{h_i}{h_o} = \frac{d_i - f}{f}$$

  - Now, the triangles OAO' and IAI's are similar as well since the angle OAO' and IAI's are the same, thus $\frac{h_i}{h_o} = \frac{d_i}{d_o}$
  - Through replacing and reorganizing, we obtain $\frac{d_i}{d_o} = \frac{d_i - f}{f}$ **Thus** $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$

The thin lens equation

Thin Lens Equation –sign conventions

- The focal length is positive for converging lenses and negative for diverging lenses
- The object distance is positive if the object is on the side of the lens from which the light is coming in, negative otherwise
- The image distance is positive if the image is on the opposite side of the lens from the side light is coming in
- The height of the image is positive if the image is upright and negative if inverted relative to the object

Lens magnification
$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

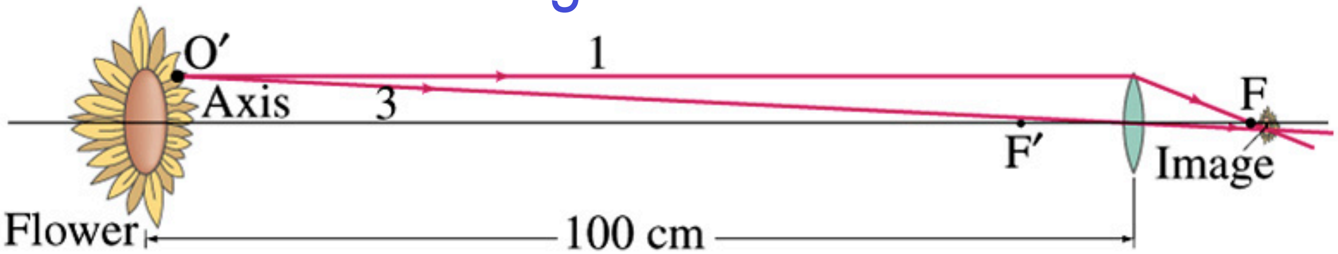
How do we solve lens problems?

- Identify the parameters given in the problems
  - Object distance, Lens diameter, object height, Image distance
- Draw a ray diagram, choosing one point of the object and minimum two rays from the point
- Solve for unknowns using the thin lens equation and the magnification equation
- Follow the sign conventions
- Check the analytical answer against result from the ray diagram

Example 23 – 9

Image formed by converging lens. What is (a) the position and (b) the size of the image of a 7.6cm high flower placed 1.00m from a +50.0-mm focal length camera lens?

Ray diagram



From thin lens equation, we obtain:

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{0.05} - \frac{1}{1} = \frac{19}{1}$$

So the distance to the image, d_i, is

$$d_i = 1/19 = 0.0526m = +5.26(cm)$$

The magnification is

$$m = -\frac{d_i}{d_o} = -\frac{5.26}{100} = -0.056$$

So the height of the image h_i

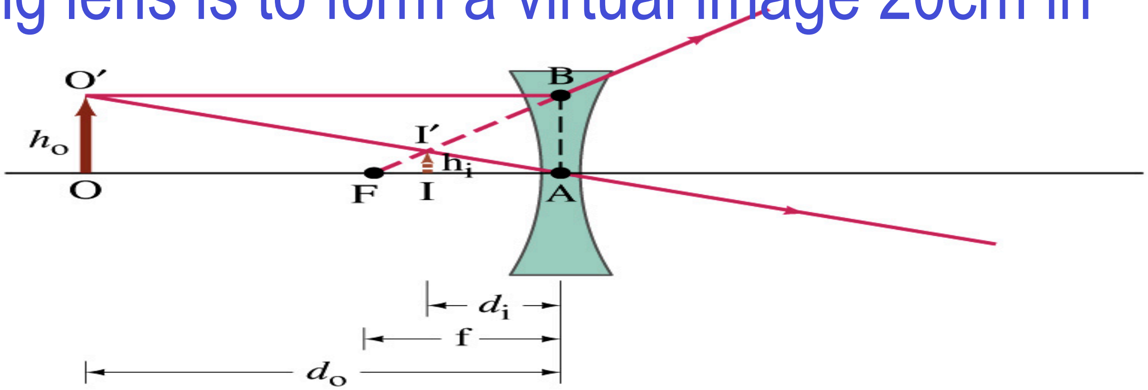
$$h_i = m \cdot h_o = -0.056 \cdot 0.076 = -0.004 = -0.4(cm)$$

What does this mean? The image is smaller and upside-down.

Example 23 – 11

Diverging lens. Where must a small insect be placed if a 25-cm focal length diverging lens is to form a virtual image 20cm in front of the lens?

Ray diagram



Since it is a diverging lens, its focal length is $f = -25(cm)$

And since the image is virtual, the distance to the image, d_i, is $d_i = -20(cm)$

From the thin lens equation, we obtain

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} = \frac{1}{-0.25} - \frac{1}{-0.2} = \frac{-4+5}{1.00} = \frac{1}{1.00}$$

$$d_o = 1(m) = 100(cm)$$

The image is always virtual for diverging lenses.

Congratulations!!!!

You have survived me!!

You all have have been fantastic!!!

I am truly proud of you!

Good luck with your exam!!!

Have a great remainder of the summer!!