

Reflection and Refraction of Light

Physics 102

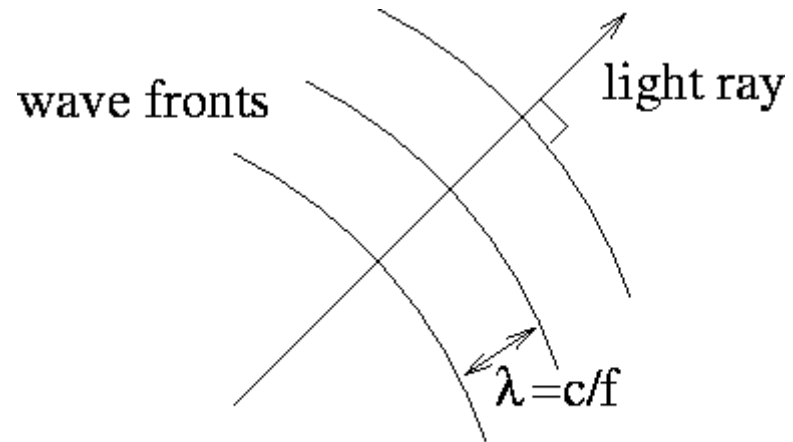
28 March 2002

Lecture 6



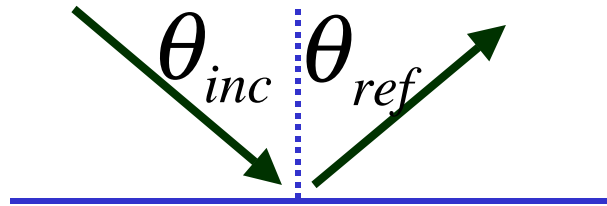
Light waves and light rays

- Last time we showed:
 - ◆ Time varying B fields \Rightarrow E fields \Rightarrow B fields to create a self-sustaining, propagating electromagnetic wave
 - ◆ EM waves are *transverse*, and travel at the speed of light
in fact, light is a form of electromagnetic radiation
- We can think of light as a wave or as a particle.
 - ◆ When the wavelength is much smaller than the optics, we use “rays”
 - ◆ next week we consider wave aspects
 - ◆ ...and later, particle aspects.

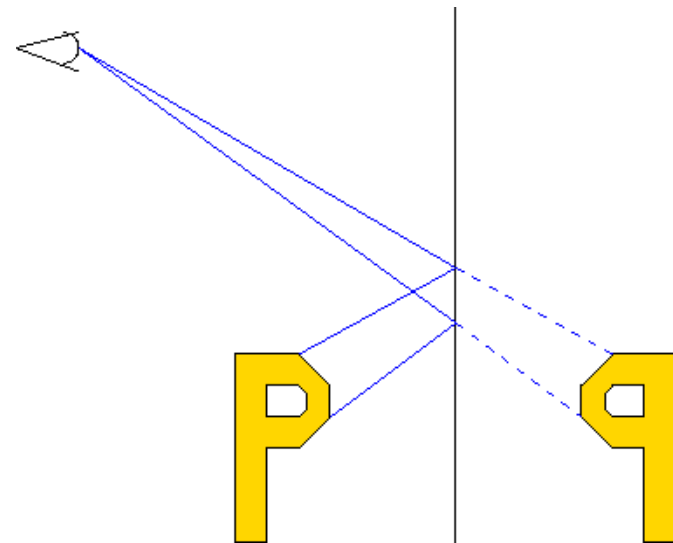


Reflection of light

- When light reflects from a surface:
angle of incidence = angle of reflection



- The image formed in a plane mirror is upright, the same size as the object, and at the same distance behind the mirror as the object is in front.
- The image is a virtual image, as the light rays don't pass through it.



What is wrong with this?



Manet's [The Bar at the Folies Bergeres](#)

Does Venus see herself in the mirror?



Venus and Cupid by
Diego Velasquez

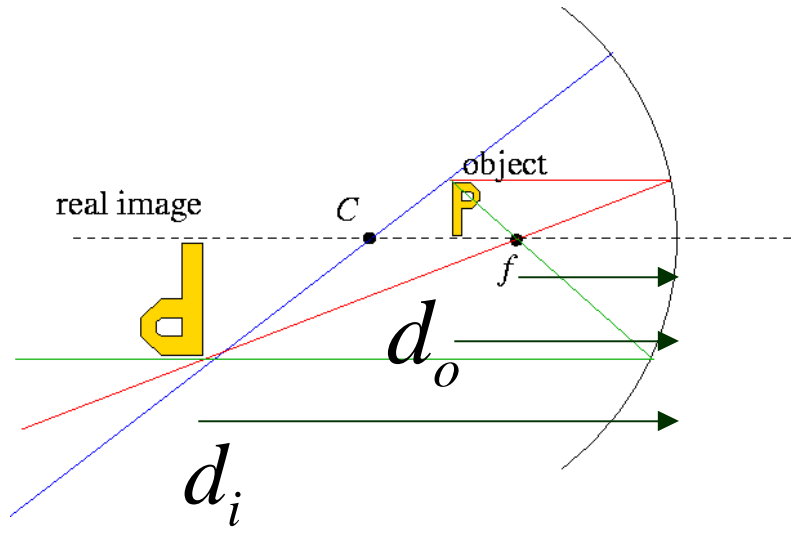
- A. No, she sees us
- B. Yes, she sees herself
- C. Can't tell with the above picture.

Spherical mirrors

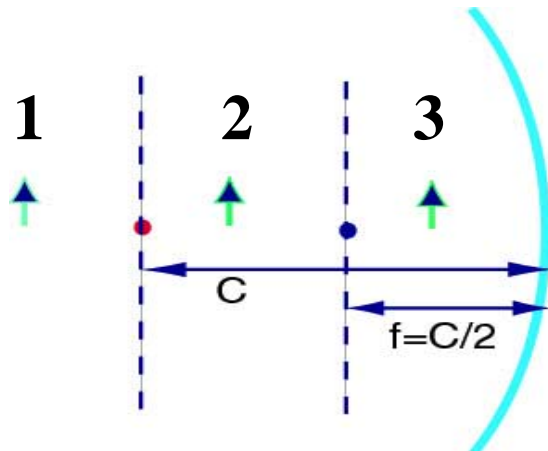
This past week you found that the image and object distances are related to the focal length by:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

with magnification: $m = -\frac{d_i}{d_o}$



For Concave Mirrors:

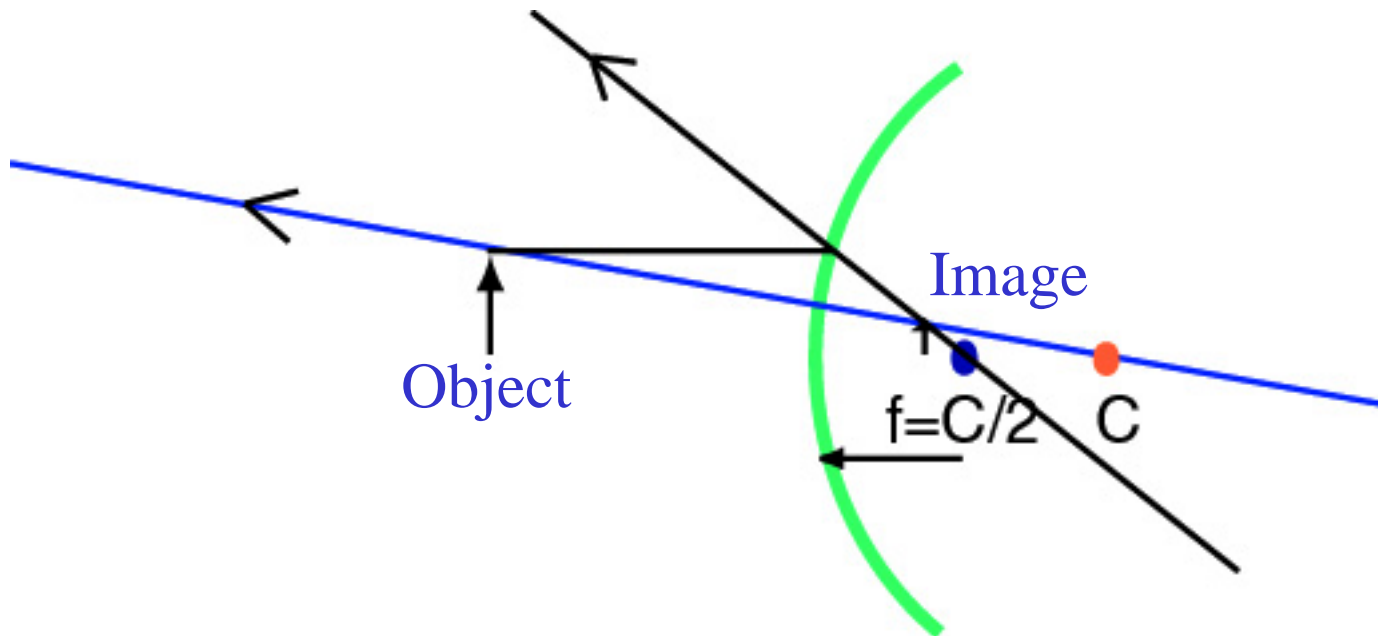


Position	Type	Magnification
Object at 1	Real	Inverted & Smaller
Object at 2	Real	Inverted & Larger
Object at 3	Virtual	Upright & Larger (makeup mirror)

**You are in WAWAs to buy health food.
You can't find any and so scan the store
by looking in the security mirror. The
mirror and image are:**

- A. Concave and Real
- B. Concave and Virtual
- C. Convex and Real
- D. Flat and Virtual
- E. Convex and Virtual

For a convex mirror, the image is **always** virtual, upright, and smaller.



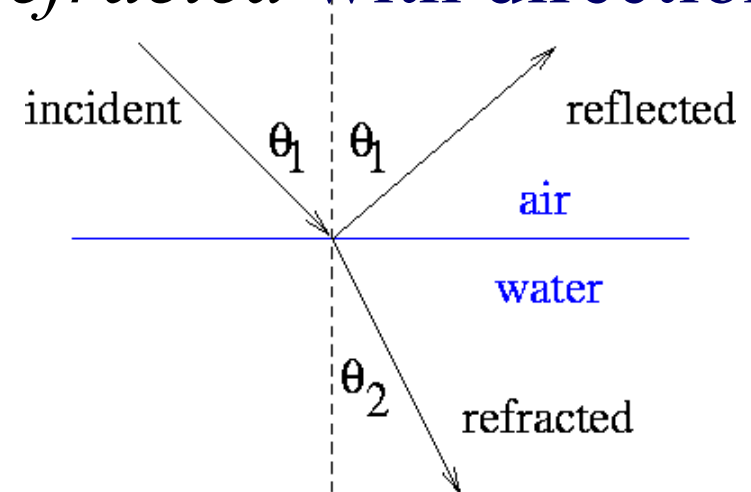
How should we think of the diverging rays?

Index of refraction and Snell's Law

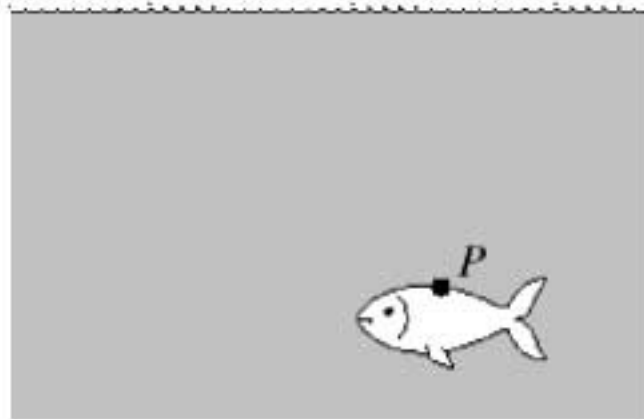
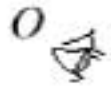
- Light travels **slower** in a material than in a vacuum but the *frequency* of light remains the same.
- The velocity ratio is the “index of refraction”: $n=c/v$. Generally, $n>1$, but n is often very close to 1 (for air, $n=1.0003$).
- When light travels from one medium to another part is reflected and part is *refracted* with direction given by Snell's Law:

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

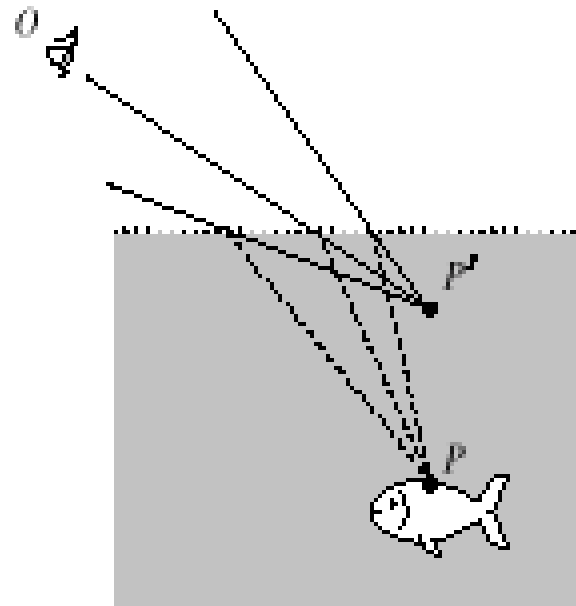
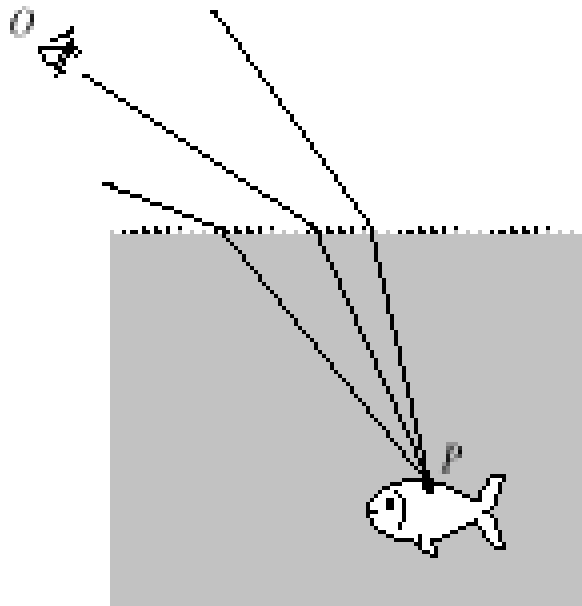
(NB: light bends towards normal in denser medium)



A fish swims below the surface of the water at P . An observer at O sees the fish at



- A. a greater depth than it really is.
- B. the same depth.
- C. a smaller depth than it really is.



Total internal reflection

- Going from a more optically dense medium (e.g., water) to a less dense medium (e.g., air), the refraction angle is 90° at the “critical angle” of incidence.

- The critical angle is

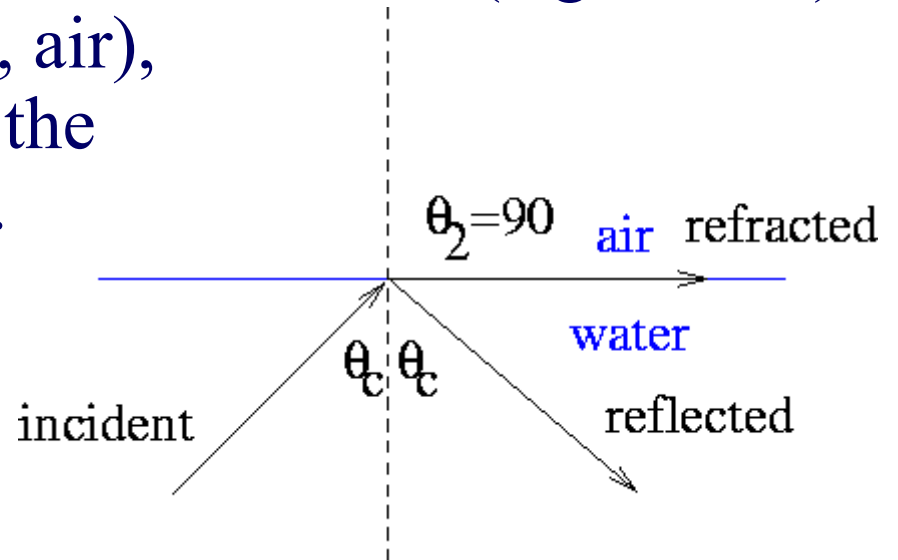
$$n_1 \sin \theta_c = n_2 \sin \theta_2$$

$$\sin \theta_c = n_2 / n_1$$

$$= 1 / 1.333$$

$$\Rightarrow \theta_c = 48.7^\circ$$

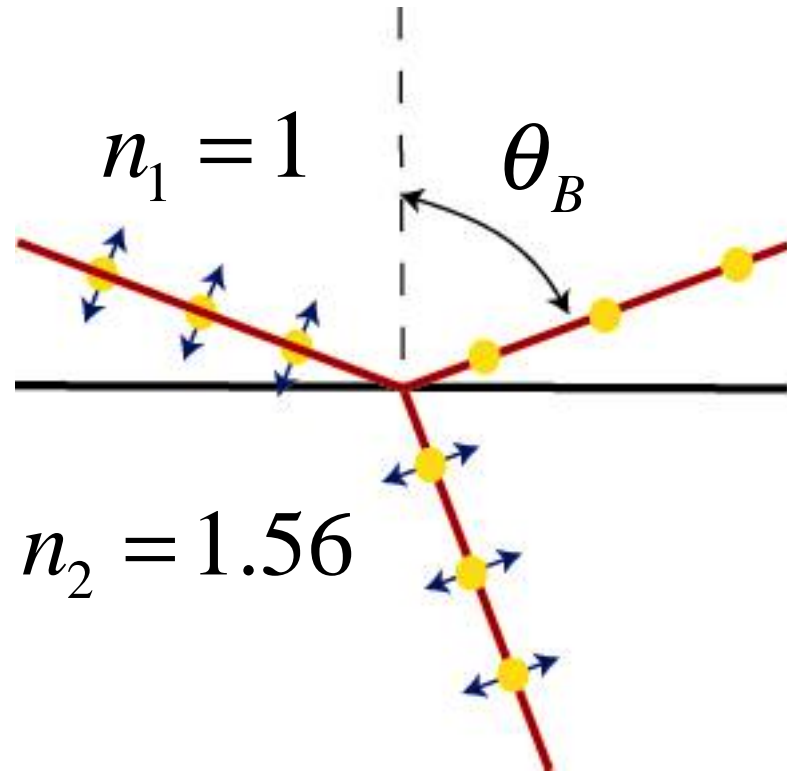
- For incident angles greater than the critical angle, “total internal reflection” takes place.



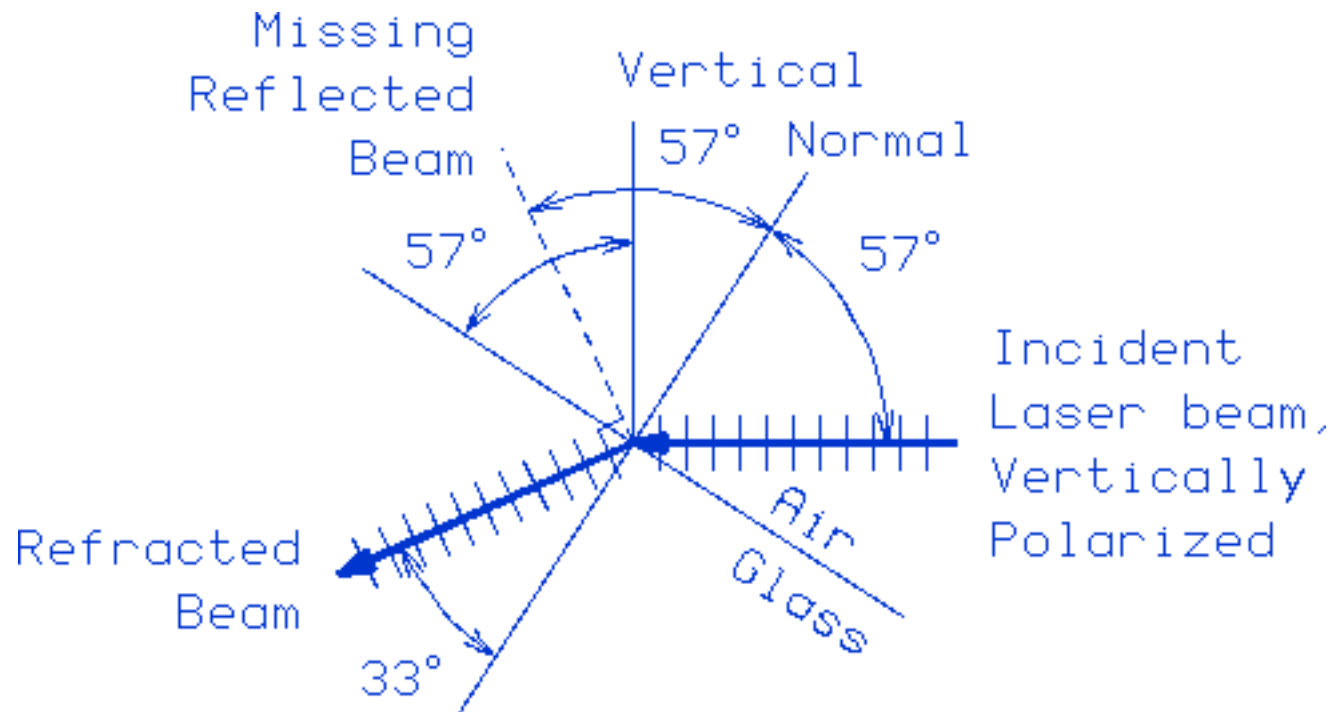
Brewster's Angle

- Light can be polarized on reflection from a surface
- Light is partially polarized parallel to the surface (e.g., horizontally when reflecting off a lake)
- The polarization is 100% when the incident angle is the “Brewster angle”

$$\begin{aligned}\tan \theta_B &= \frac{n_2}{n_1} \\ &= \frac{1.56}{1} \\ \Rightarrow \theta_B &= 57^\circ\end{aligned}$$

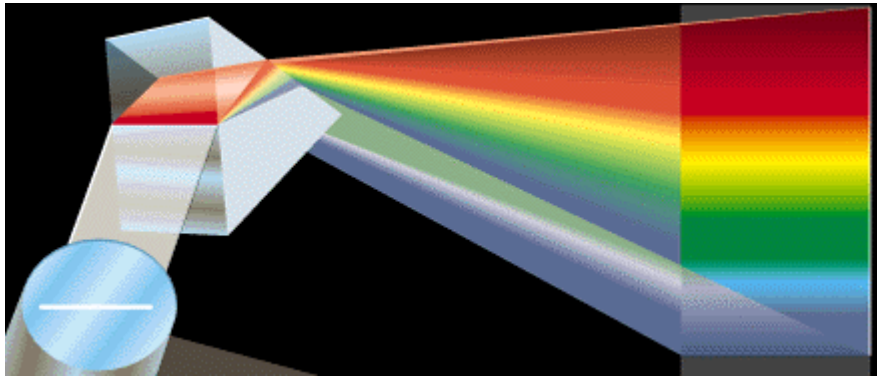


Brewster's Angle Demo: Geometry



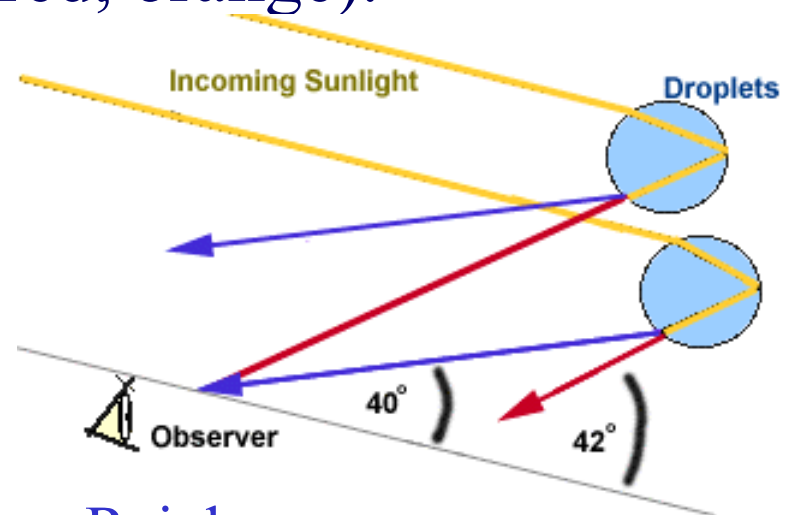
Prisms and the dispersion of light

- The index of refraction typically depends slightly on λ (normally higher for shorter wavelength light).
- Recall: going into an optically denser medium, light is refracted towards the normal.
- Shorter wavelengths (violet, blue) are thus refracted more than longer wavelengths (red, orange).



Picture copyright 1994 by Encyclopedia Britannica

Prism



Rainbow

Lenses

- Light incident on a lens is refracted at entry and exit.
- Converging lenses focus parallel rays through a real focal point.
- Diverging lenses focus rays through a virtual focus point.

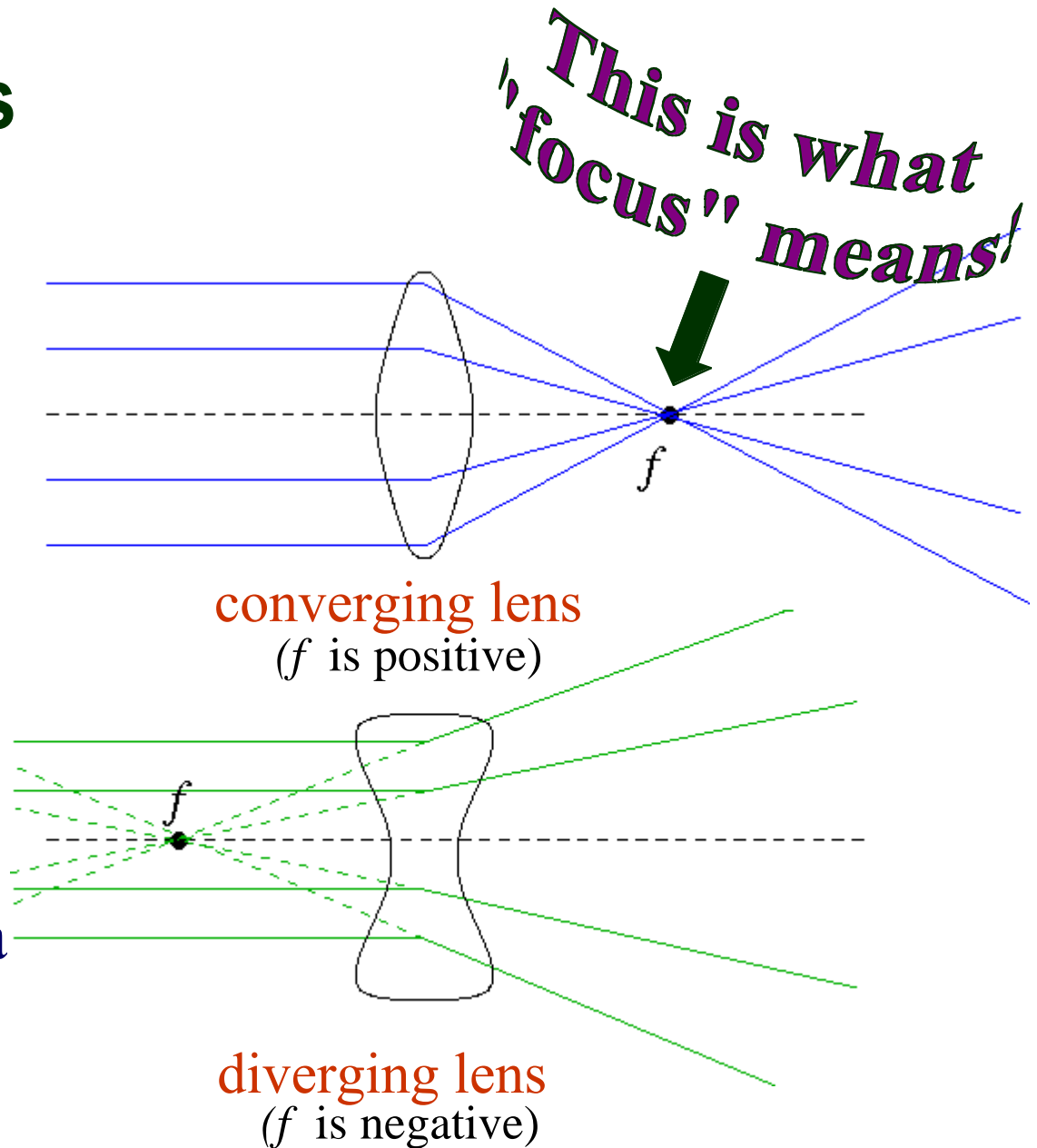
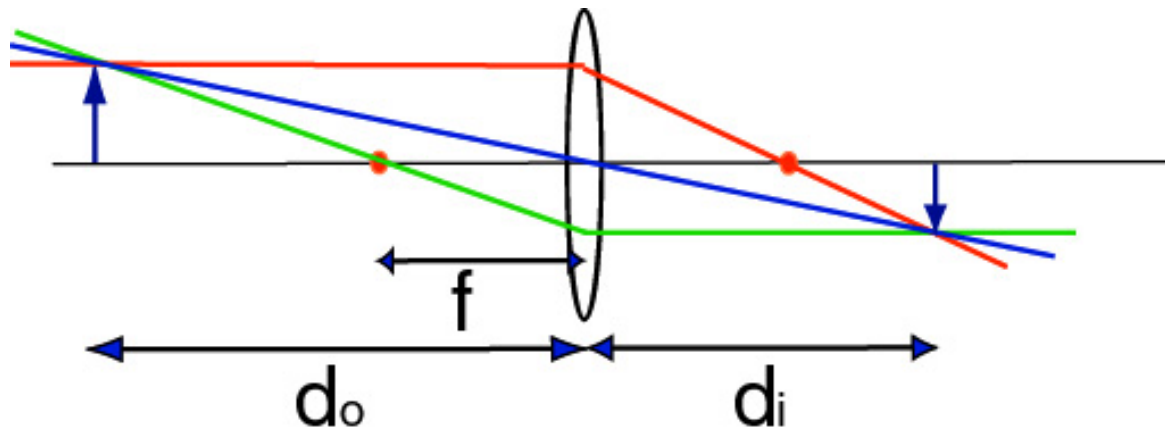


Image formation with lenses

Just as for mirrors, RAY TRACE with three magic lines to locate the image.

Thin lens equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ $m = -\frac{d_i}{d_o}$

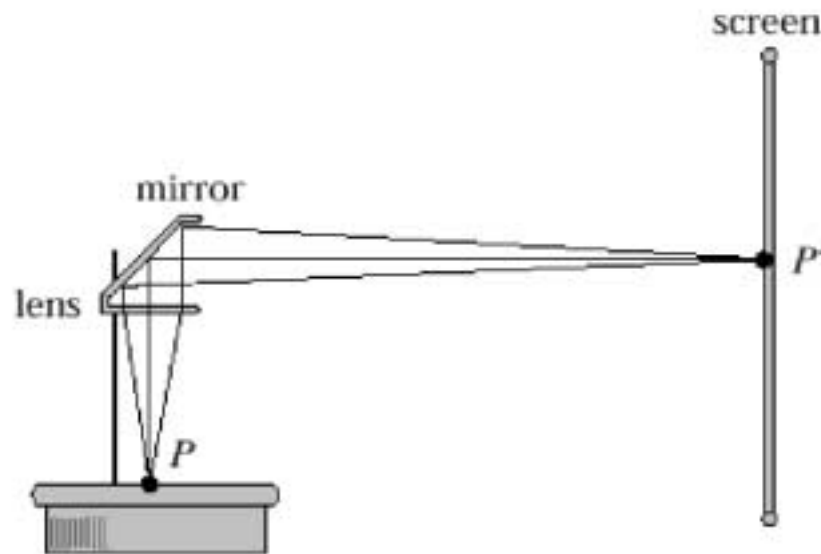
Signs: f positive for a converging lens, negative for diverging one
 d_o is positive for a real object, negative for a virtual one
 d_i is positive for a real image, negative for a virtual one



Note: blue line is through center of lens, not center of curvature!

Note: d_i is positive when on the right (unlike for mirrors).

The lens in an overhead projector forms an image P' of a point P on an overhead transparency. If the screen is moved closer to the projector, the lens must be:



- A. moved up
 - B. left where it is
 - C. moved down
- to keep the image in focus.

A lens is used to image an object onto a screen. If the right half of the lens is covered,

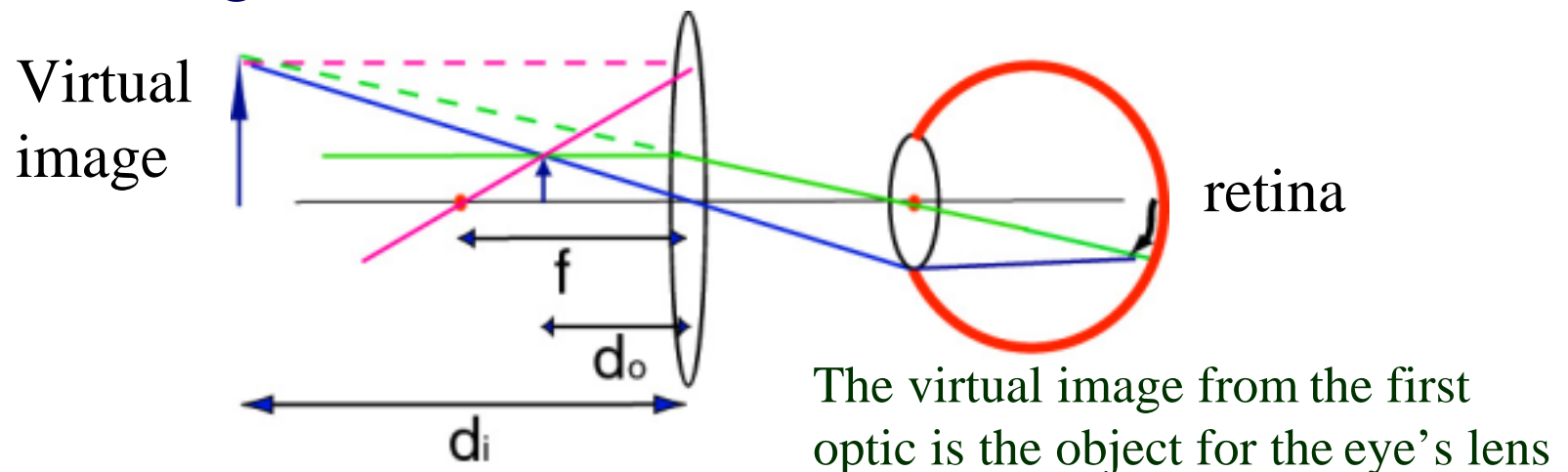
- A. the left half of the image disappears.
- B. the right half of the image disappears.
- C. the entire image disappears.
- D. the image becomes fuzzy.
- E. the image becomes faint.

The magnifying glass

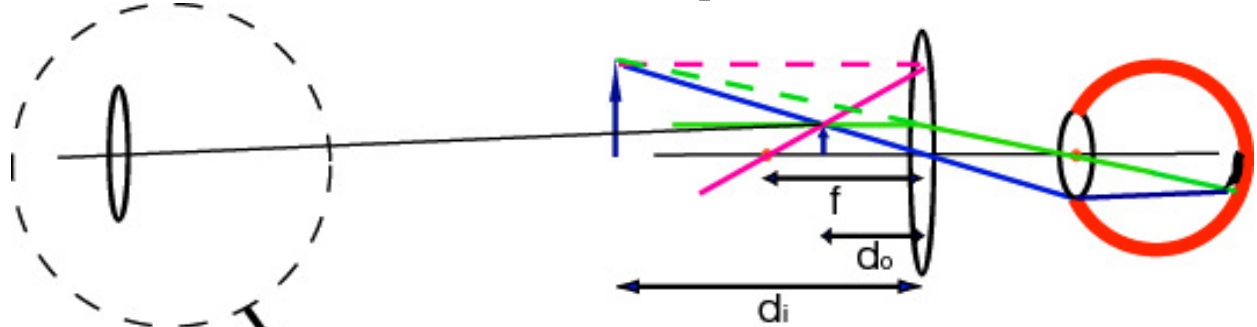
The closest an object can be and still be focused by the eye is the “near point” at roughly 25 cm.

Closer objects appear larger (angular size $\sim h/d$ radians), so they have maximum apparent size at the near point.

If the eye is held near a converging lens, and an object is brought within the focal distance (~ 10 cm), a **large** virtual image is formed.

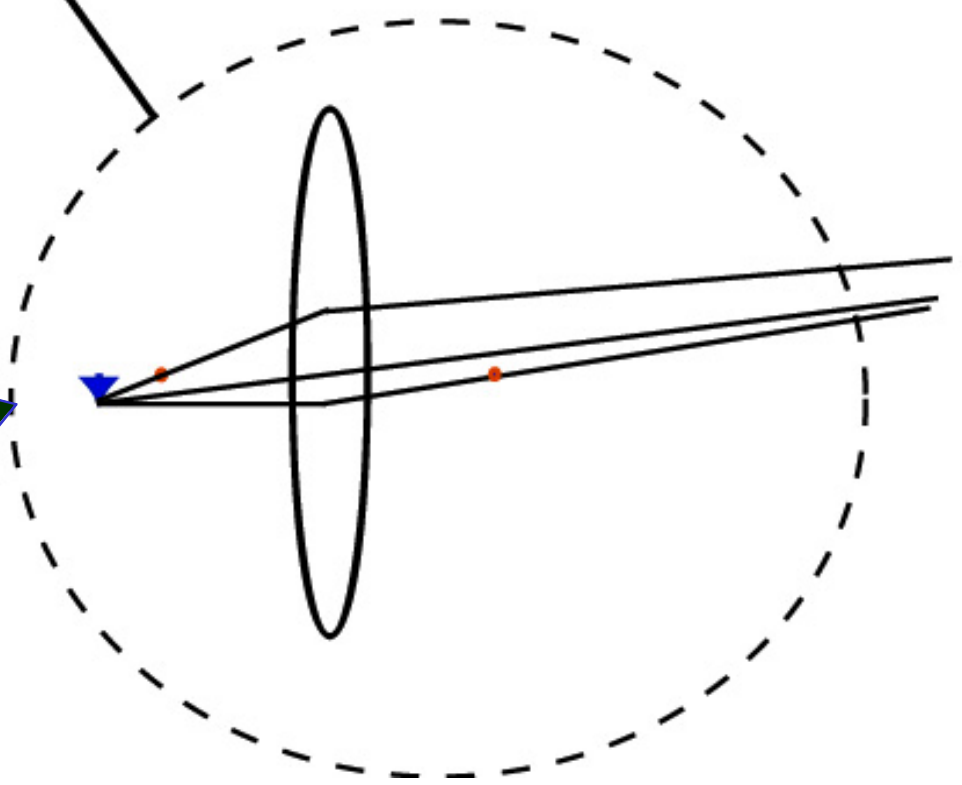
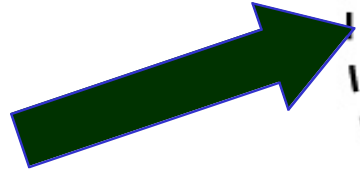


The microscope



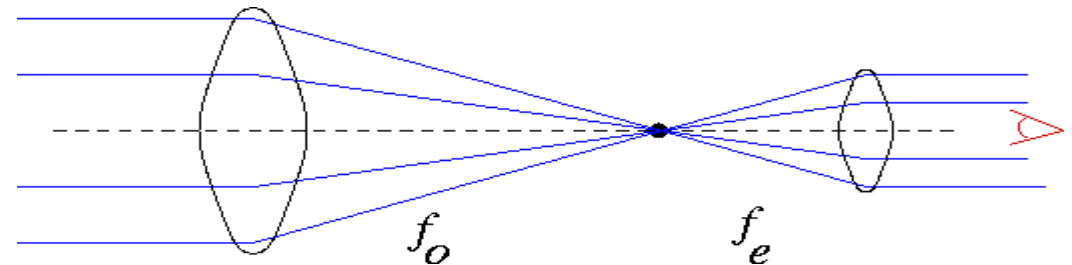
Systems of lenses can be combined.

Tiny object

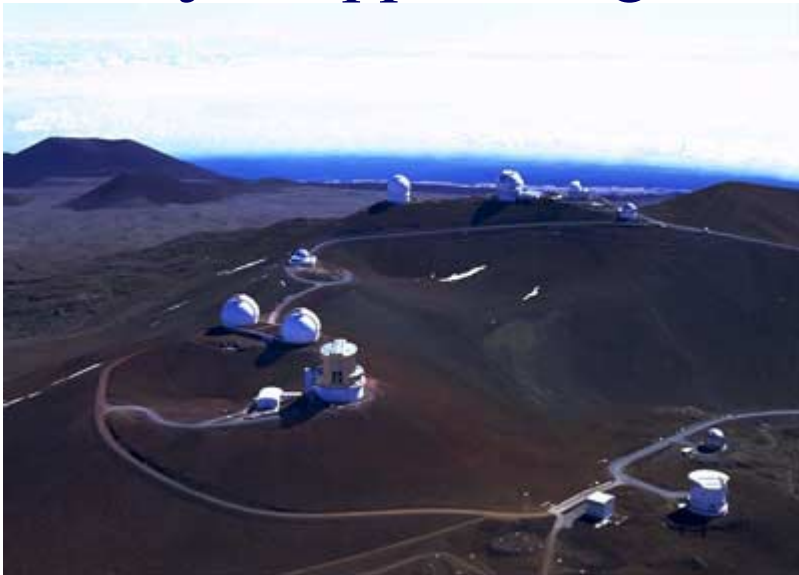


Telescopes

- Two converging lenses, or mirrors, can be used to form a telescope.



- First lens (aperture) is large. It collects lots of light from an object and concentrates it into a smaller area, making the object appear brighter.



PUZZLER

Theresa took a spring break sailing cruise in the sunny Caribbean. Her group spent the night on an isolated beach but unfortunately left Theresa there sleeping while they returned to the ship.

When she awoke, she grabbed her glasses to scan the horizon for her “friends.” Not finding them, she decided to start a fire to send smoke signals.

Could she use her glasses to start the fire?