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Refraction of Light

General Physics II
PHYS 111

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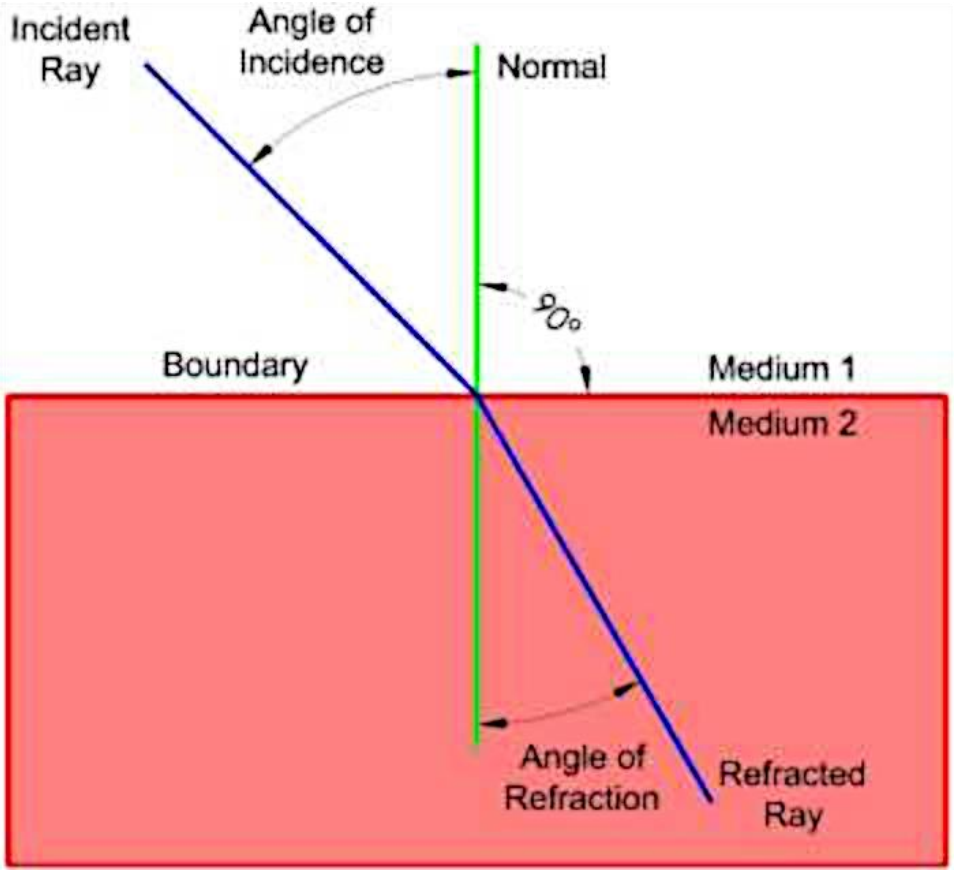
Introduction

- Refraction is based on the idea that LIGHT is passing through one MEDIUM into another which the wave travels at different speeds.
- Light travels through at a **vacuum** at speed 3 x10^8 m/s.
- Light travels through **materials** at a speed **less** than its speed in a **vacuum**.



The index of Refraction

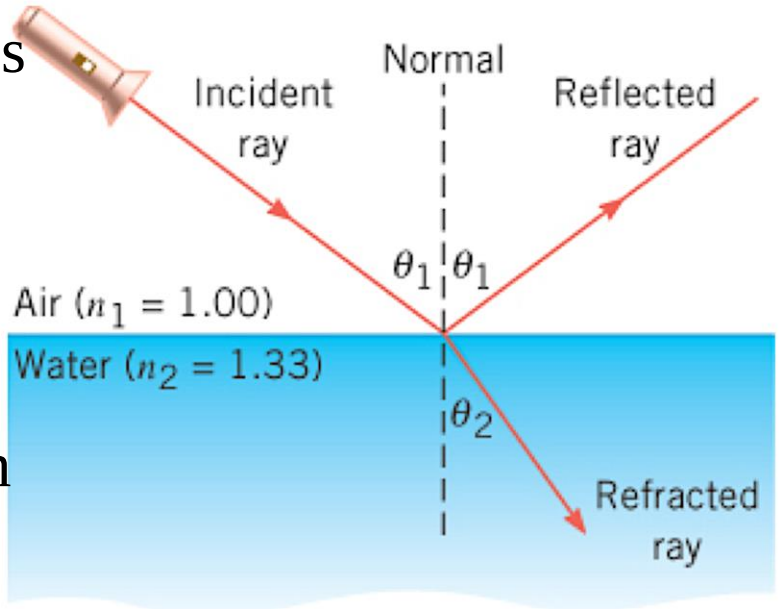
- The index of refraction of a material is the ratio of the speed of light in a vacuum to the speed of light in the material:

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in the material}} = \frac{c}{v}$$

- All substances have an index of refraction and can be used to identify the material.

Snell's Law

- When light strikes an interface between two materials it breaks up into two pieces - one **reflected** and one **refracted** (transmitted).



- When light travels from a material with one index of refraction to a material with a different index of refraction, the angle of incidence is related to the angle of refraction by

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

The Displacement of Light by A Slab of Material

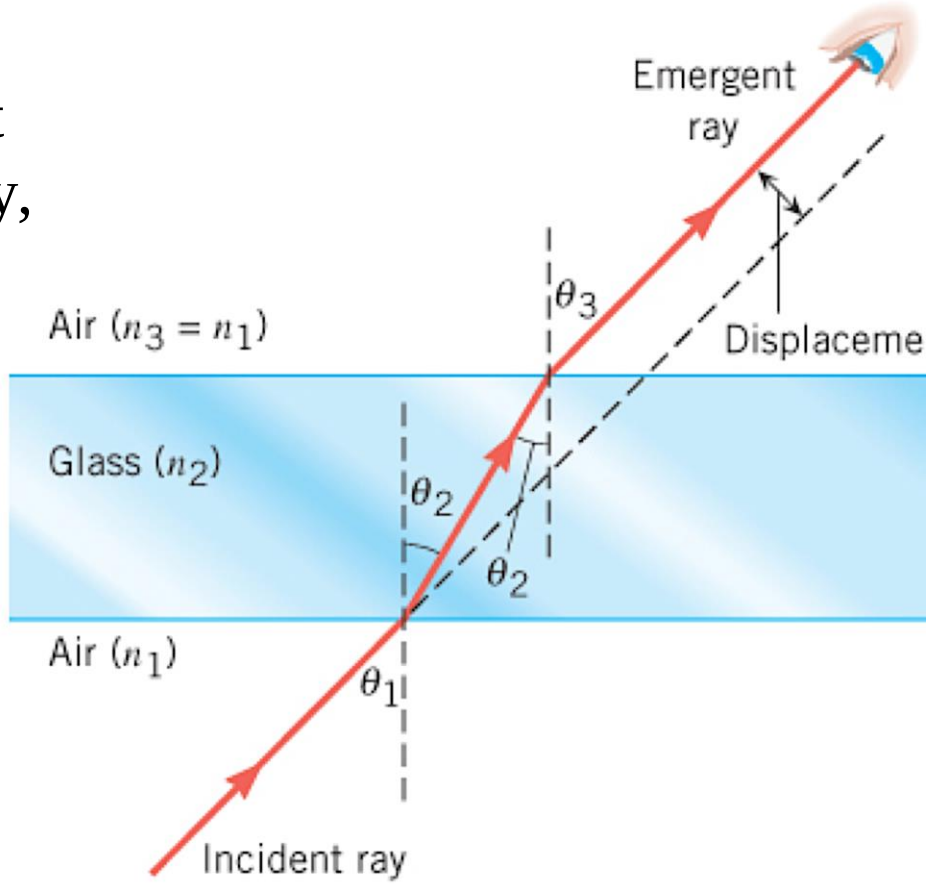
- When a ray of light passes through a pane of glass that has parallel surfaces and is surrounded by air, the emergent ray is parallel to the incident ray, $\theta_3 = \theta_1$, but is displaced from it
- 1st interface:

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

2nd interface:

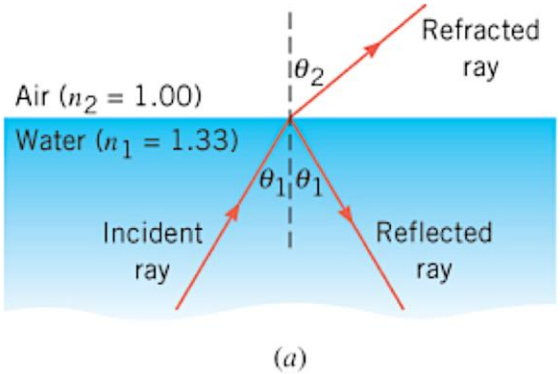
$$n_2 \sin\theta_2 = n_1 \sin\theta_3$$

$\rightarrow\rightarrow n_1 \sin\theta_1 = n_1 \sin\theta_3 \rightarrow\rightarrow \theta_3 = \theta_1$



Critical Angle

- When light passes from a medium of larger refractive index into one of smaller refractive index, the refracted ray bends away from the normal.

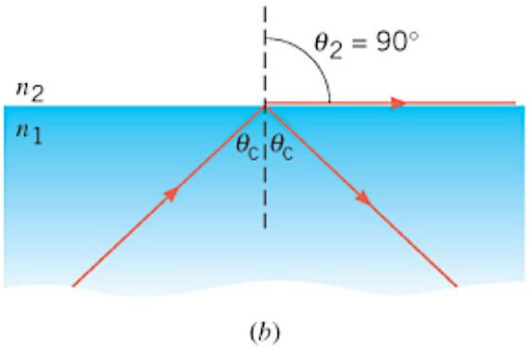


(a)

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

- **Critical angle**

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



(b)

$$n_1 \sin \theta_c = n_2 \sin 90^o$$

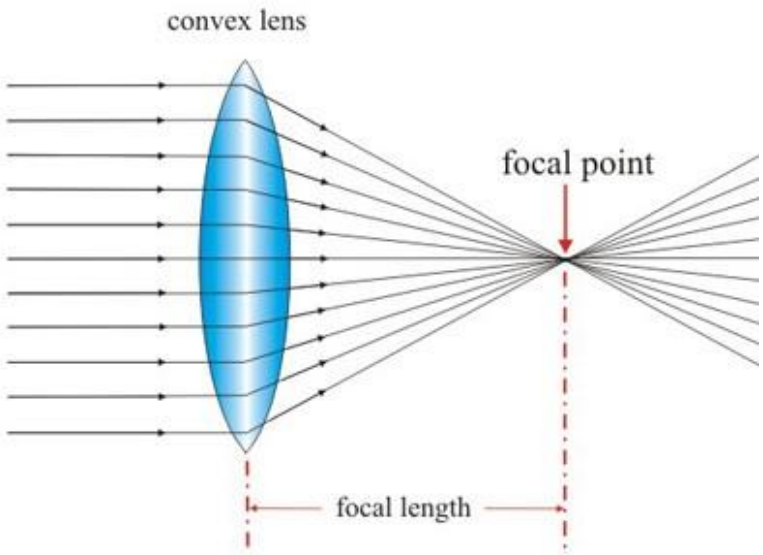
The Type of Lenses

1. Converging lenses.
2. Diverging lenses.

- Lenses refract light in such a way that an image of the light source is formed.

A Converging Lens

- A converging lens (Convex) takes light rays and bring them to a point.
- Paraxial rays that are parallel to the principal axis converge to the focal point, F. The focal length, f, is the distance between F and the lens.

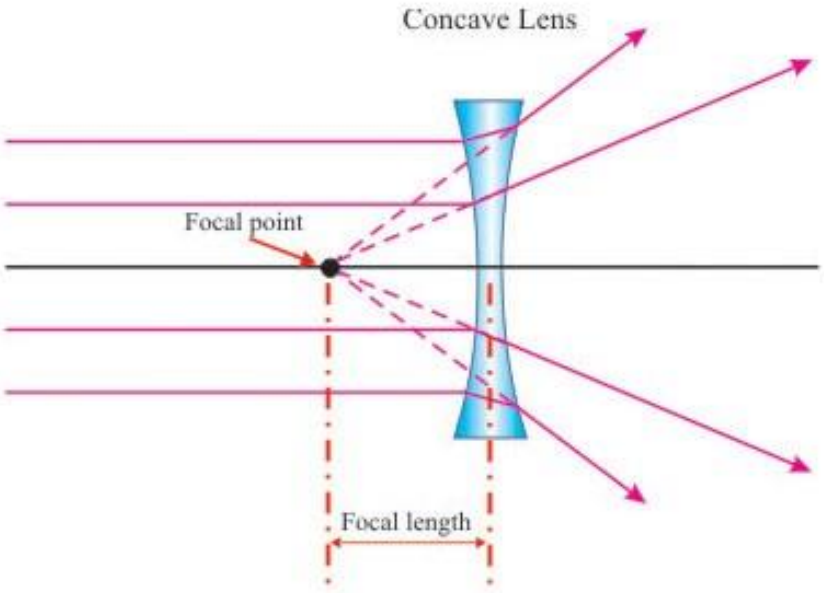


Rules for Converging Lenses

1. Any incident ray traveling parallel to the principal axis of a converging lens will refract through the lens and travel through the focal point on the opposite side of the lens.
2. Any incident ray traveling through the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.
3. An incident ray which passes through the center of the lens will in effect continue in the same direction that it had when it entered the lens.

A Diverging

- A diverging lens (concave) takes light rays and spreads them outward.
- Paraxial rays that are parallel to the principal axis appear to originate from the focal point, F. The focal length, f, is the distance between F and the lens.

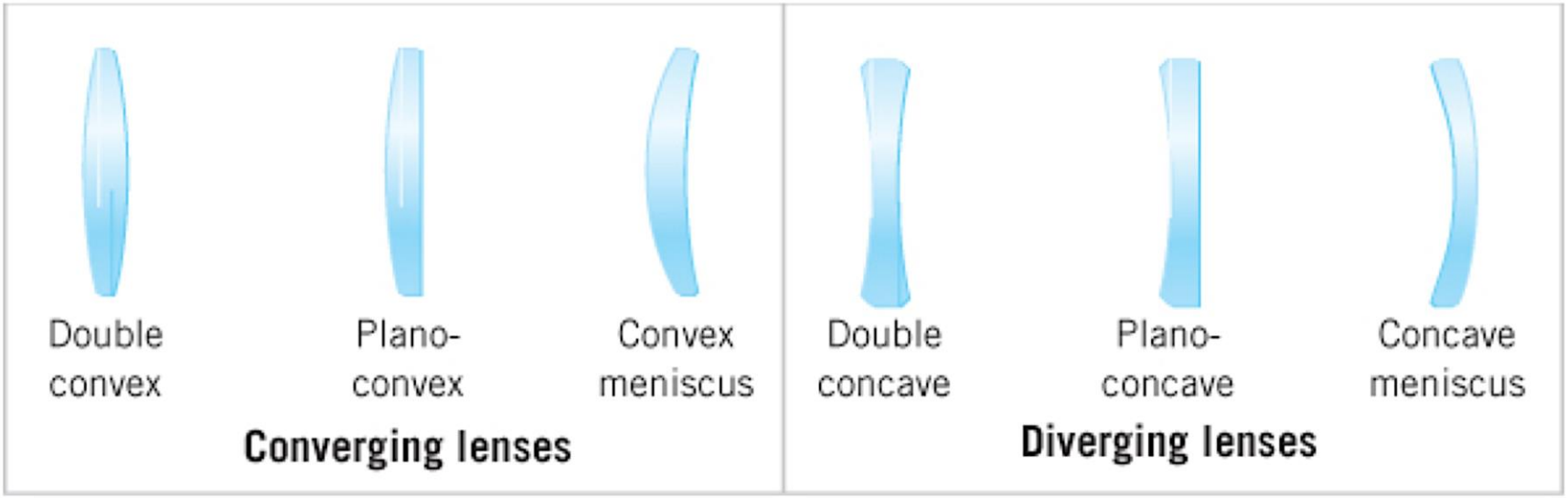


Rules for Diverging Lenses

1. Any incident ray traveling parallel to the principal axis of a diverging lens will refract through the lens and travel in line with the focal point (i.e., in a direction such that its extension will pass through the focal point).
2. Any incident ray traveling towards the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.
3. An incident ray which passes through the center of the lens will in effect continue in the same direction that it had when it entered the lens.

The Shape of Lenses

- Converging and diverging lens come in a variety of shapes depending on their application.



Ray Diagrams

- Here are some useful rays in determining the nature of the images formed by converging and diverging lens.
- Since lenses pass light through them (unlike mirrors) it is useful to draw a focal point on each side of the lens for ray tracing.

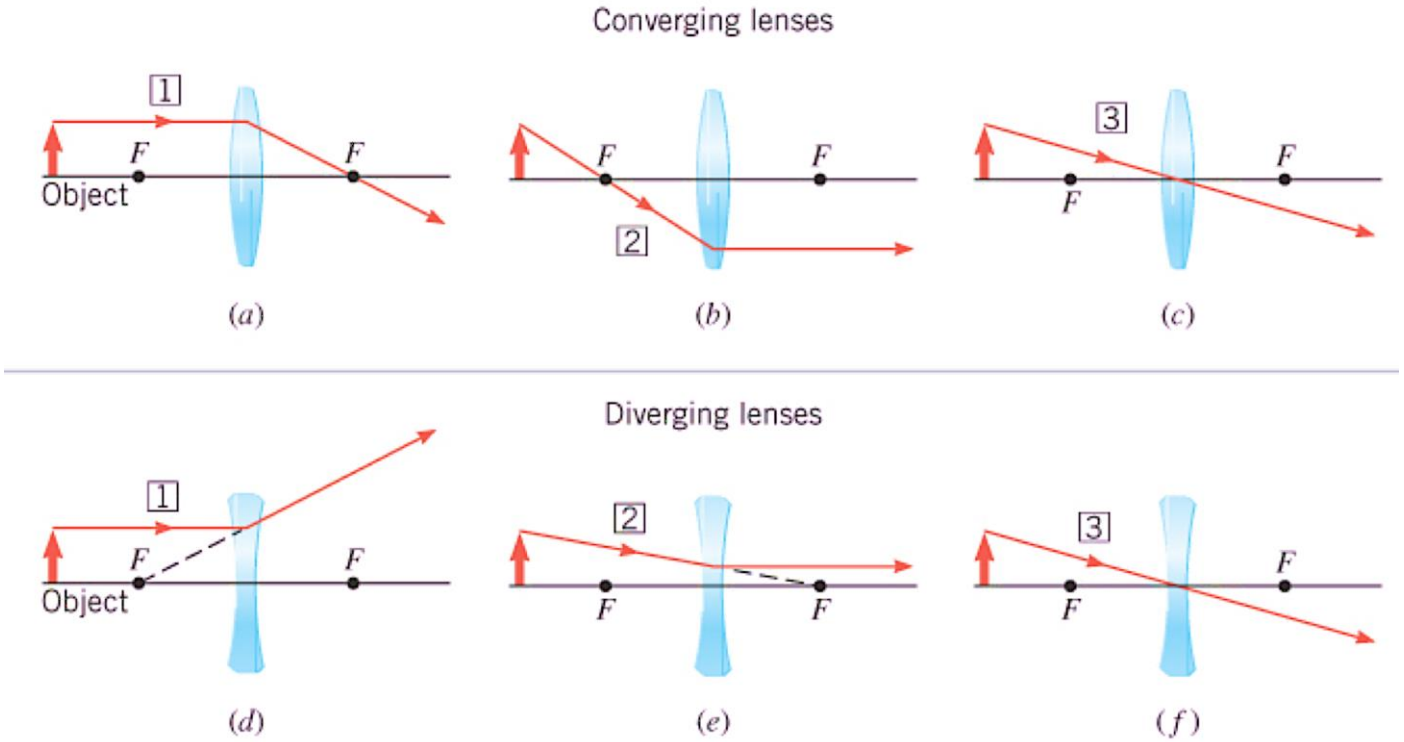
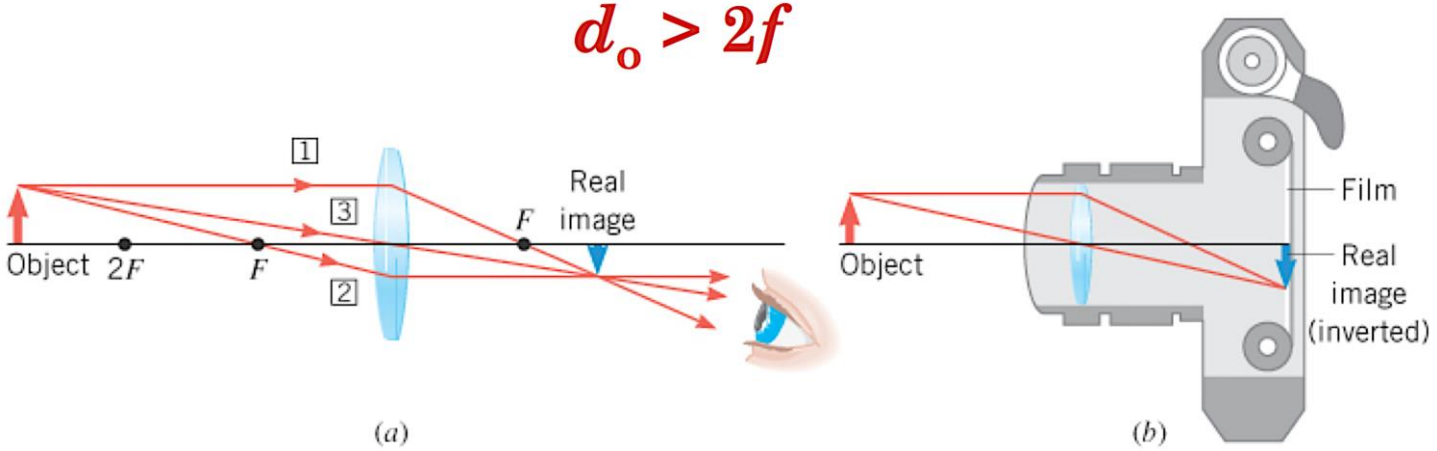


Image Formation by A Converging Lens

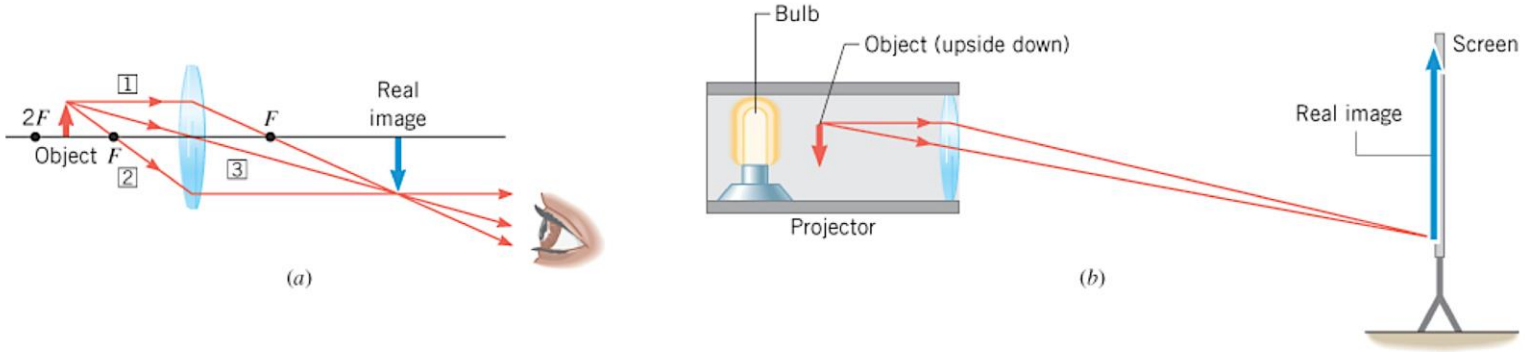
$d_o > 2f$



- When the object is placed further than twice the focal length from the lens, the real image is inverted and smaller than the object.
- **This is the configuration for a camera**. The focal length of the lens system of a camera must be adjusted for a particular object distance so that the image distance is at the location of the film and thus the real image on the film is sharp (focused).

Image Formation by A Converging Lens

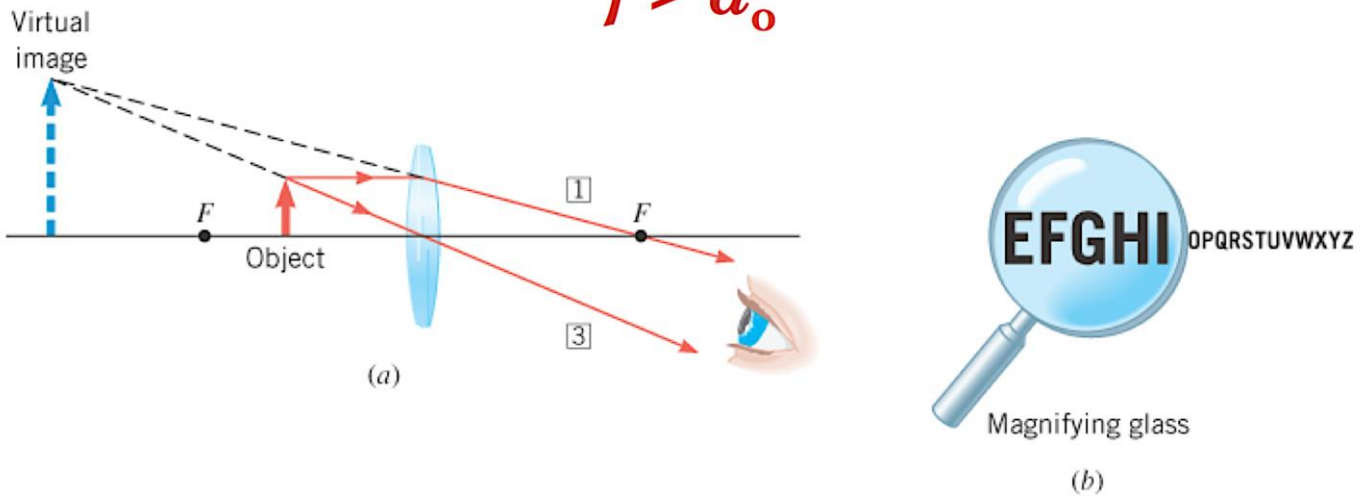
$2f > d_o > f$



- When the object is placed between F and 2F, the real image is inverted and larger than the object.
- **This is the configuration for a projector**. Since you normally want the real image on the screen to be upright, the object (film or slide) is placed upside down in the projector.

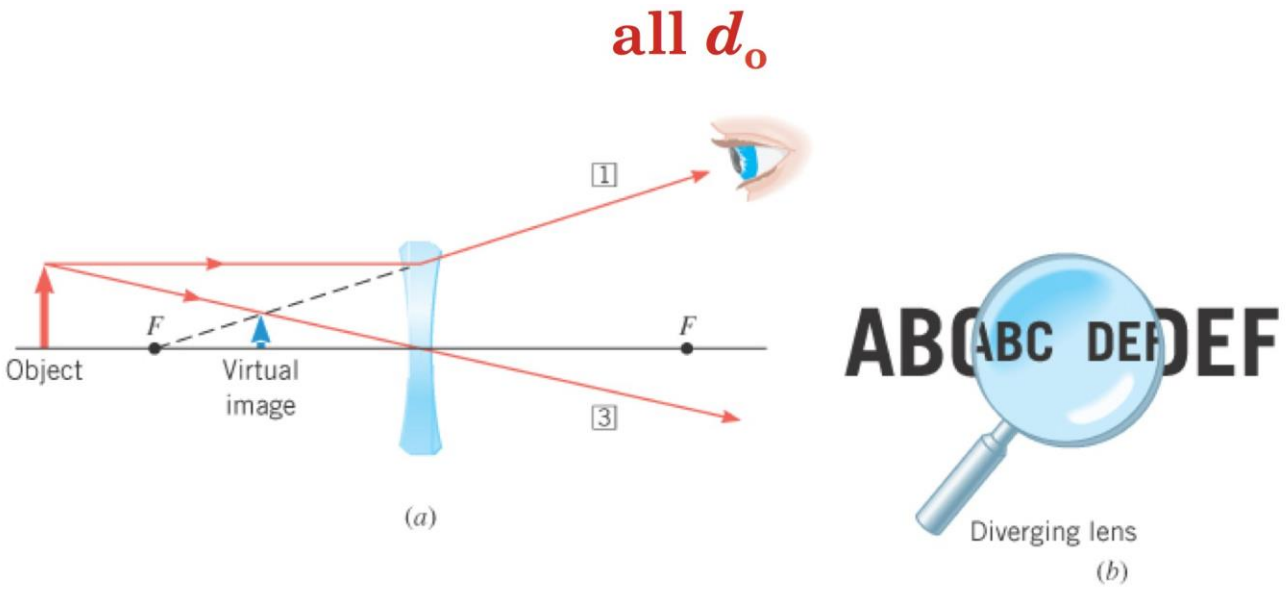
Image Formation by A Converging Lens

$f > d_o$



- When the object is placed between F and the lens, the virtual image is upright and larger than the object.
- **This is the configuration for a magnifying glass**. The magnifying glass must clearly be positioned so that the object distance is less than its focal length.

Image Formation by A Diverging Lens



- A diverging lens always forms an upright, virtual, diminished image.

Equation of Lenses and Magnification

- A converging lens have positive focal length (+f)
- A diverging lens have negative focal length (-f)
- *di* is + if the object is in front of the mirror (real image).
- *di* is − if the object is behind the mirror (virtual image).
- *m* is + for an image upright with respect to the object.
- *m* is - for an image inverted with respect to the object.

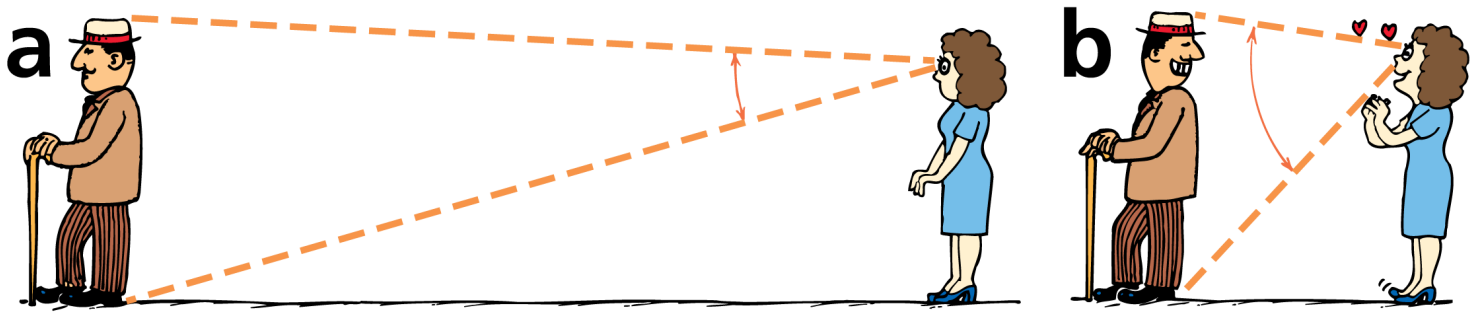
$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$$

$$M = -\frac{d_i}{d_0}$$

Image Formation by a Lens

a. A distant object is viewed through a narrow angle.

b. When the same object is viewed through a wide angle, more detail is seen

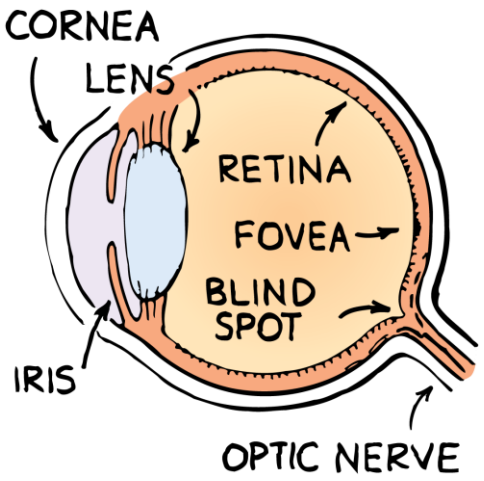


Magnification of Converging Lenses

a. When you use a magnifying glass, you hold it close to the object you wish to see magnified.
b. A converging lens will magnify only when the object is between the focal point and the lens.
c. The magnified image will be farther from the lens than the object and right-side up.

The Eye

- In many respects, the human eye is similar to the camera.
  - Light enters through the transparent covering, the cornea.
  - The amount of light that enters is regulated by the iris, the colored part of the eye that surrounds the pupil.
  - The pupil is the opening through which light passes.
  - Light passes through the pupil and lens and is focused on a layer of tissue at the back of the eye—the retina. Different parts of the retina receive light from different directions.



The Camera and The Eye

- In both the camera and the eye, the image is upside down, and this is compensated for in both cases.
- You simply turn the camera film around to look at it.
- Your brain has learned to turn around images it receives from your retina.

Nearsightedness

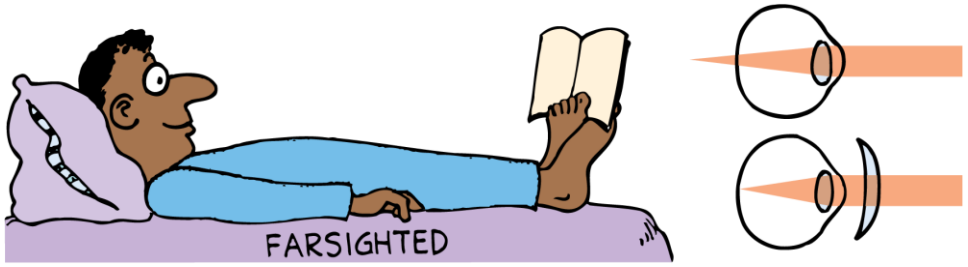
- A nearsighted person can see nearby objects clearly, but does not see distant objects clearly.
  - Distant objects focus too near the lens, in front of the retina.
  - The eyeball is too long.
  - A remedy is to wear lenses that diverge the rays from distant objects so that they focus on the retina instead of in front of it.

Camera and Human Eye

- A principal difference between a camera and the human eye has to do with focusing.
  - In a camera, focusing is accomplished by altering the distance between the lens and the film or chip.
  - In the human eye, most of the focusing is done by the cornea, the transparent membrane at the outside of the eye.
  - The image is focused on the retina by changing the thickness and shape of the lens to regulate its focal length. This is called *accommodation*.

Farsightedness

- A farsighted person has trouble focusing on nearby objects.
  - The eyeball is too short and images form behind the retina.
  - Farsighted people have to hold things more than 25 cm away to be able to focus them.
  - The remedy is to increase the converging effect of the eye by wearing eyeglasses or contact lenses with converging lenses.
  - Converging lenses converge the rays sufficiently to focus them on the retina instead of behind the retina.



Questions

1. The action of lenses depends mainly on
   a. convexing light in various directions.
   b. changing the direction of light rays or waves.
   c. converging light rays or waves.
   d. diverging light rays or waves.

Questions

2. A real image can be cast on a screen by
   a. converging lens.
   b. diverging lens.
   c. concave lens.
   d. any lens.

4. A diverging lens forms
   a. only a real image.
   b. only a virtual image.
   c. both a real image and a virtual image.
   d. a perfect image.