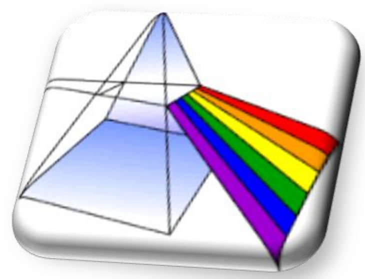
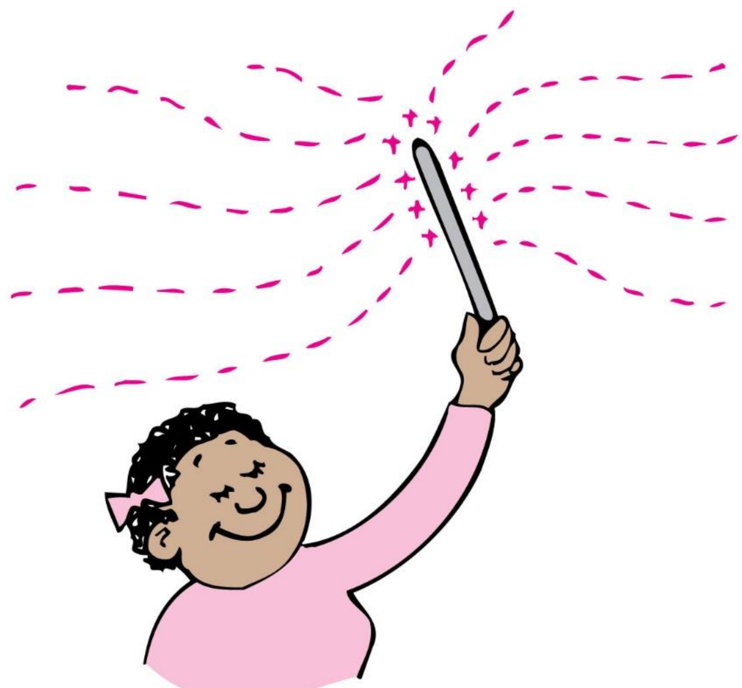
Chapter 5
Light, Optics and Applications



Electromagnetic Waves

Light is the only thing we can see.

- Originates from the accelerated motion of electrons
- Electromagnetic phenomenon

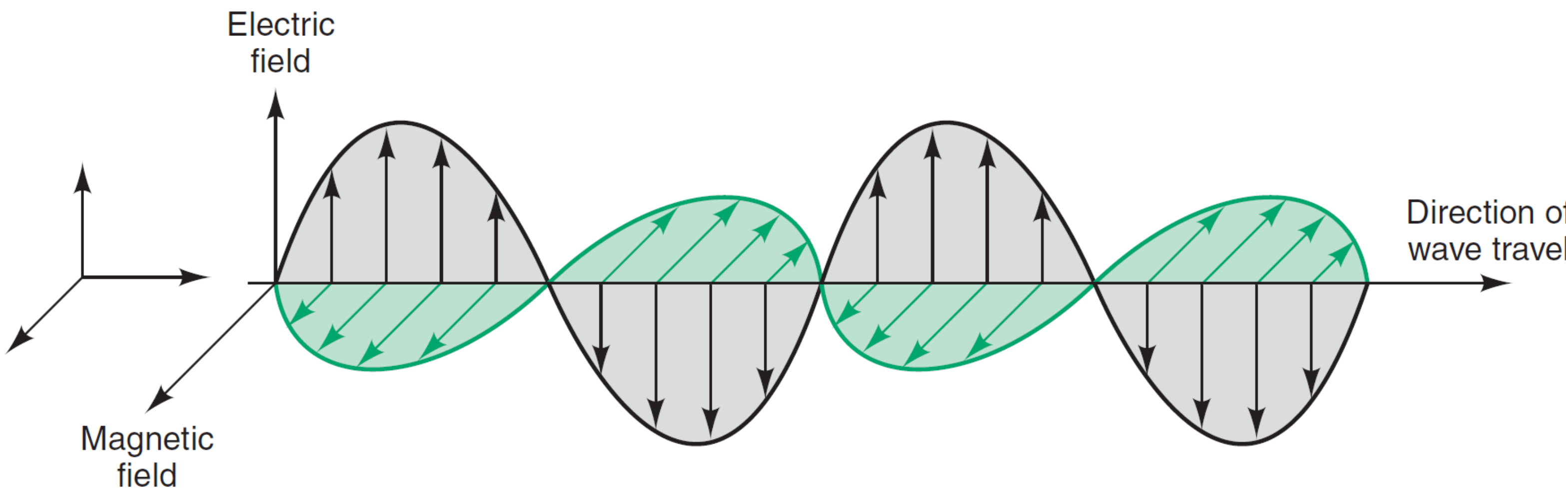


Nature of Light

A new theory for the nature of light:

light is an oscillating disturbance of an electric field and a corresponding magnetic field

⇒ Light ≡ Electromagnetic wave.



The electric and magnetic field components of an electromagnetic wave are perpendicular to each other as well as to the direction of travel of the electromagetic wave.

Electromagnetic Spectrum

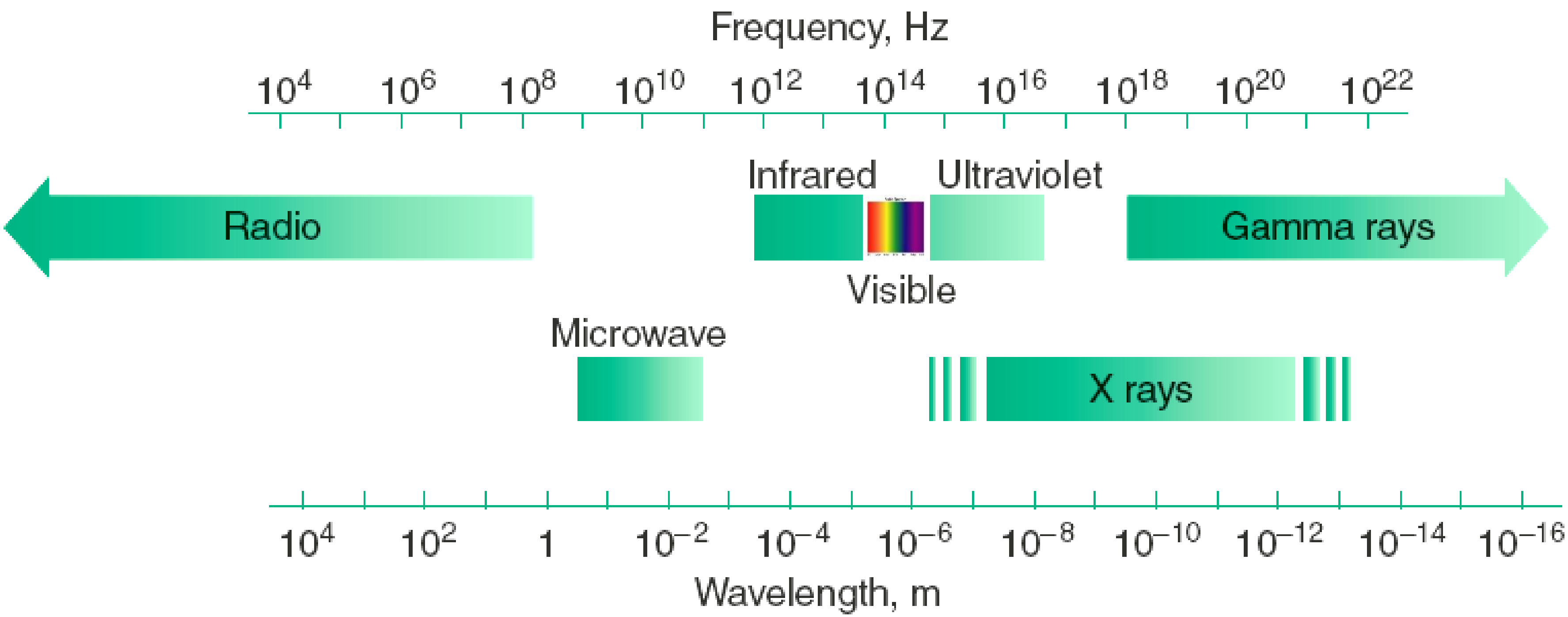


FIGURE 5.2

Electromagnetic spectrum.

Example 1

If an electron vibrates up and down 1000 times each second, it generates an electromagnetic wave with a

- Ⓐ period of 1000 s.
- Ⓑ speed of 1000 m/s.
- Ⓒ wavelength of 1000 m.
- Ⓓ None of the above.

Explanation:

The vibrating electron would emit a wave with a *frequency* of 1000 Hz, which is not in the list above.

The Speed of Light

Electromagnetic wave speed (in vacuum)

c = 299,792,458 m/s ≈ 3×10^8 m/s

$$s = ct$$

t = time

c = speed of light, 3.00×10^8 m/s

s = distance

A **light-year** is the distance travelled by light in one earth year, so 1 light-year equals 9.45×10^{15} m.

⇒ Convenient for expressing distance between stars

EXAMPLE 5.1

Find the distance (in mi) traveled by an X ray in 0.100 s.

Data:

$$c = 186{,}000 \text{ mi/s}$$
$$t = 0.100 \text{ s}$$
$$s = ?$$

Basic Equation:

$$s = ct$$

Working Equation: Same

Substitution:

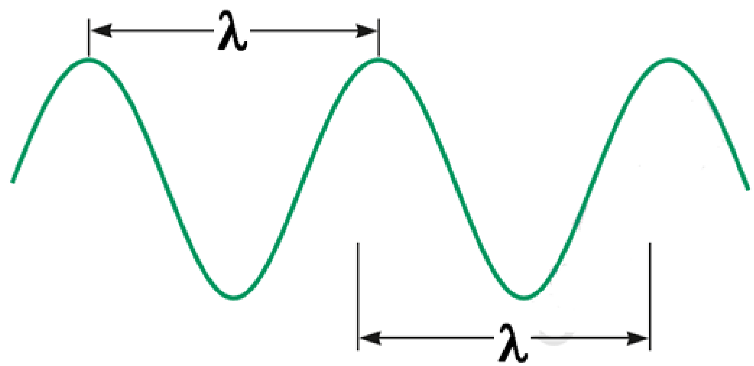
$$s = (186{,}000 \text{ mi/s})(0.100 \text{ s})$$
$$= 18{,}600 \text{ mi}$$

Light as a Wave

The wavelength, λ:
The distance between two successive corresponding points on the wave.

The wavelength of visible light ranges from about 4.0×10^{-7} m to 7.6×10^{-7} m.

The frequency:
- The number of vibrations or cycles per second of a wave.
- Unit: cycles/second = Hertz (**Hz**)



$$c = \lambda f$$

f = frequency
λ = wavelength
c = speed of light

EXAMPLE 5.2

Find the frequency of a light wave with a wavelength of 5.00×10^{-7} m.

Data:

$$\lambda = 5.00 \times 10^{-7}\ \text{m}$$
$$c = 3.00 \times 10^{8}\ \text{m/s}$$
$$f = ?$$

Basic Equation:

$$c = \lambda f$$

Working Equation:

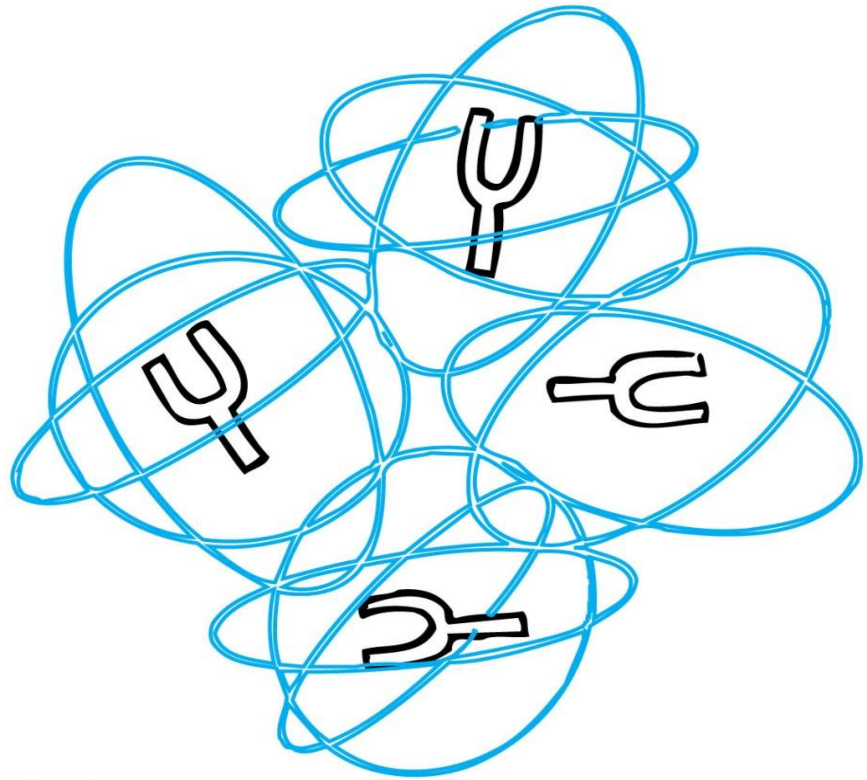
$$f = \frac{c}{\lambda}$$

Substitution:

$$f = \frac{3.00 \times 10^{8}\ \text{m/s}}{5.00 \times 10^{-7}\ \text{m}}$$
$$= 6.00 \times 10^{14}\ Hz \quad (\text{or cycles/s})$$

Reflection of light

- We say light is *reflected* when it is returned into the medium from which it came—the process is **reflection.**
- When light illuminates a material, electrons in the atoms of the material move more energetically in response to the oscillating electric fields of the illuminating light.
- The energized electrons re-emit the light by which you see the material.



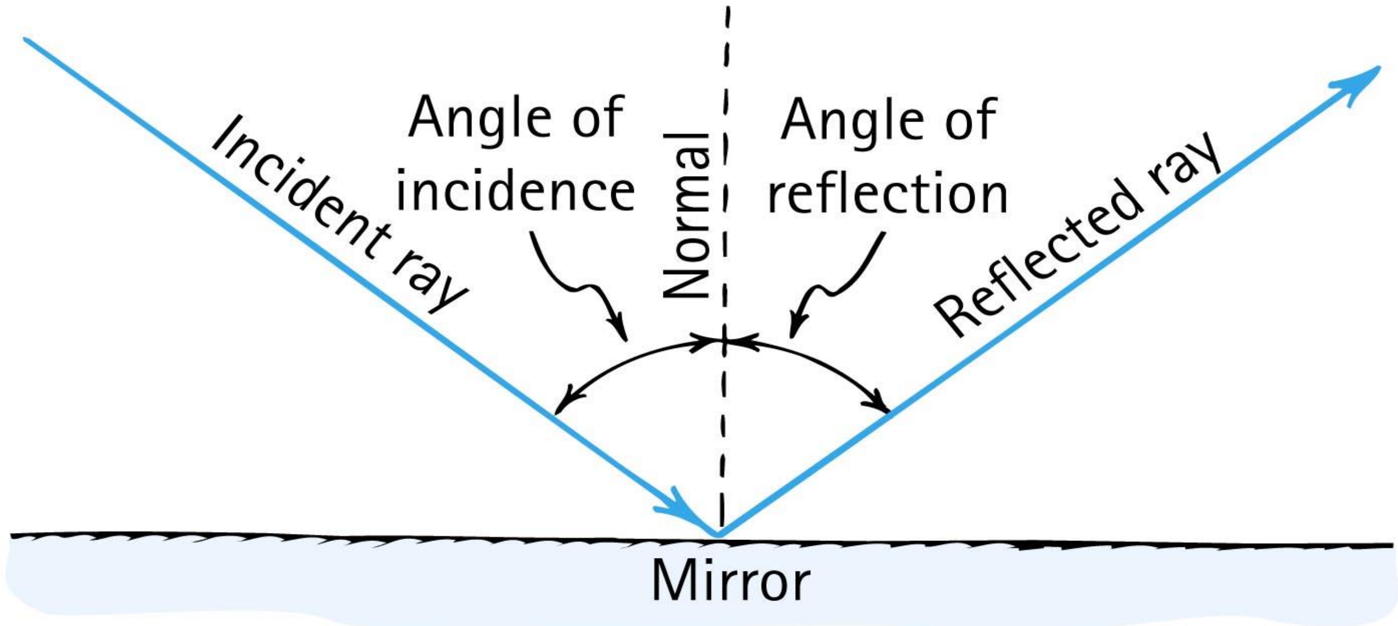
Law of Reflection

- Angle of incidence
  - Angle made by the incoming ray and the perpendicular
- Angle of reflection
  - Angle made by the reflected ray and the perpendicular
- Normal
  - Imaginary line perpendicular to the plane of the reflecting surface
  - Lies in the same plane as the incident and reflected rays

Law of Reflection

First Law of reflection

- The angle of reflection equals the angle of incidence.



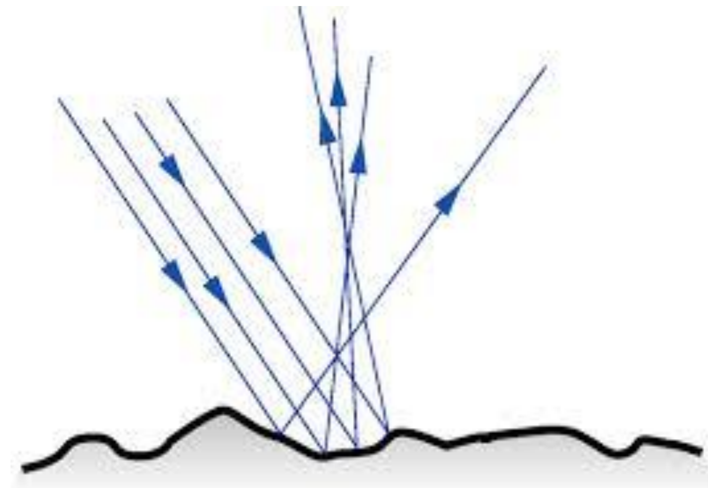
Second Law of reflection

The incident ray, the reflected ray and the normal all lie in the same plane.

Diffuse Reflection

- When light is incident on a ***rough* surface,** it is reflected in many directions. This is called *diffuse reflection*.

- How can the surface of water in a lake exhibit both specular and diffuse reflection?



After diffuse reflection, light goes in *all directions*

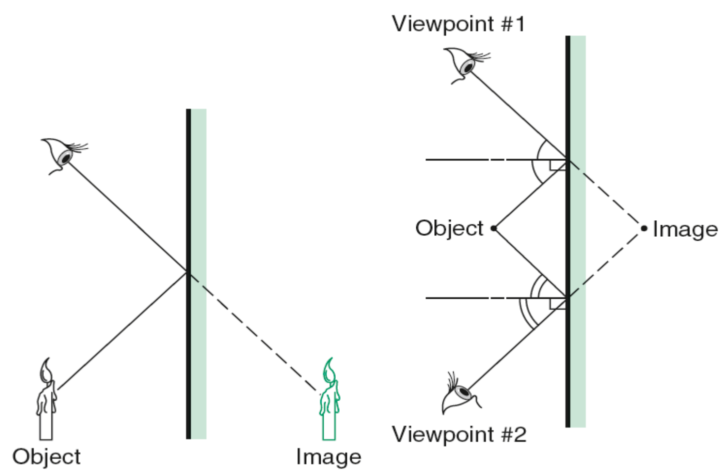
Where the water is very still and
The surface smooth, reflected images
Occur. This is *specular* reflection.

Where the water is rough and doesn't show reflected images, the reflection is *diffuse*.

Law of Reflection

Virtual image

- is same size as object, formed behind a plane mirror, and located at the position where the extended reflected rays converge.
- is as far behind the mirror as the object is in front of the mirror.



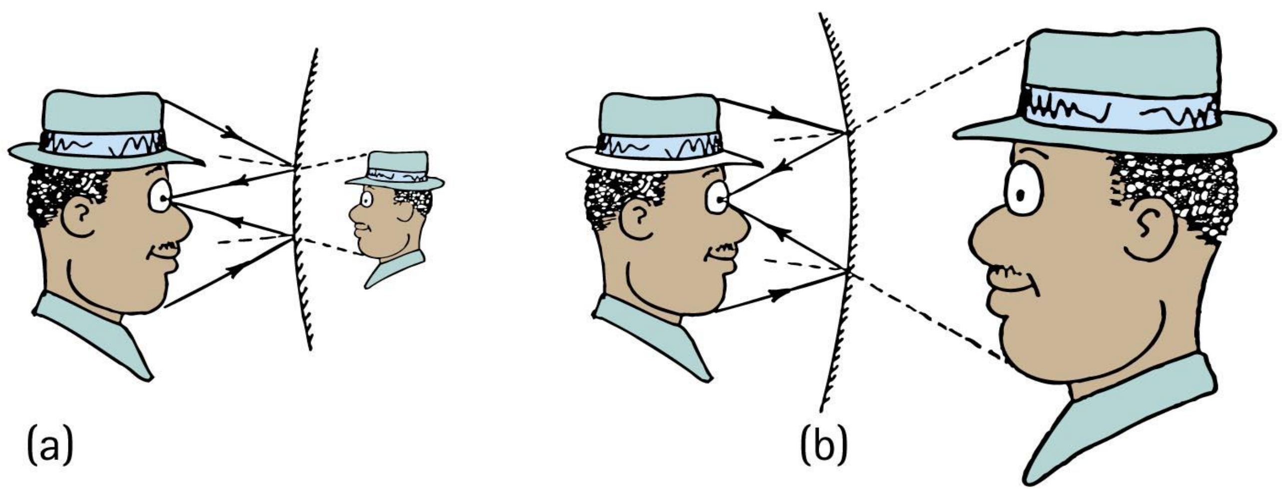
(a) Plane mirror image

(b) Location of an image in a plane mirror

Law of Reflection

Shape of mirror forms a different virtual image.

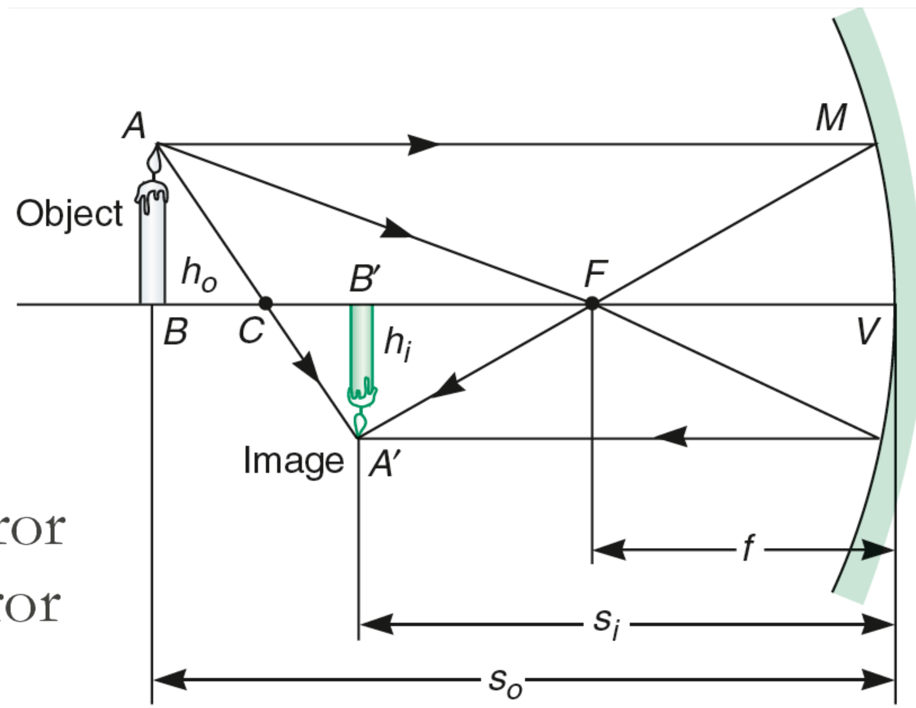
- Convex mirror (that curves outward): virtual image is smaller and closer to the mirror than the object.
- Concave mirror (that curves inward): virtual image is larger and farther away than the object.



The Mirror Formula

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

f = focal length of mirror
s_o = distance of object from mirror
s_i = distance of image from mirror



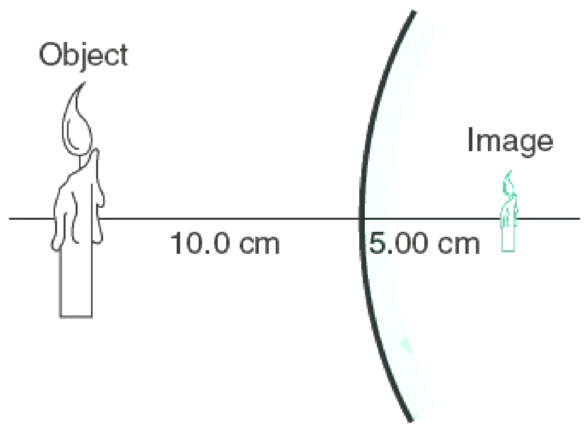
$$M = \frac{h_i}{h_o} = \frac{-s_i}{s_o}$$

M = magnification
h_i = image height
h_o = object height
s_i = image distance
s_o = object distance

EXAMPLE 5.3

An object 10.0 cm in front of a convex mirror forms an image 5.00 cm behind the mirror. What is the focal length of the mirror?

Sketch:



Data:

$$s_o = 10.0 \text{ cm}$$

$$s_i = -5.00 \text{ cm}$$

Note: The image is virtual (appears behind the mirror) so *si* is given a (−) sign to show this. [Won't *f* also be (−)?]

$$f = ?$$

Basic Equation:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

Working Equation: Same

Substitution:

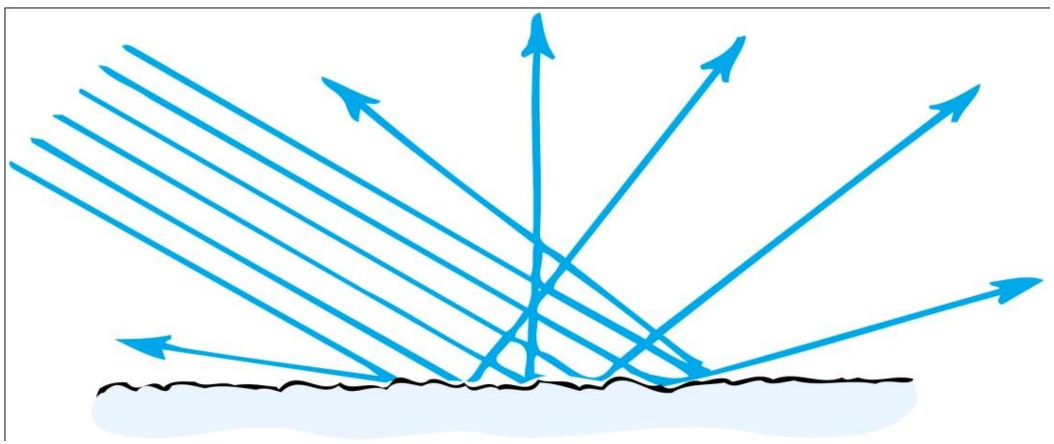
$$\frac{1}{f} = \frac{1}{10.0\,cm} + \frac{1}{-5.00\,cm} = \frac{1}{10.0\,cm} - \frac{1}{5.00\,cm}$$

$$f = -10.0 \text{ cm}$$

Law of Reflection

Diffuse reflection

- When light strikes a rough or irregular surface and reflects in many directions
- An undesirable circumstance is the ghost image that occurs on a TV set when TV signals bounce off buildings and other obstructions.



Law of Reflection

Different road surfaces determine amount of diffuse reflection

- Rough road surface—because of diffuse reflection, see road ahead of car at night.
- Wet road surface is smooth—because of less diffuse, reflection, difficult to see.

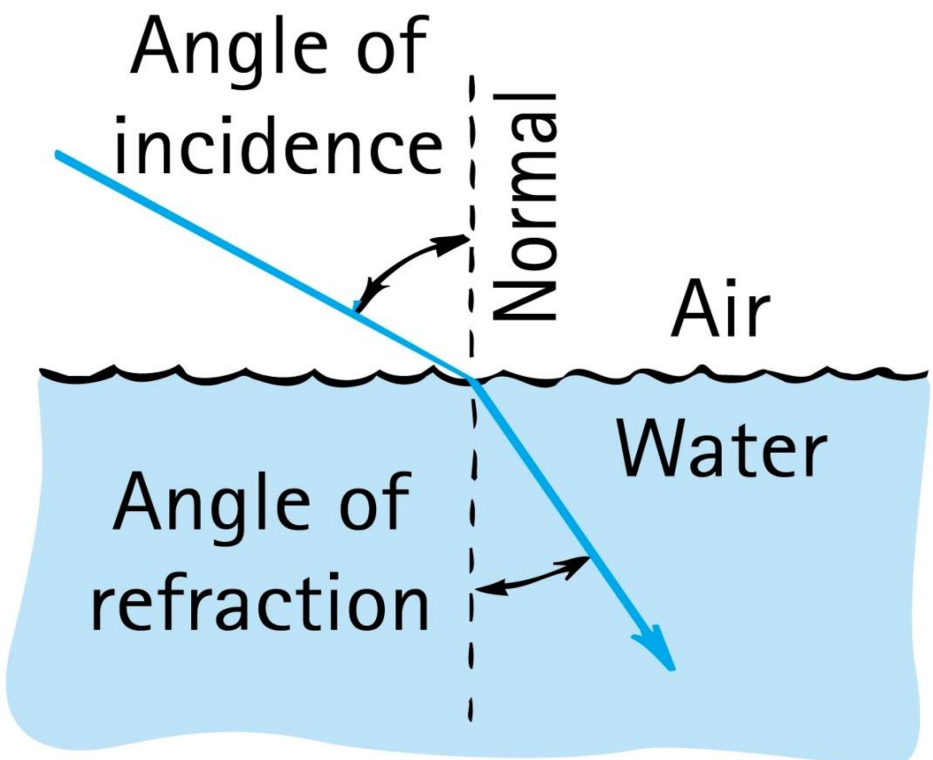
Example 6

Diffuse reflection occurs when the sizes of surface irregularities are

- Ⓐ small compared with the wavelength of reflected radiation.
- Ⓑ large compared with the wavelength of reflected radiation.
- Ⓒ Both A and B.
- Ⓓ None of the above.

Refraction of Light

When light bends in going obliquely from one medium to another, we call this process refraction.



Refraction

Refractive index:

Index of refraction, *n*, of a material

- indicates how much the speed of light differs from its speed in a vacuum.
- indicates the extent of bending of rays.
- ratio of speed of light in a vacuum to the speed in a material.

Refraction

Refractive index (continued):

- In equation form:

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$$

- Medium with a high index means high bending effect and greatest slowing of light.

Snell's law:

$$n_1 \sin \mathrm{i} = n_2 \sin \mathrm{r} \quad (\text{Snell's law})$$

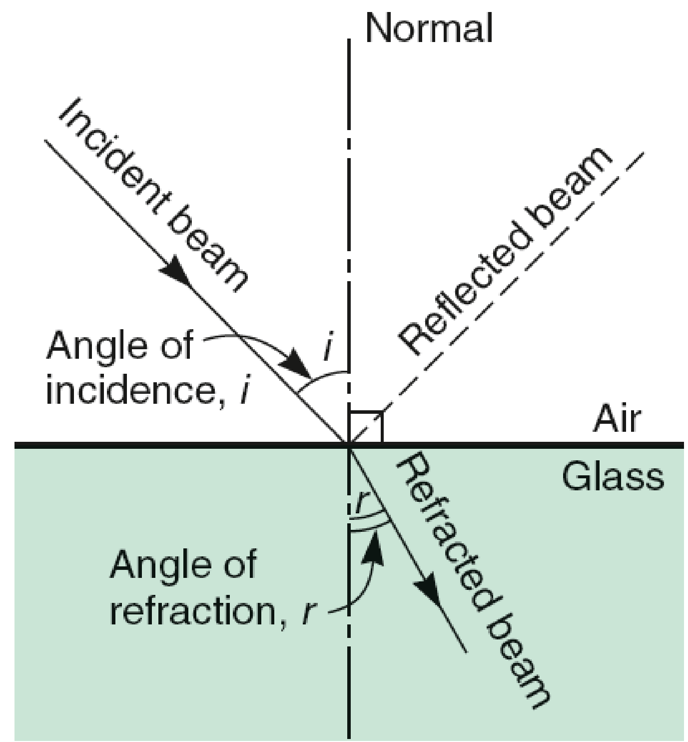


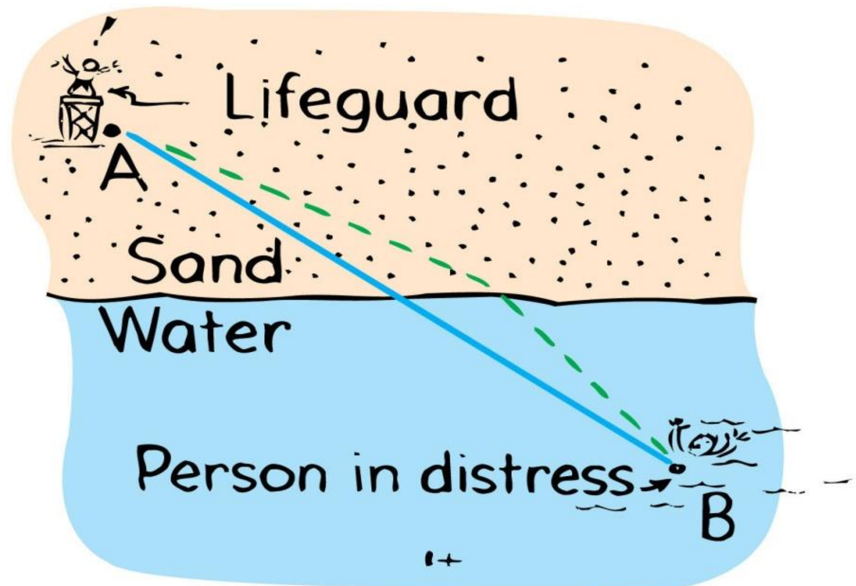
FIGURE 5.16

The angles of incidence and refraction are measured from the normal.

Refraction

- Refraction occurs to minimize the time taken by light to travel from A to B.

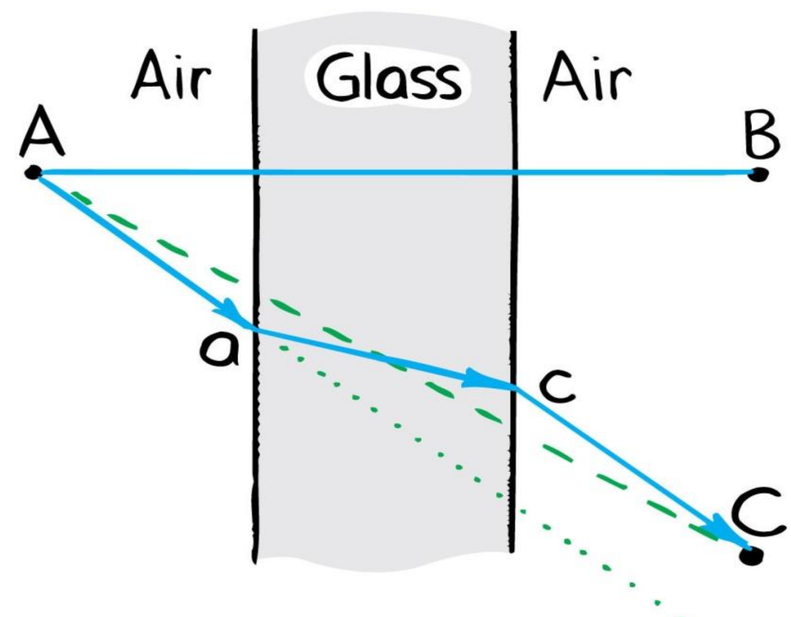
- Just as if you wanted to save someone from drowning, the quickest path would not be a straight line – it would be the dashed path shown.



Refraction

Light follows a less inclined path in the glass.

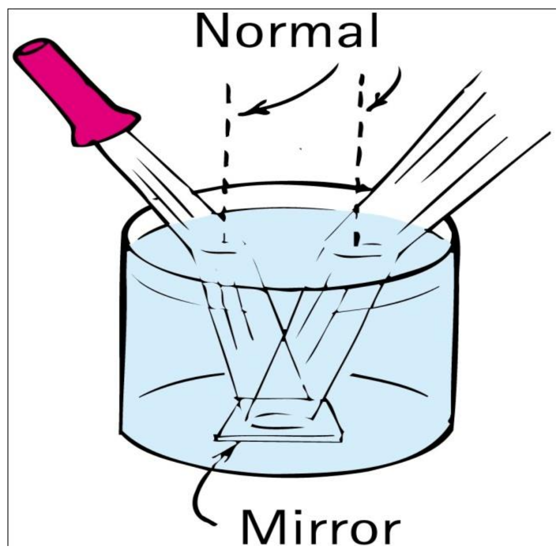
- Light travels slower in glass than in air, so it minimizes the time it spends in the glass.



Refraction

Light rays pass from air into water and water into air.

- Pathways are reversible for both reflection and refraction.



EXAMPLE 5.4

The index of refraction of water is 1.33. What is the speed of light in water?

Data:

$$n = 1.33$$
$$c = 3.00 \times 10^8 \text{ m/s}$$
$$v_{\text{water}} = ?$$

Basic Equation:

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in substance}}$$

Working Equation:

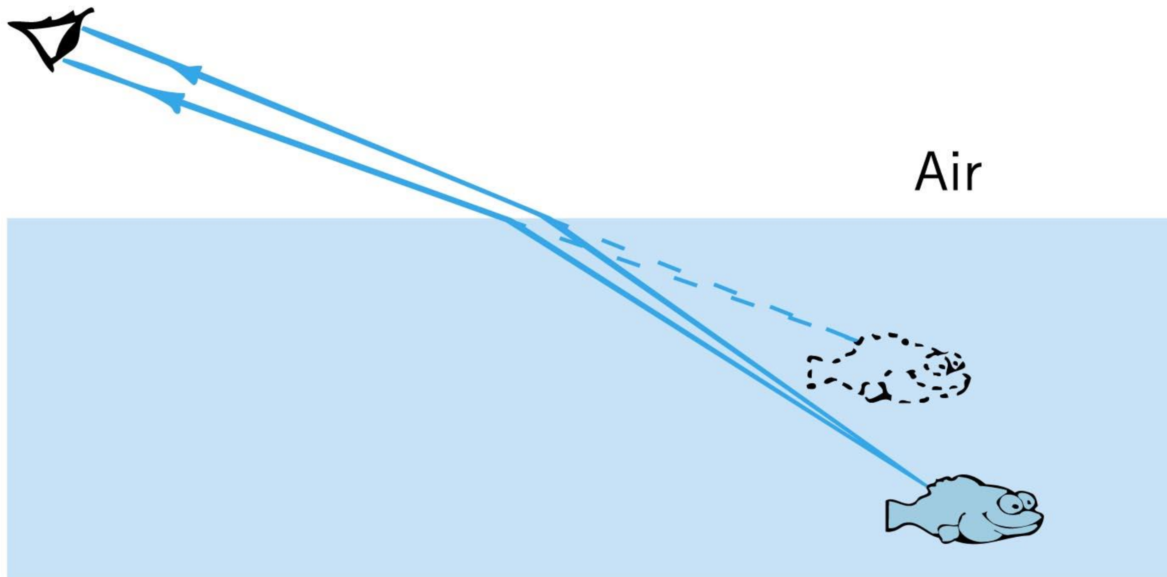
$$\text{speed of light in water} = \frac{\text{speed of light in vacuum}}{n}$$

Substitution:

$$\text{speed of light in water} = \frac{3.00 \times 10^8 \text{ m/s}}{1.33}$$
$$= 2.26 \times 10^8 \text{ m/s}$$

Refraction

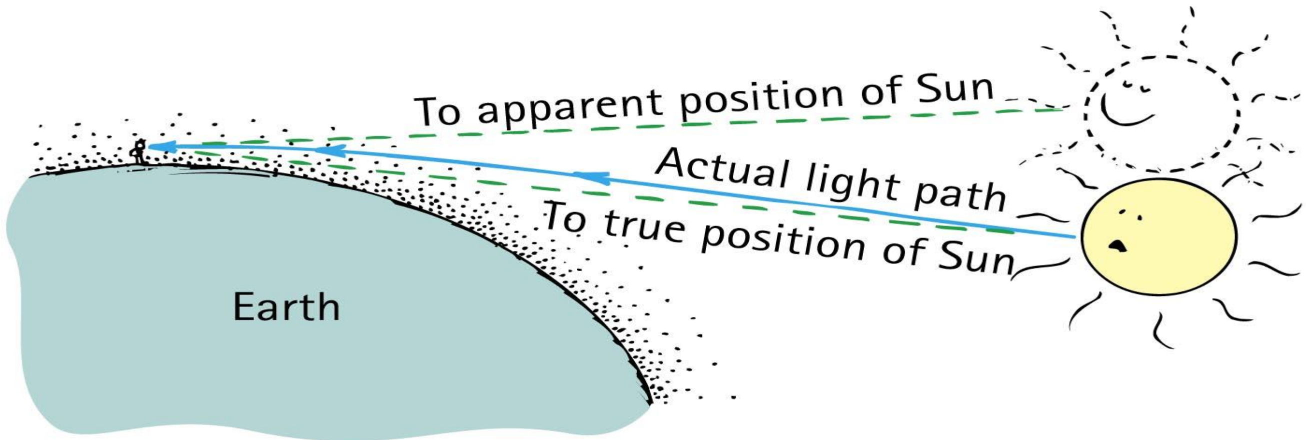
Illusions caused by refraction



- Objects submerged in water appear closer to the surface.

Refraction

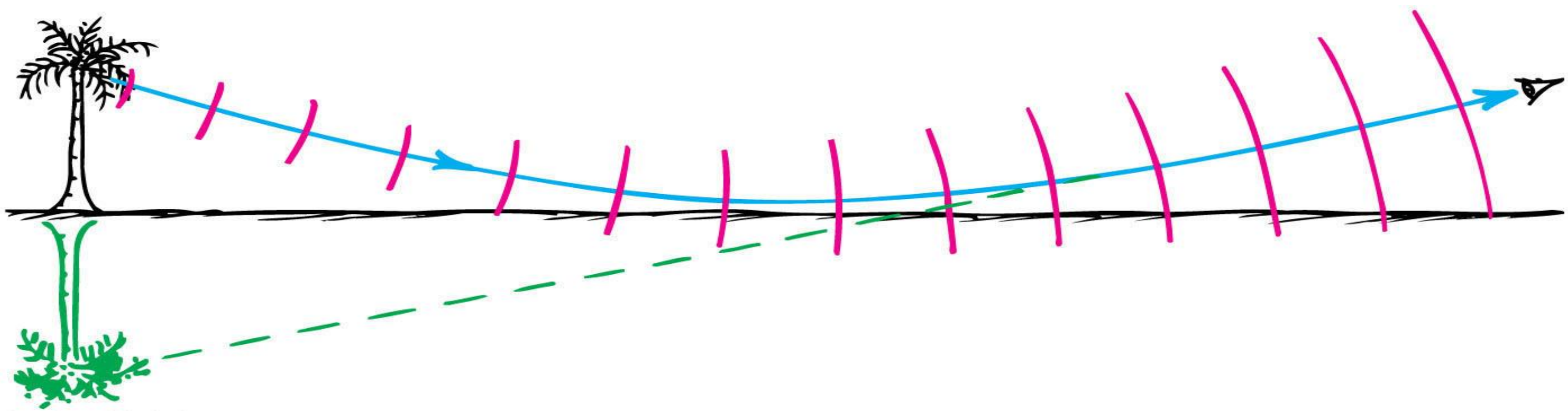
Illusions caused by refraction (continued)



- Objects such as the Sun seen through air are displaced because of atmospheric refraction.

Refraction

Illusions caused by refraction (continued)

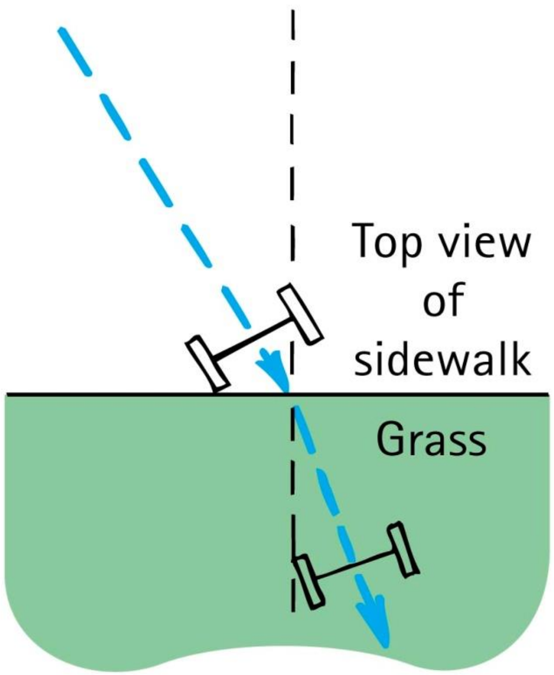


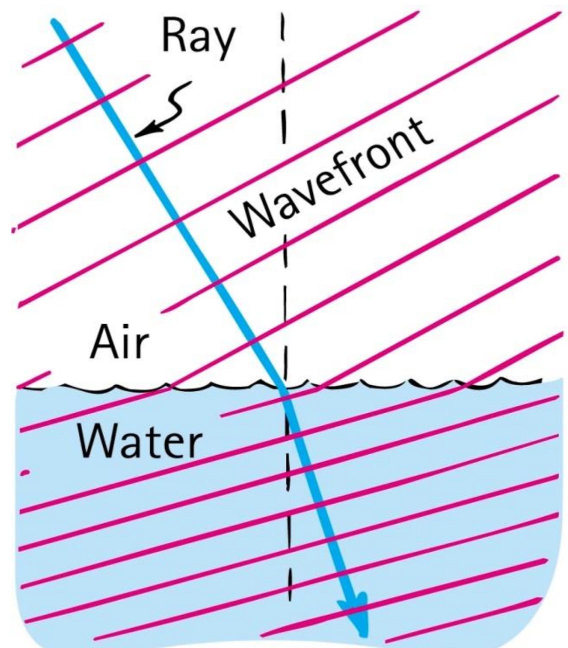
- Atmospheric refraction is the cause of mirages (سراب) .

Cause of Refraction

Refraction

- Bending of light when it passes from one medium to another
- Caused by change in speed of light

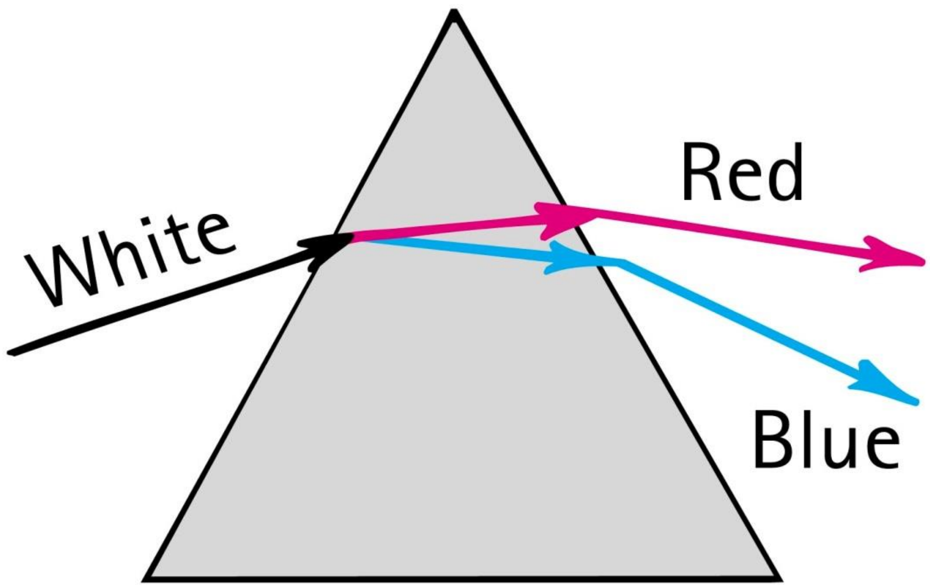


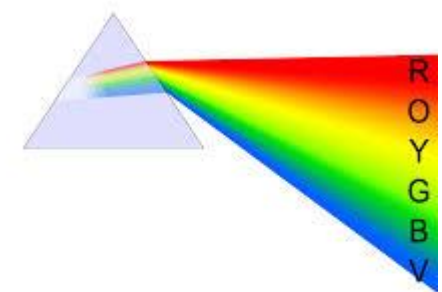


Dispersion

Dispersion

- Process of separation of light into colors arranged by frequency



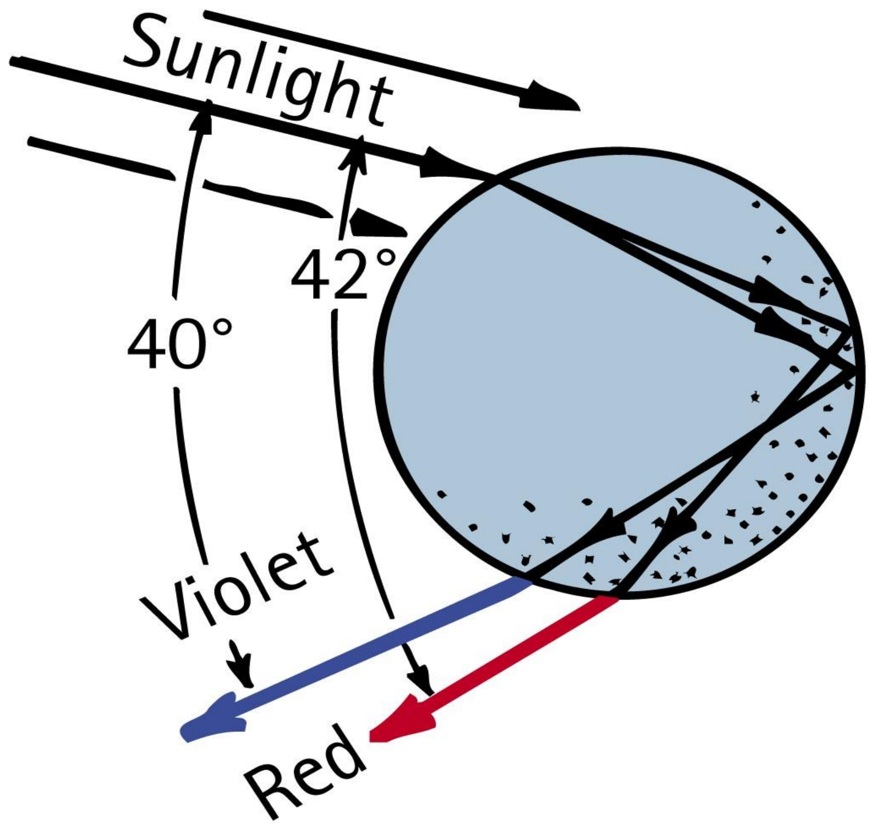


- Components of white light are dispersed in a prism (and in a diffraction grating).

Rainbows

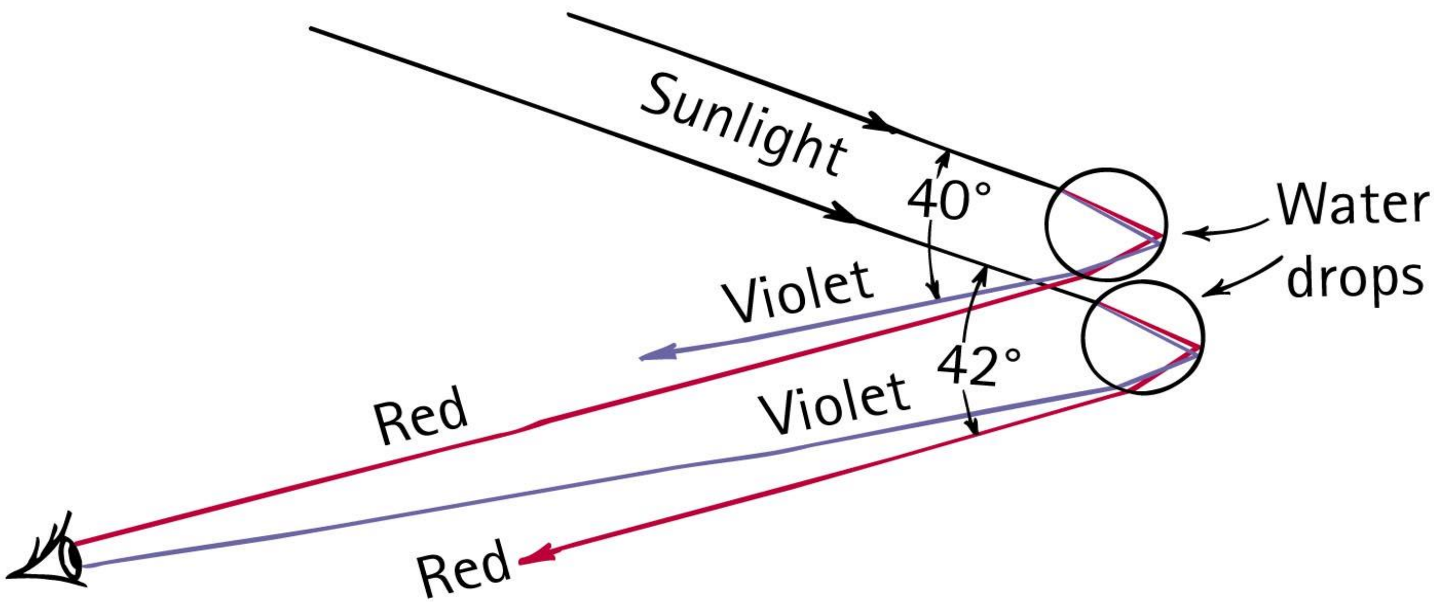
Rainbows are a result of dispersion by many drops.

- Dispersion of light by a single drop



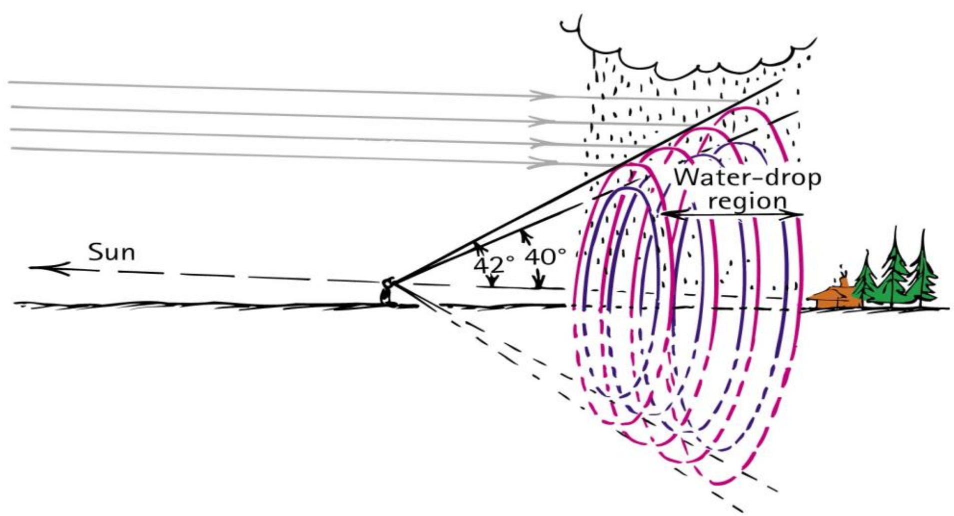
Rainbows

- Sunlight incident on two sample raindrops, as shown, emerges from them as dispersed light.
- The observer sees the red light from the upper drop and the violet light from the lower drop.
- Millions of drops produce the whole spectrum of visible light.



Rainbows

When your eye is located between the Sun (not shown off to the left) and a water drop region, the rainbow you see is the edge of a three-dimensional cone that extends through the water drop region.



Rainbows

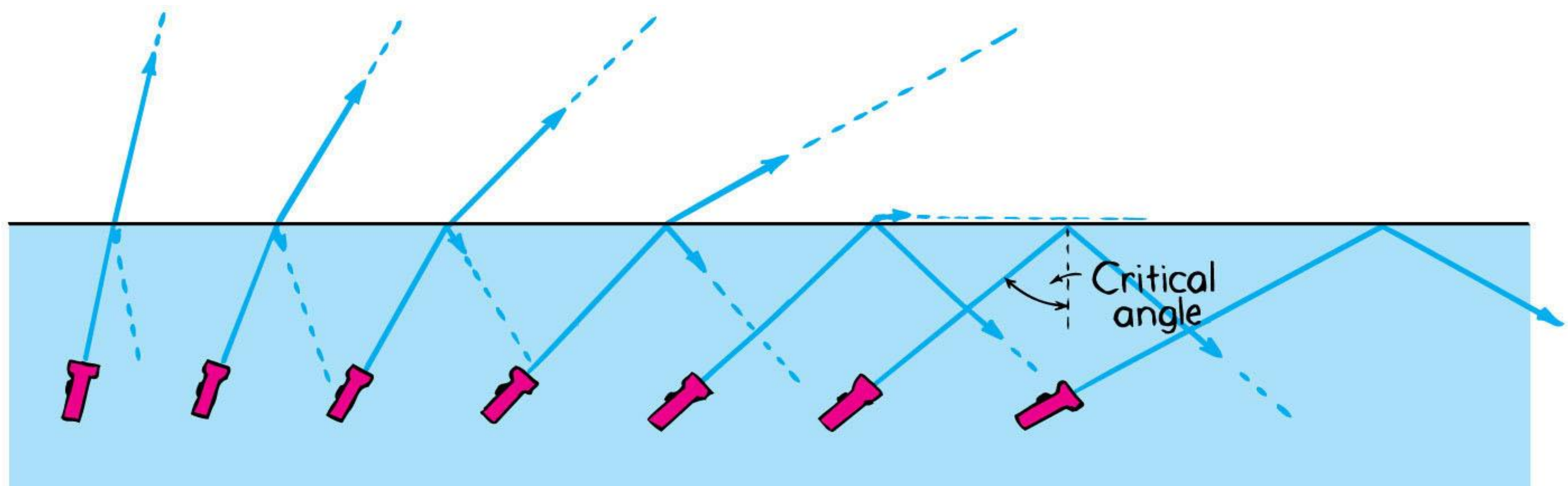
Rainbow facts (continued)

- Secondary rainbow is fainter (due to two internal reflections and refracted light loss).
- Secondary bow is reversed in color (due to the extra internal reflection).

Total Internal Reflection

Total internal reflection

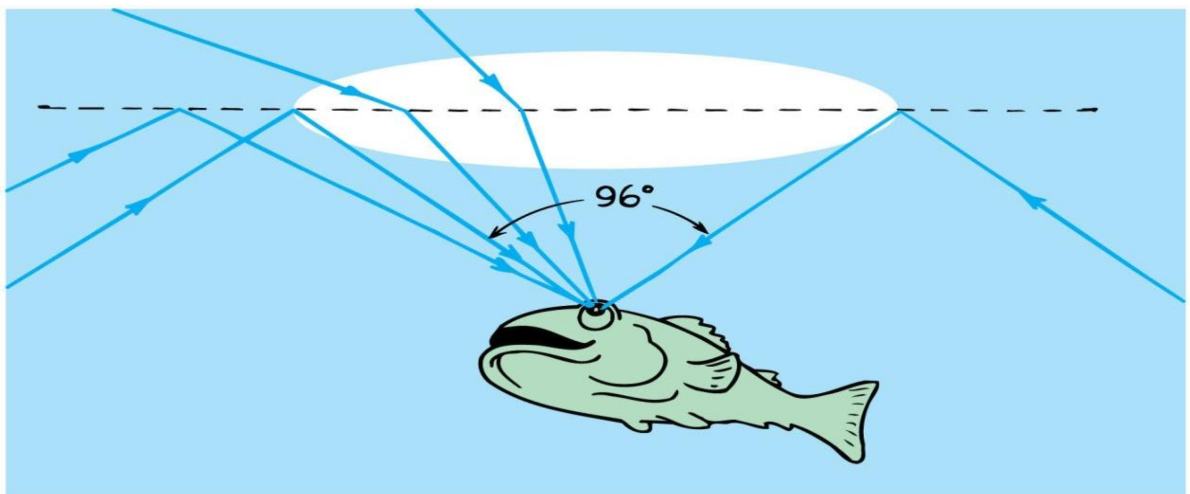
- Total reflection of light traveling within a medium that strikes the boundary of another medium at an angle at, or greater than, the critical angle



Total Internal Reflection

Critical angle (الزاوية الحرجه)

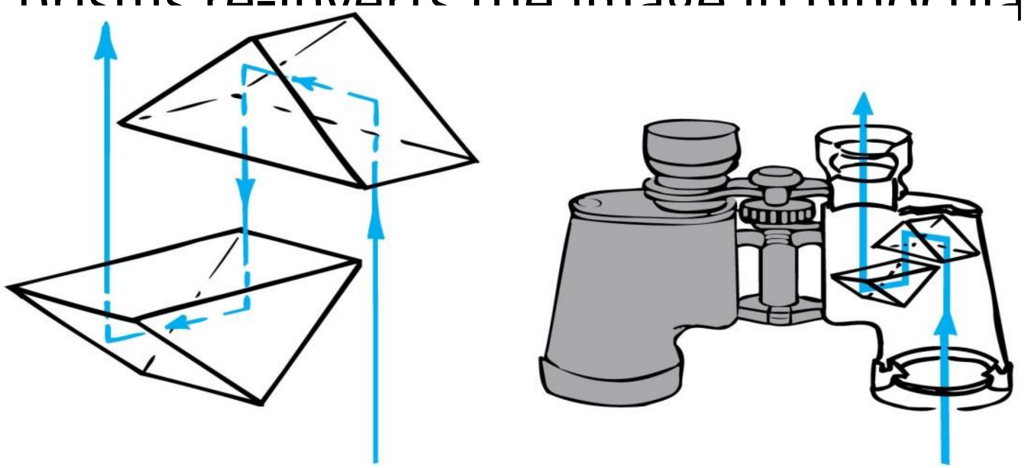
- Minimum angle at which beam of light no longer emerges into the air above the surface; varies for different materials



Total Internal Reflection

Advantages of glass prisms

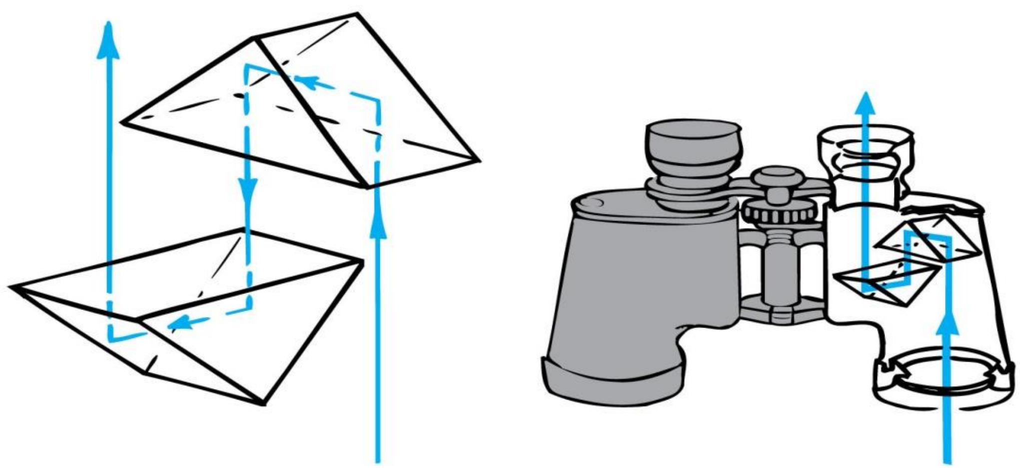
- Internally reflect 100%, which is the principal reason for use in many optical instruments
- Lengthen the light path between lenses, thus eliminating the need for long barrels in binoculars
- Reflection by prisms re-inverts the image in binoculars



Total Internal Reflection

Optical fibers or light pipes (الألياف الضوئية)

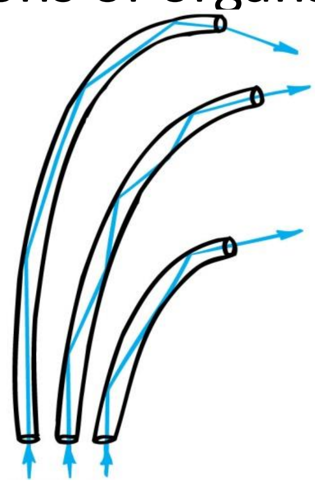
- Thin, flexible rods of special glass or transparent plastic.
- Light from one end of the fiber is total internally reflected to the other end, resulting in nearly the same brightness of light.



Total Internal Reflection

Optical fibers or light pipes (continued)

- Used in
  - illuminating instrument displays
  - concentrating light in dental procedures
  - viewing of inaccessible regions of organs and other devices
  - communications



What is the critical angle of incidence for water that has an index of refraction of 1.33?

Data:

$$n = 1.33$$
$$i_c = ?$$

Basic Equation:

$$\sin i_c = \frac{1}{n}$$

Working Equation: Same

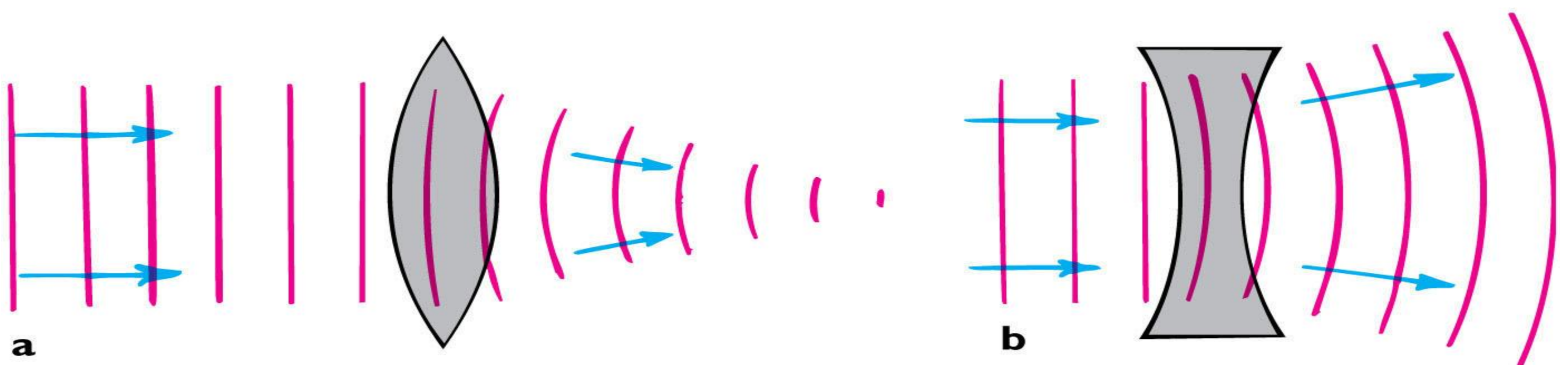
Substitution:

$$\sin i_c = \frac{1}{1.33} = 0.752$$

Physics: Lesson 5.3

Lenses

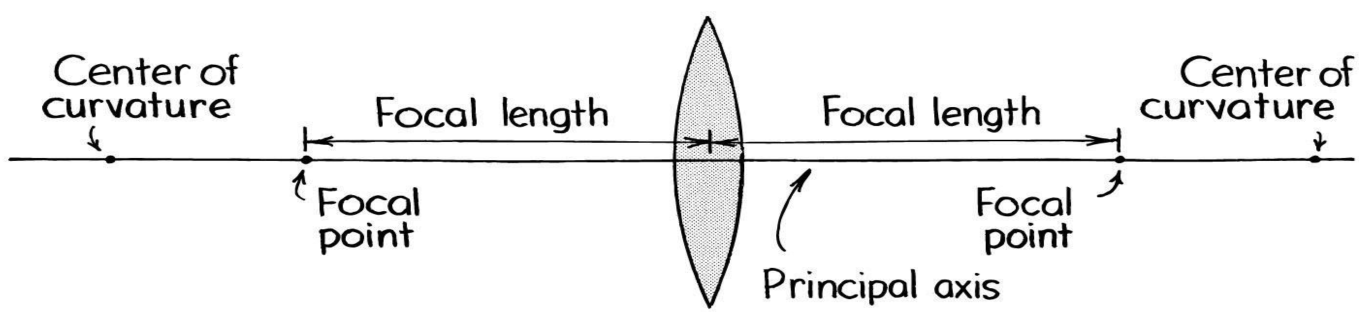
- Two common types:
  - Converging (convex) lens محدبة
    - thicker at the center than edges
    - converges light
  - Diverging (concave) lens مقعرة
    - thinner at the center than edges
    - diverges light



Lenses

Key features of lenses

- Principal axis
  - line joining the centers of curvature of the two lens surfaces
- Focal point
  - point at which all the light rays come together
- Focal length
  - distance between the center of the lens and either focal point



The Lens Equation

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

f = focal length
s_o = distance of object from lens center
s_i = distance of image from lens center

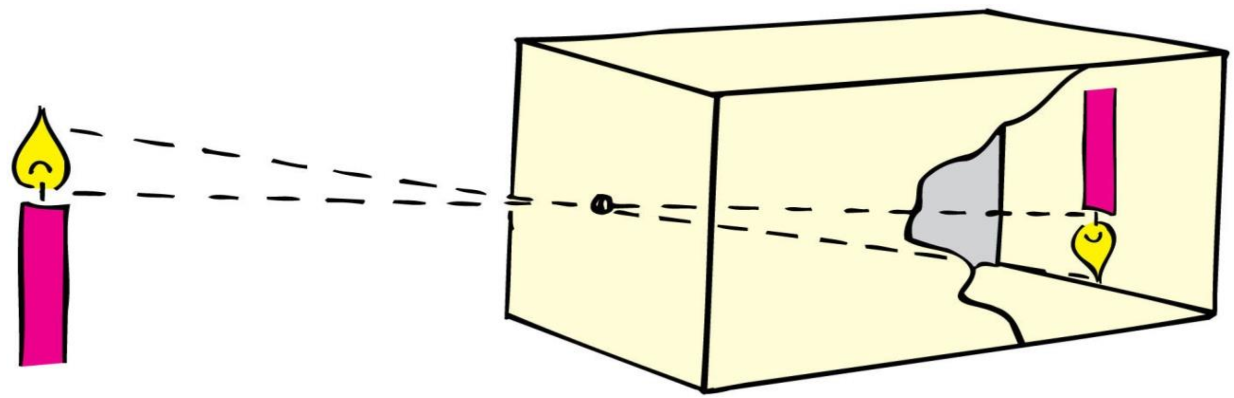
$$M = \frac{h_i}{h_o} = \frac{-s_i}{s_o}$$

M = magnification
h_i = image height
h_o = object height
s_i = image distance from lens center
s_o = object distance from lens center

When the image is virtual, s_i is negative $(-)$, and for diverging lenses, both s_i and f are negative.

Lenses

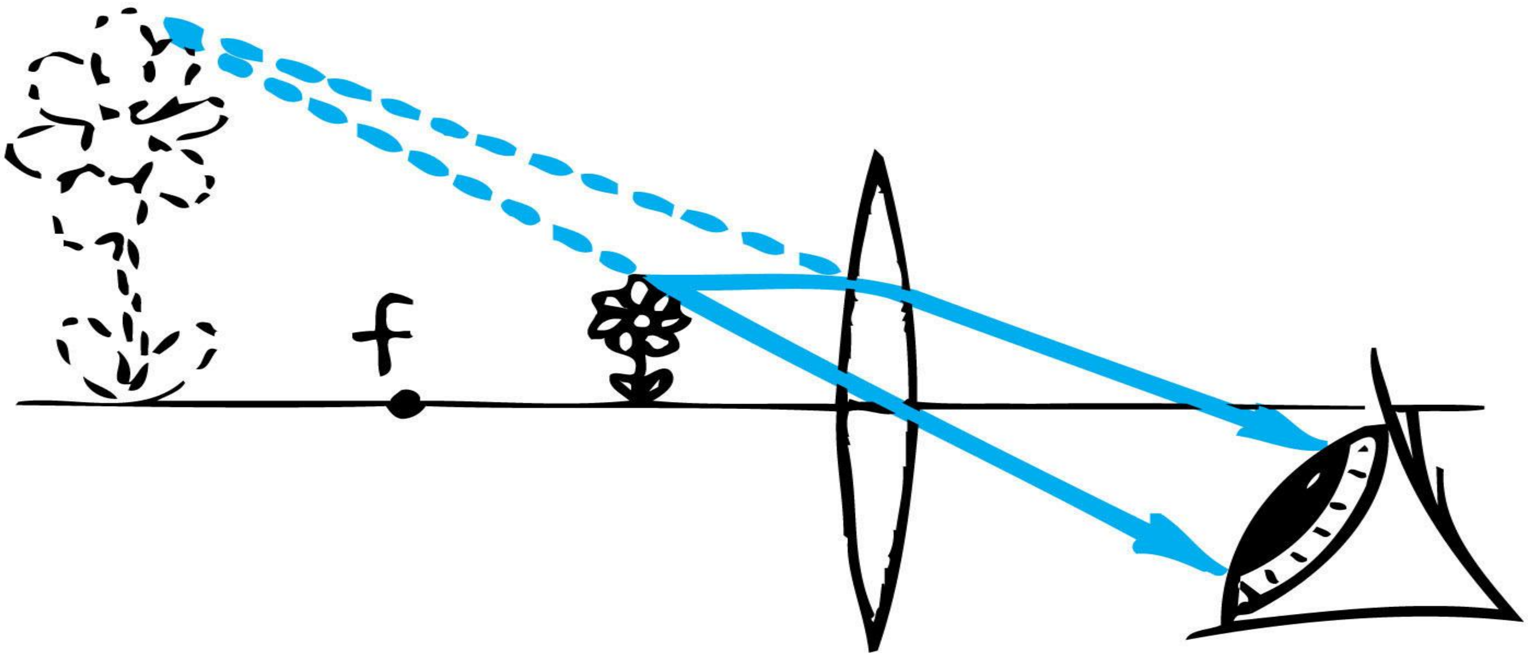
- Image formation is a consequence of light traveling in straight lines.



- The first camera—the pinhole camera— illustrates this fact.

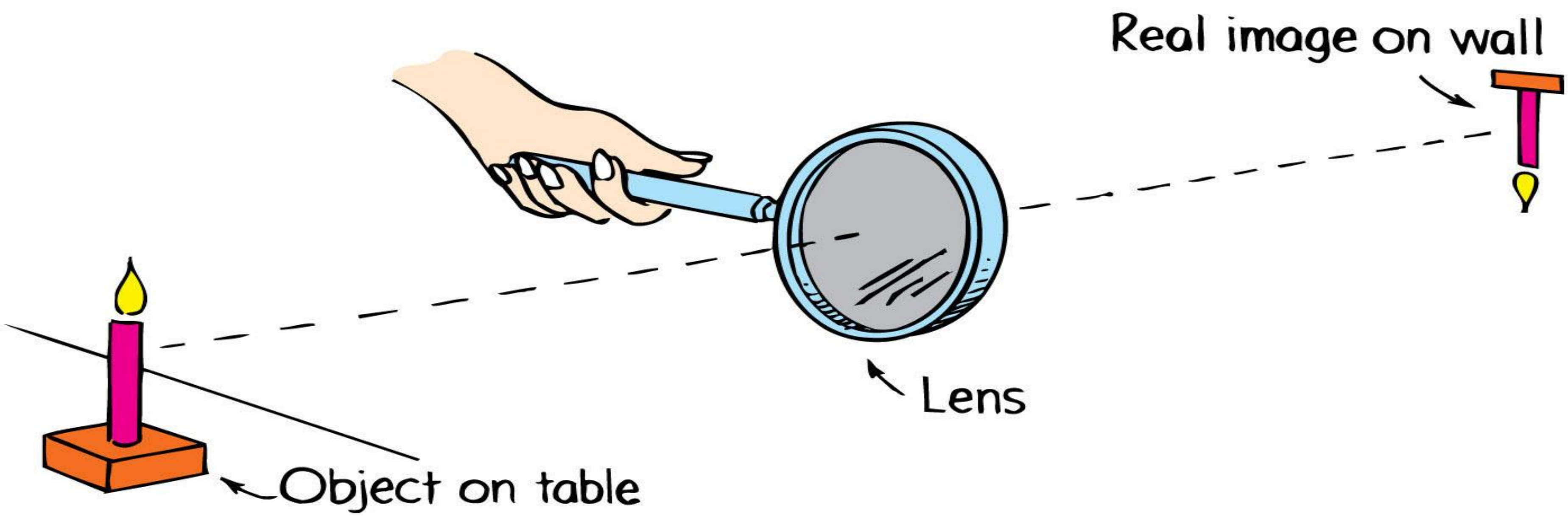
Lenses

A lens nicely bends the straight-line paths of light.



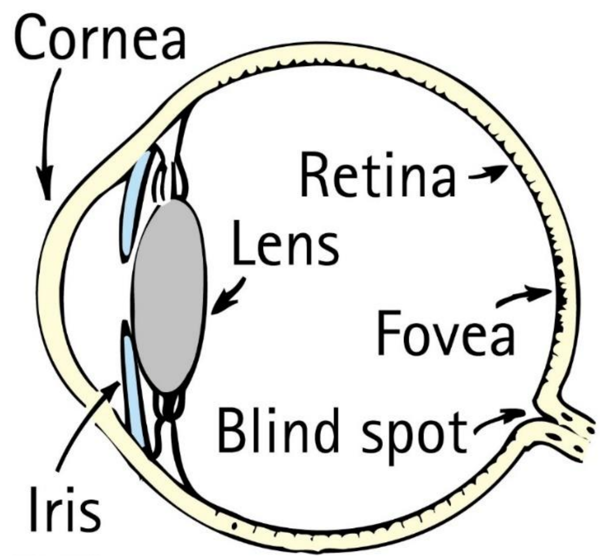
Lenses

A converging lens can project an image.



Seeing Light – The Eye

- The opening is called the *pupil*.
- The light then reaches the *crystalline lens,* which fine- tunes the focusing of light that passes through a gelatinous fluid called *vitreous humor*.
- Light then passes to the *retina,* which covers the back two-thirds of the eye and is responsible for the wide field of vision that we experience.



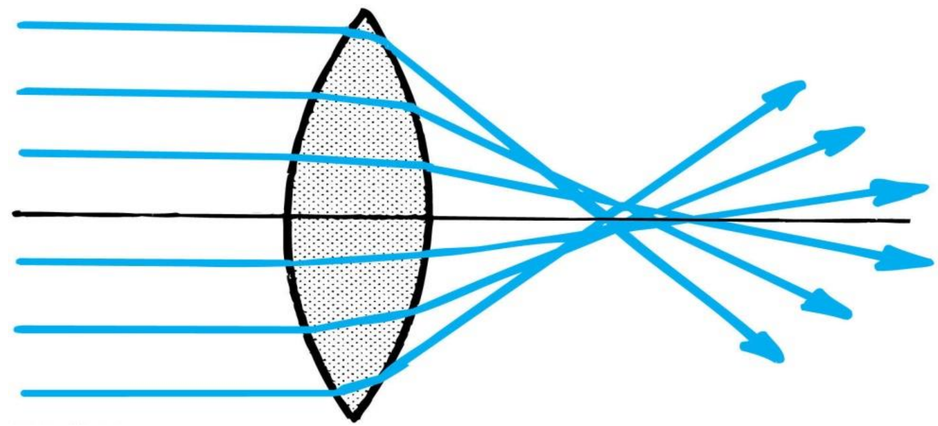
- For clear vision, light must focus directly on the retina.
- The retina is not uniform.
  - In the middle is the *macula,* and a small depression.
  - in the center is the *fovea,* the region of most distinct vision.
  - Behind the retina is the *optic nerve,* which transmits signals from the photoreceptor cells to the brain.
  - There is also a spot in the retina where optic nerves are connected; this is the blind spot.

- Light is the only thing we see with the most remarkable optical instrument known—the eye.
- As light enters the eye, it moves through the transparent cover called the *cornea,* which does about 70% of the necessary bending of the light before it passes through an opening in the *iris* (colored part of the eye).

Lens Defects عيوب العدسات

Aberration

- distortion in an image
- types of aberrations
- Spherical aberration
  - result of light passing through the edges of a lens and focusing at a slightly different place from where light passing through the center of the lens focuses



الزيغ عباره عن تشوه فى صوره تنتجها عدسه والتى تكون إلى حد ما موجوده فى جميع النظم البصرية.

Lens Defects

Aberration (continued)

- Chromatic aberration
  - result of various colors having different speeds and different refractions in the lens
- Astigmatism (اللانقطية)
  - front surface of the eyeball is unequally curved