

Light Waves

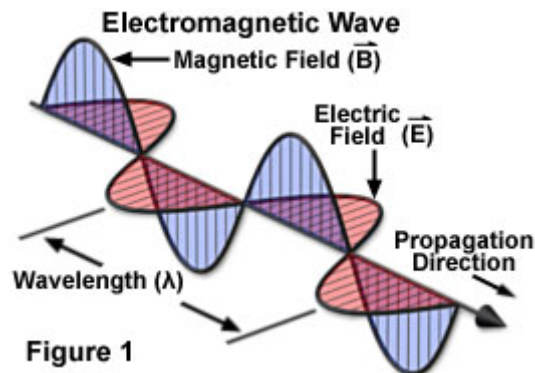
(Chapter 11)

Student Learning Outcome: Describe an electromagnetic wave and determine the behavior of electromagnetic waves as they interact with different mediums.

1. What is an electromagnetic wave?
2. What determines how light will interact with matter?
3. What are the properties of a mirror?
4. When and how is light refracted?
5. What causes diffraction?
6. How are colors produced?
7. What is polarized light?

What is an electromagnetic wave?

- ❖ **An electromagnetic wave is an electric field and a magnetic field that travel together and carry energy.**



<http://micro.magnet.fsu.edu/primer/java/wavebasics/index.html>

- The EM wave is generated by the vibrations of accelerated charges.
 - These two fields (E and B) continuously induce the other, allowing propagation of the wave.
- ❖ The fields exist and travel together with or without a medium. Energy is carried from place to place. (**Radiation**)
 - ❖ “Light” has a limit to its speed. All electromagnetic waves travel at the same speed in a vacuum (in space).

IN METRICS	IN MILES
3×10^8 m/s	186,000 miles/sec
3×10^5 km/s	670×10^6 mph

- ❖ The speed of an EM wave is related to the wavelength and frequency, like any other wave.

$$c = \lambda f$$

Question: A particular ray of red light has a frequency of 4.2×10^{14} Hz. What is the wavelength of this red light?

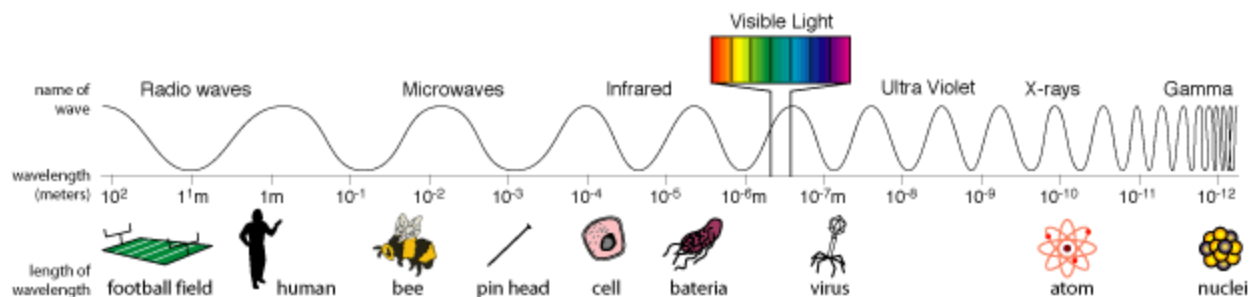
- ❖ It takes time for light to travel, so the light we see was generated in the past!

Examples:

- ✚ Sun
- ✚ Proxima Centauri 4.2 LY
- ✚ Sirius 8.6 LY
- ✚ Andromeda Galaxy 2.5×10^6 LY

- ❖ Electromagnetic waves come in many wavelengths.

Type of "light"	λ	f	Energy
Gamma rays			
X-rays			
Ultraviolet			
Visible			
Infrared			
Radio			



❖ The entire range of electromagnetic wave frequencies is called the electromagnetic spectrum.

❖ We see visible light with our eyes.

➤ White light can be split into a full color spectrum.

visible spectrum

➤ We interpret particular wavelengths of visible light as particular colors!

Go To: <http://science.hq.nasa.gov/kids/imagers/ems/visible.html>
<http://csep10.phys.utk.edu/astr162/lect/light/spectrum.html> (end of page)

❖ Each color of the visible spectrum corresponds to a specific wavelength, frequency, energy and temperature.

Red	Yellow	Blue
650 nm	575 nm	475 nm
cooler		warmer
less Energy		more Energy

❖ The primary source of **infrared** radiation is heat or thermal radiation.

➤ Everything radiates in the infrared, including ice!

Go To: http://spaceplace.jpl.nasa.gov/en/kids/sirtf1/sirtf_action.shtml

❖ Light is a wave and a particle (photon).

❖ A photon is a particle of light.

What determines how light will interact with matter?

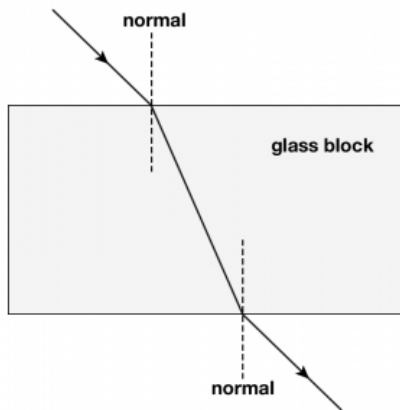
❖ How light interacts with the matter depends on four quantities.

- 1) Surface
- 2) Material
- 3) Angle of incidence
- 4) Wavelength

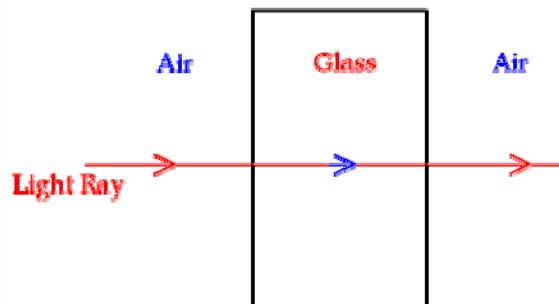
❖ **Transmission: light may travel through a transparent material.**

- Light may be absorbed and re-emitted, or it may simply pass through a transparent material.
- While the light is in the transparent material, it will have a different speed than it does in a vacuum.

Examples: Glass & Air



<http://musingsofscience.wordpress.com/page/2/>



<http://www.gcsescience.com/pwav22.htm>

❖ **Absorption: light may be absorbed by an opaque material.**

Example: Blacktop

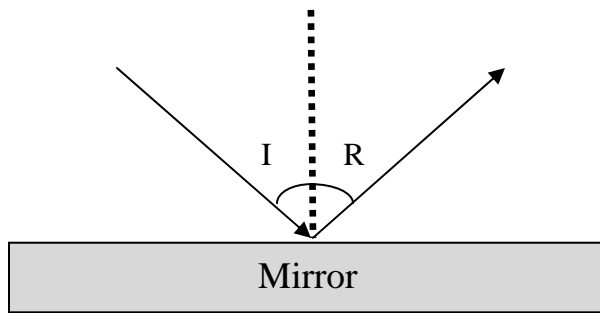
Question: If a material absorbs radiant energy, what is the result?

What are the properties of a mirror?

❖ **Reflection: light may bounce from a surface back into the original medium.**

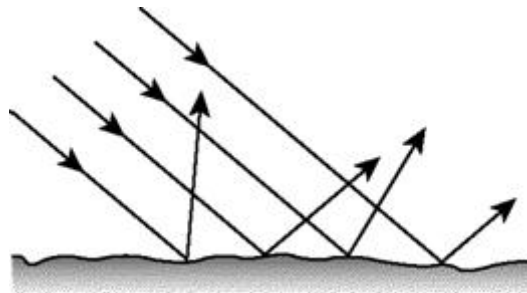
- ❖ The law of reflection states that incoming light rays and outgoing light rays have the same angle with respect to the normal line.

Angle of incidence = Angle of reflection



❖ The law of reflection applies to all reflective surfaces.

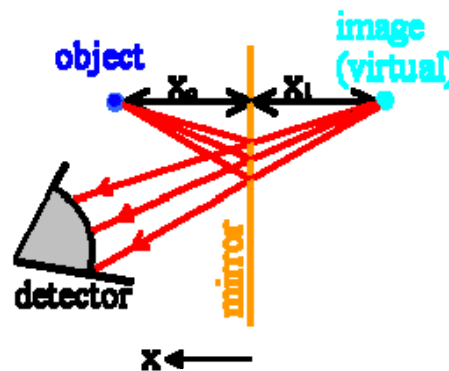
❖ **Diffuse reflection:** light rays are reflected in various directions from an irregular surface.



http://www.mryoungphysics.com/PAPP_MT_Chapter_14_KEY.htm

❖ A **flat mirror** reflects all light rays in the same direction and creates an image.

- 1) Upright
- 2) Same size
- 3) Same distance
- 4) Left-right reversed
- 5) Virtual



Question: Why do we “see” an image behind the mirror?

❖ Curved mirrors change the image size and apparent distance of the image because of how the light rays are reflected from each part of the mirror.

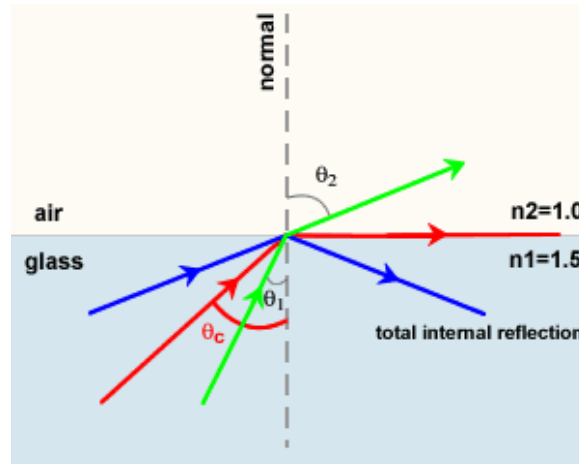
❖ **Convex mirrors** curve outward and always produce smaller images. The image is virtual and upright.

❖ **Concave mirrors** curve inward and produce a larger image if the person is between the mirror and the focal point.

Go To: <http://www.bettesbounces.com/MISC/pages/FUNHOUSE%20MIRRORS.htm>

Questions: Which mirror has the larger field of view? What kind of mirror is the side-mirror on your car?

- ❖ **Total internal reflection:** light may be internally reflected if it approaches the boundary of the material at *the critical angle*.



Examples: Diamonds & Fiber Optics

When and how is light refracted?

- ❖ **Refraction:** light will change speed and may change direction when it is transmitted from one material to another.
- ❖ The amount of refraction depends on three quantities.
 1. **Wavelength:** each wavelength of light interacts with a material differently.
 2. **Angle of incidence:** larger angles of incidence result in larger changes in direction.
 3. **Material:** different materials result in different light speeds.

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

❖ The change in index of refraction determines the direction light “bends”.

➤ Low to high $n \rightarrow$ light is bent toward the normal

➤ High to low $n \rightarrow$ light is bent away from normal

Questions:

1. In which substance, would light travel faster, ethyl alcohol or air?

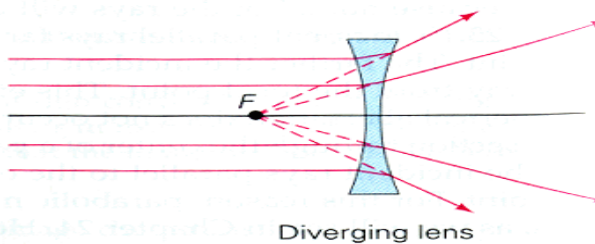
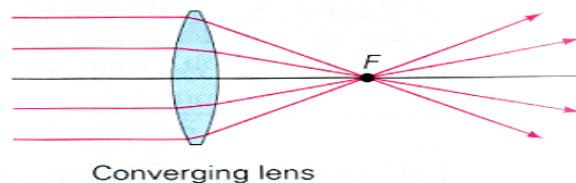
2. What is the speed of light in ethyl alcohol?

3. As the light goes from air into the ethyl alcohol, will it bend toward or away from the normal line?

❖ **Refraction affects where objects appear to be.**

Go To: <http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/redsun.html>

❖ **Glass lenses refract light.**



<http://www.physics.uiowa.edu/~umallik/adventure/geo-optics/lightnw.htm>

❖ **A convex lens causes parallel light rays to converge.** The image at the focal point of a convex lens is a true image.

❖ **A concave lens causes parallel light rays to diverge.** The image at the focal point of a concave lens is a virtual image.

Go To: <http://www.mysciencesite.com/optics4.html>

❖ **Temperature gradients refract light.**

Go To: <http://www.wonderquest.com/Mirages.htm>

What causes diffraction?

❖ **Diffraction: light waves may bend around corners.**

- ❖ The amount of diffraction depends on the how the size of the wavelength compares to the size of the barrier.

Example: Shadows

How are colors produced?

❖ **Light interacting with matter or being emitted from matter produces colors.**

- ❖ **Selective reflection**: A particular wavelength of light is reflected. All other wavelengths are absorbed.

- Some objects reflect all wavelengths of white light. Any color shined on the surface will be reflected.
- Some objects reflect no wavelengths of white light. Any color shined on the surface will be absorbed.

Examples: Red Rose, White Paper, Black Ink

- ❖ **Selective transmission**: A particular wavelength of light is transmitted. All other wavelengths are absorbed.

Example: Stained Glass

- ❖ **Temperature**: for every object, there is a specific wavelength at which it radiates most of its energy.

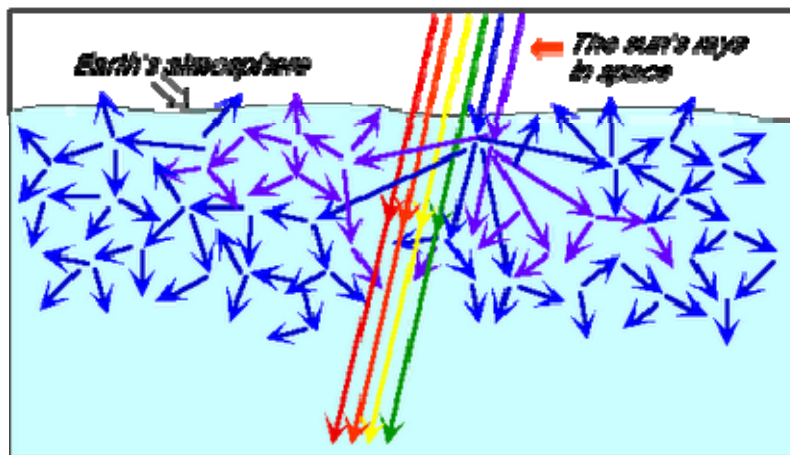
Wien's Law

$$T(\text{Kelvin}) = \frac{3,000,000}{\lambda_{\text{max}} (\text{nm})}$$

Examples: Stars & Flames

Question: Our Sun has a surface temperature of 5,800 K. What is the wavelength of maximum emission for our Sun?

- ❖ **Scattering:** Particular wavelengths of light may be bounced around in a substance causing particular colors to be seen.
- ❖ The sky on Earth appears **blue** because blue (and **violet**) photons are scattered as they collide with atoms and molecules within the air.



<http://cliffmass.blogspot.com/2010/08/why-did-smoke-cause-a-reddish-sun.html>

- ❖ Longer wavelengths of light pass through air.

Question: Why does our sky appear to be mostly blue, and not violet?

- ❖ At sunset (and sunrise), the Sun is close to the horizon and the sunlight must pass through more air than when it is high overhead. (**red sunset**)

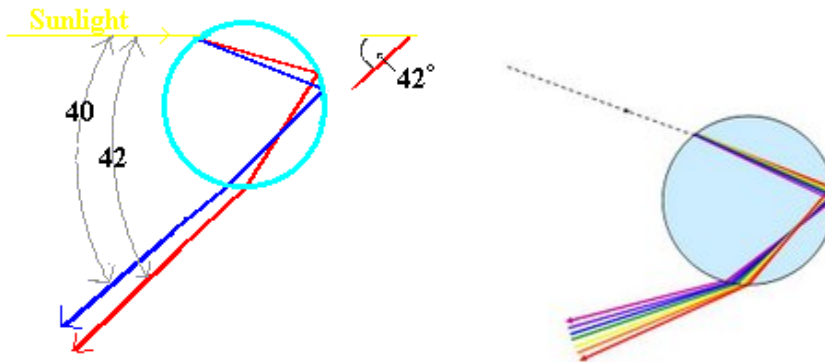
Go To: <http://www.astronomynotes.com/telescop/s12.htm>

Questions:

1. What color would our sky be if atmospheric particles were slightly larger?
2. Why is the sky black on the moon?
3. Why are some clouds white and some clouds dark grey?

- ❖ **Dispersion:** Visible light may be divided into separate colors.

Examples: Prisms, Rainbows



Question: What three processes happen to light to form a rainbow?

- ❖ Each person sees a different rainbow because each person sees along a different line of sight.

Go To: <http://www.mathdemos.org/mathdemos/MCRain/MCRain.html> (half way)

- ❖ The rainbow you see is a portion of the three dimensional cone of colors produced by the water droplet's.

What is polarized light?

- ❖ **Polarized light has only one direction of vibration.**
- ❖ Unpolarized light is made up of transverse waves vibrating in several directions.
- ❖ Polarizing materials, crystals, allow only light that is vibrating in a particular plane to be transmitted.

Go To: <http://www.polarization.com/water/water.html>
<http://www.prescriptionglassesonline.net/cheapglasses/?help122.html>

Question: How could you determine whether sunglasses are truly polarized?