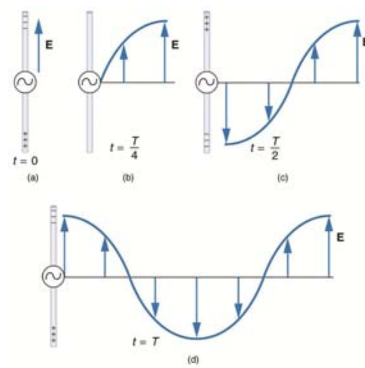
Chap 19 Electromagnetic Spectrum

Electromagnetic fields are produced by oscillating charges.

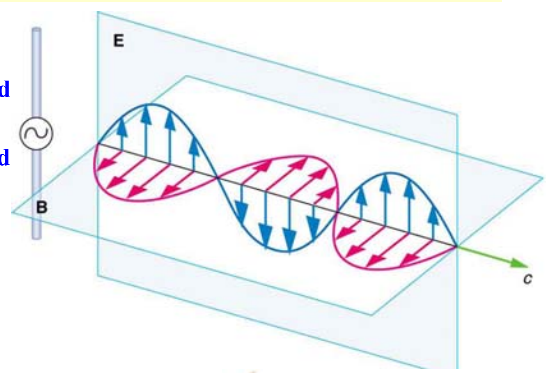


With the electric field a magnetic field is also generated, perpendicular both to the electric field and to the direction of propagation.

The electric field produced by an antenna connected to an ac generator propagates away from the antenna, analogous to a wave on a string moving away from your hand as you wiggle it up and down.

Production of Electromagnetic Waves

An electromagnetic wave propagating in the positive *x* direction, showing the electric and magnetic fields:

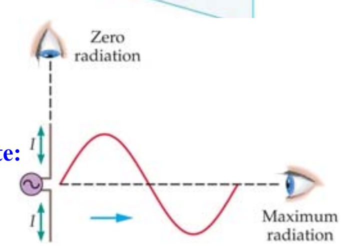


The direction of propagation and the directions of the electric and magnetic fields in an electromagnetic wave can be determined using a right-hand rule:

Point the fingers of your right hand in the direction of $\vec{E}$, curl your fingers toward $\vec{B}$, and your thumb will point in the direction of propagation.

Any time an electric charge is accelerated, it will radiate:

Accelerated charges radiate electromagnetic waves.



Maxwell's Predictions

- **A varying magnetic field induces an emf and hence an electric field (Faraday's Law)**
- **Magnetic fields are generated by moving charges or currents (Ampère's Law)**
- **Maxwell hypothesized that a changing electric field would produce a magnetic field and that *electric and magnetic fields play symmetric roles in nature***
- **He concluded that visible light and all other electromagnetic waves consist of fluctuating electric and magnetic fields, with each varying field inducing the other, and calculated the speed of light to be $3\text{x}10^8$ m/s**

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

$$\nabla \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$$

$$\nabla \cdot \vec{B} = 0$$

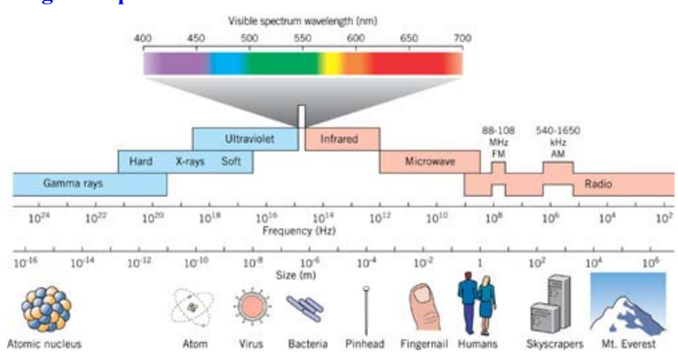
Electromagnetic Spectrum

Because all electromagnetic waves have the same speed in vacuum, the relationship between the wavelength and the frequency is simple:

$$c = f\lambda$$

photon energy

The full range of frequencies of electromagnetic waves is called the electromagnetic spectrum.



Electromagnetic Spectrum

Radio waves are the lowest-frequency electromagnetic waves that we find useful. Radio and television broadcasts are in the range of 10^6 Hz to 10^9 Hz.

Microwaves are used for cooking and also for telecommunications. Microwave frequencies are from 10^9 Hz to 10^{12} Hz, with wavelengths from 1 mm to 30 cm.

Infrared waves are felt as heat by humans. Remote controls operate using infrared radiation. The frequencies are from 10^{12} Hz to 4.3×10^{14} Hz.

Visible light has a fairly narrow frequency range, from 4.3×10^{14} Hz (red) to 7.5×10^{14} Hz (violet).

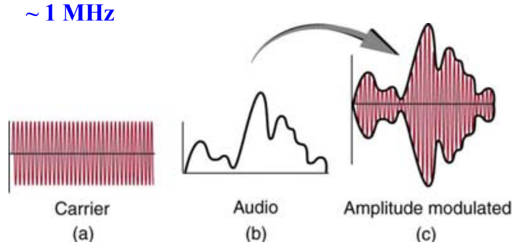
Ultraviolet light starts with frequencies just above those of visible light, from 7.5×10^{14} Hz to 10^{17} Hz. These rays cause tanning, burning, and skin cancer. Some insects can see in the ultraviolet, and some flowers have special markings that are only visible under ultraviolet light. (peta=10^{15})

X-rays have higher frequencies still, from 10^{17} Hz to 10^{20} Hz. They are used for medical imaging. (exa=10^{18})

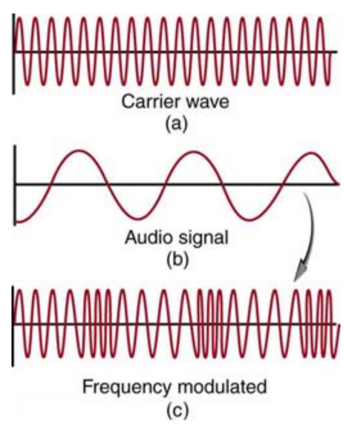
Gamma rays have the highest frequencies of all, above 10^{20} Hz. These rays are extremely energetic, and are produced in nuclear reactions. They are destructive to living cells and are therefore used to destroy cancer cells and to sterilize food.

AM FM Radio

~ 1 MHz



~ 100 MHz



3. The FM radio band in most places goes from frequencies of about 88 to 108 MHz. How long are the wavelengths of the radiation at the extreme ends of this range?

4. The AM radio band in most places goes from frequencies of about 535 to 1610 KHz. How long are the wavelengths of the radiation at the extreme ends of this range?

Examples

3. Suppose a sound wave and a light wave have the same frequency. Which one has the longer wavelength?

7. Compare the frequency, speed, and wavelength of microwaves versus visible light.

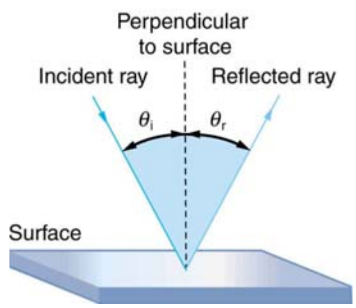
8. Compare the frequency, speed, and wavelength of radio waves versus ultraviolet light.

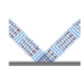
9. Which has more energy, visible light or ultraviolet light? What determines the energy of electromagnetic waves?

Ch 20 Classical and Modern Optics

Reflection of Light

- When an *incident ray* encounters a boundary with a second medium, part of it is *reflected* back into the first medium
- Specular and diffuse scattering of light





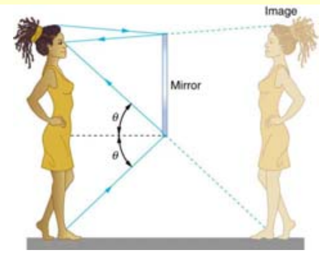
(a) Specular reflection (b) Diffuse reflection

Law of Reflection

- The angle of reflection is equal to the angle of incidence
- $\theta_i = \theta_r$

Forming Images with a Plane Mirror

Light reflected from the flower and vase hits the mirror. Obeying the law of reflection, it enters the eye. The eye interprets the ray as having had a straight-line path, and sees the image behind the mirror.

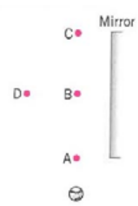


Properties of Mirror Images Produced by Plane Mirrors:

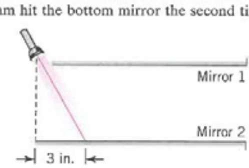
- **A mirror image is upright, but appears reversed right to left.**
- **A mirror image appears to be the same distance behind the mirror that the object is in front of the mirror.**
- **A mirror image is the same size as the object.**

Mirror Examples

3. A baseball is sitting near a plane mirror, as shown. At which of the marked locations could an observer stand and see the image of the baseball?

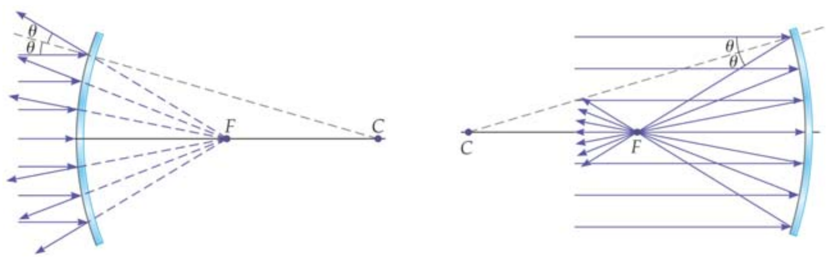


2. Two large plane mirrors are aligned so that they are parallel and facing each other, as shown. A flashlight beam strikes the bottom mirror, as shown. Where will the flashlight beam hit the bottom mirror the second time?

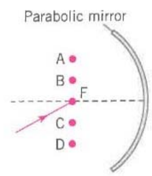


Spherical Mirrors

Parallel rays hitting a spherical mirror come together at the focal point (or appear to have come from the focal point, if the mirror is convex).

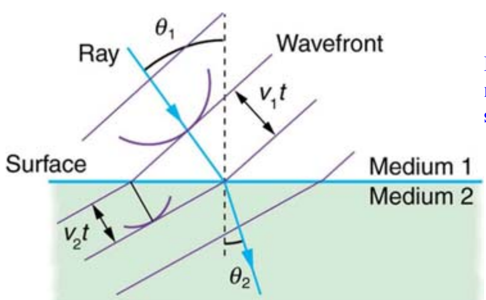


6. A laser beam passes through the focal point of a concave parabolic mirror, labeled F in the figure. After the beam reflects off the mirror, which other point will the beam pass through?



Refraction of Light

Light moves at different speeds through different media. When it travels from one medium into another, the change in speed causes the ray to bend.



From Huygens Principle, the angle of refraction is related to the different speeds:

$$\frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$

The speed of light in a medium is given by the index of refraction of that medium:

Definition of the Index of Refraction, *n*

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

Refraction of Light

We can now write the angle of refraction in terms of the index of refraction:

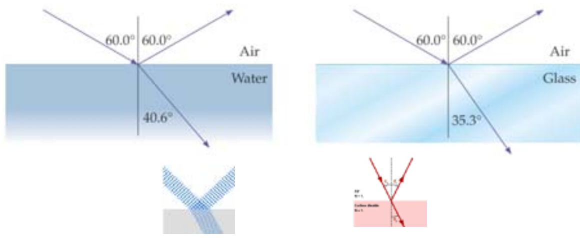


TABLE 26–2 Index of Refraction for Common Substances

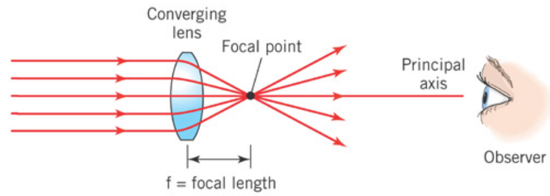
Substance	Index of refraction, n
Solids	
Diamond	2.42
Flint glass	1.66
Crown glass	1.52
Fused quartz (glass)	1.46
Ice	1.31
Liquids	
Benzene	1.50
Ethyl alcohol	1.36
Water	1.33
Gases	
Carbon dioxide	1.00045
Air	1.000293

Example

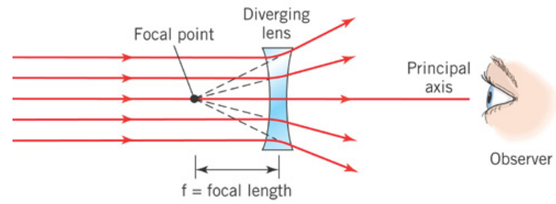
1. How fast does light travel through crown glass? Take the index of refraction of crown glass to be 1.52 and the speed of light to be 3×10^8 m/s.
2. If the speed of light through material Z is 2.5×10^8 m/s, what is this material's index of refraction?
3. Diamond has a high index of refraction at about 2.4, which helps account for its sparkle. How fast does light travel through a diamond? Using Problem 1, which material, diamond or crown glass, bends a light ray more as it passes from air into the respective material?

Lenses

The change in the direction of light during refraction can be used to produce lenses. Converging lenses converge parallel light that goes through at the focal point. Diverging lenses diverge parallel light that goes through as if emitted from a focal point at the same side of the incident light.

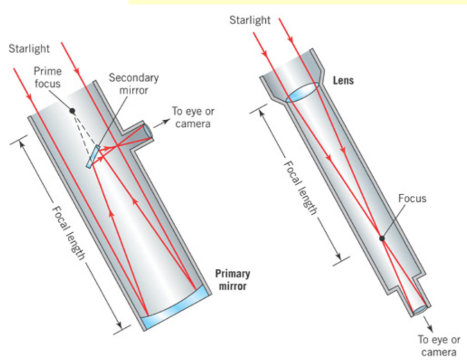


(a)



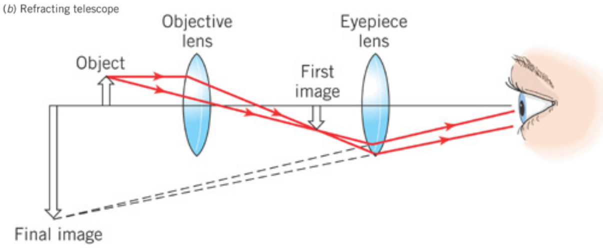
(b)

Telescopes and Microscopes



(a) Reflecting telescope

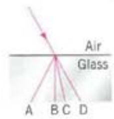
(b) Refracting telescope



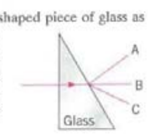
(a)

Examples

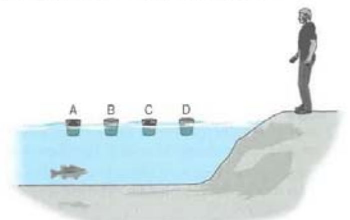
8. The figure shows a beam of light striking a flat interface between air and glass. Which is the correct refracted beam, A, B, C, or D?



10. Light passes through a triangular-shaped piece of glass as shown. Which is the correct emerging beam, A, B, or C? How would your answer change if the glass were submerged in a liquid that had the same index of refraction as the glass?



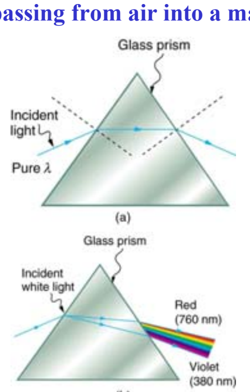
13. A man is standing by the lake looking at a piece of cork floating on the surface. At that moment, he notices a fish in the same line of sight as the cork. The figure shows the actual position of the fish. Where is the cork?

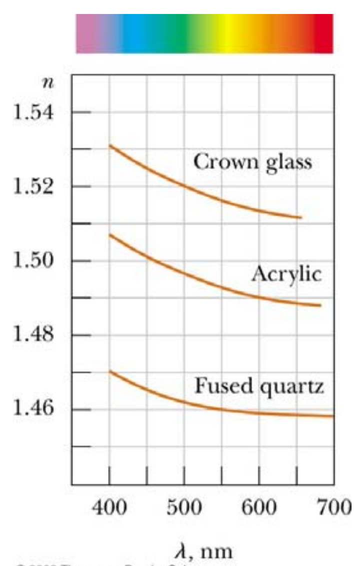


he aim to spear the fish? Due to refraction, is the fisl tually located nearer or farther from where he sees it

Dispersion and the Rainbow

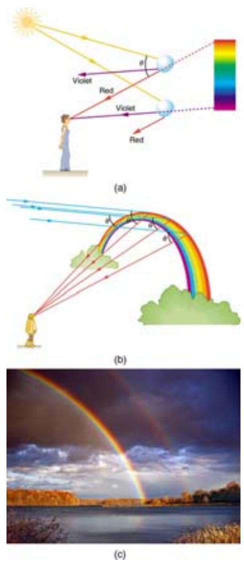
- **The index of refraction in anything except a vacuum depends on the wavelength of the light. This dependence of n on λ is called *dispersion***
- **The index of refraction for a material usually decreases with increasing wavelength**
- **Violet light refracts more than red light when passing from air into a material**



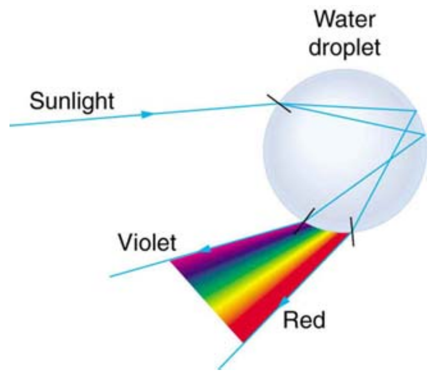


© 2003 Thomson - Brooks Cole

Dispersion and the Rainbow

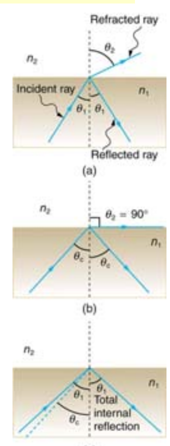


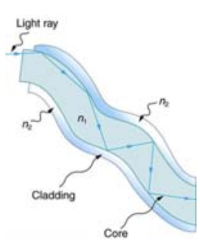
primary rainbow

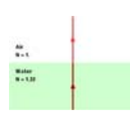


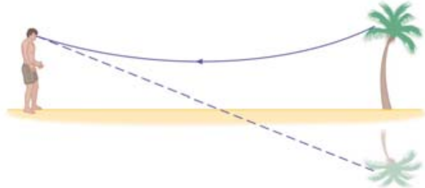
Other Effects of Refraction

If light enters a medium of lower index of refraction, it will be bent away from the normal. If the angle of incidence is large enough, the angle of refraction is 90°; at larger incident angles the light will be totally reflected. (Total internal reflection)

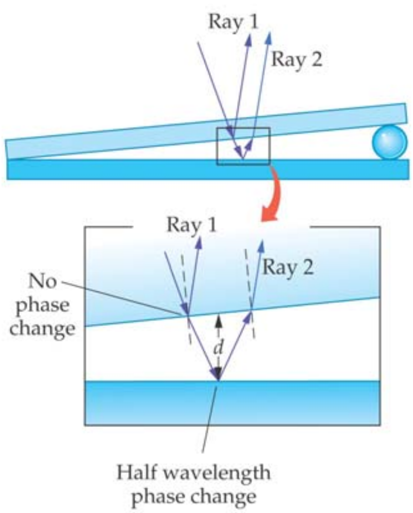




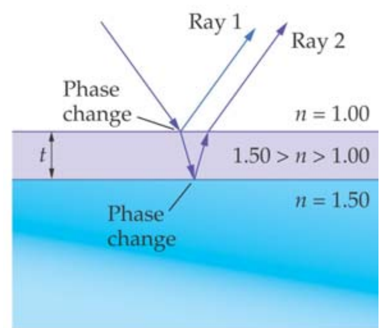




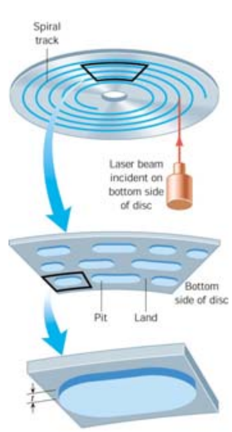
Interference in Reflected Waves

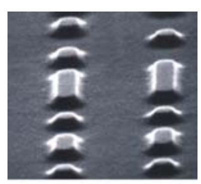


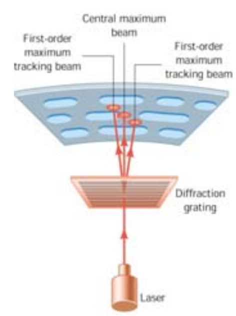
Different separations could lead to constructive or destructive interference.

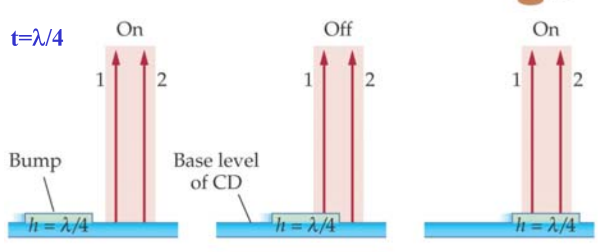


Application of Interference: CD's









Polarization

LCDs use liquid crystals, whose direction of polarization can be rotated depending on the voltage across them.