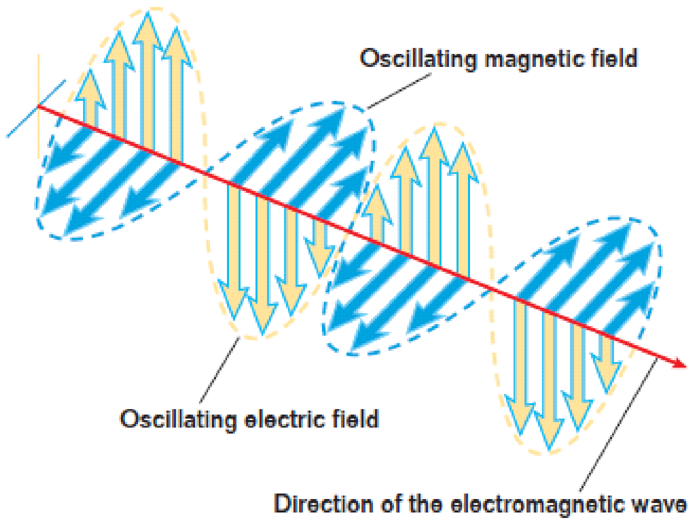
Physics I Notes Chapter 14: Light, Reflection, and Color

Characteristics of light

- Light is an ***electromagnetic wave***. As shown below, an **electromagnetic wave** is a transverse wave consisting of mutually perpendicular oscillating electric and magnetic fields. Electromagnetic waves are ultimately produced by an accelerating charge. A changing electric field produces a changing magnetic field which in turn produces a changing electric field and so on. Because of this relationship between the changing electric and magnetic fields, an ***electromagnetic wave is a self-propagating wave that can travel through a vacuum or a material medium*** since electric and magnetic fields can exist in either one.



Animation of e.m. wave with vibrating charge Scroll down after webpage loads for animation.
http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=35.0

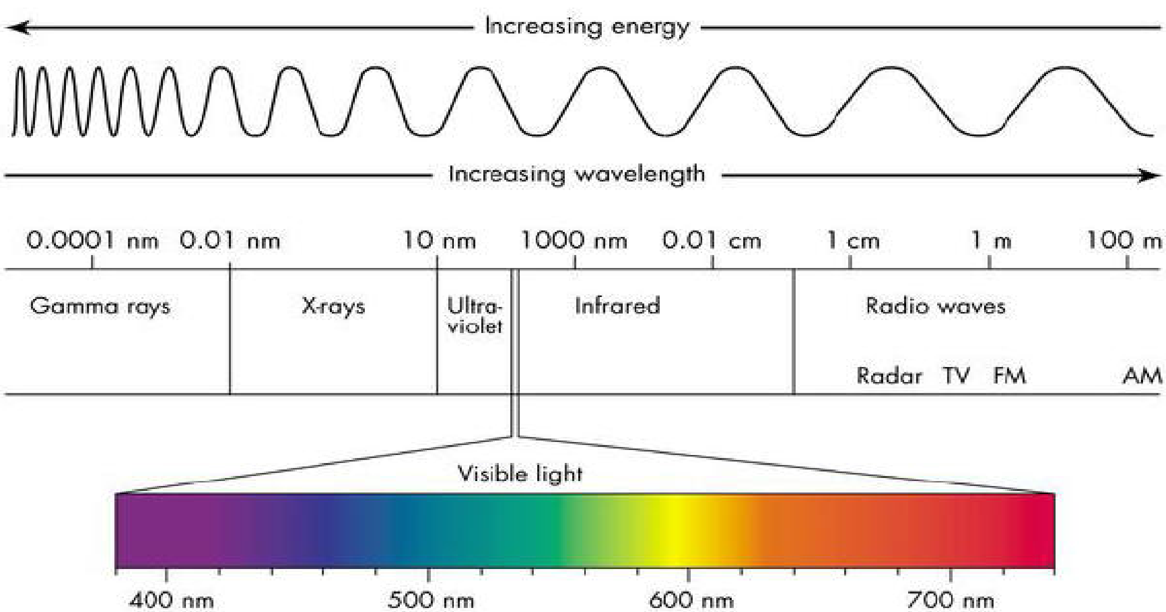
- ***All electromagnetic waves travel at the speed of light.*** Electromagnetic waves are distinguished from each other by their differences in ***wavelengths and frequencies*** (wavelength is inversely related to frequency).

  $c=f\lambda$ ***c = speed of light = 3.0×10^8 m/s in a vacuum = 300,000 km/s = 186,000 miles/s***

  A ***light year*** is the ***distance*** that light travels in one year in a vacuum. So haw many miles would that be?

  What would a light-minute be?

- The **electromagnetic spectrum** is a continuum of all electromagnetic waves arranged according to frequency and wavelength. Visible light is only a small portion of the entire electromagnetic spectrum.

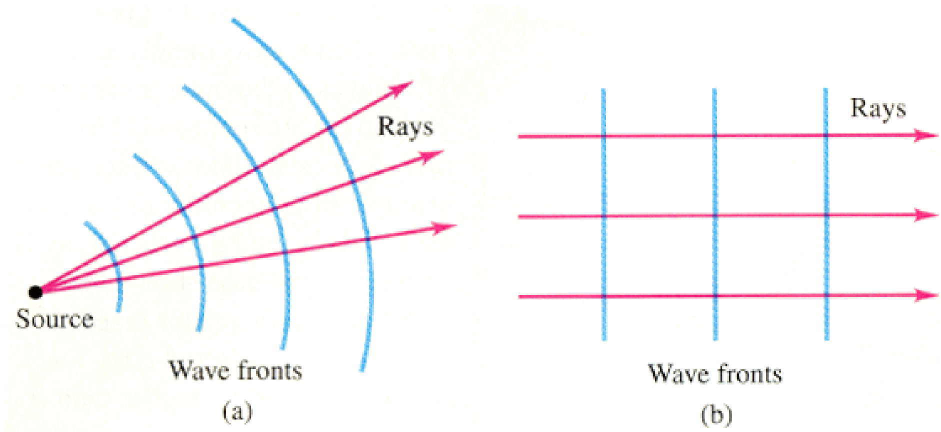


- **Brightness or intensity of light** ***decreases by the square of the distance from the source (inverse square law). .***
  Question: How much would the brightness change if you were 3 times farther away from the source as your classmate?

- ***Everything you see… is light! You do not see people or objects - you only see the light they reflect!!***

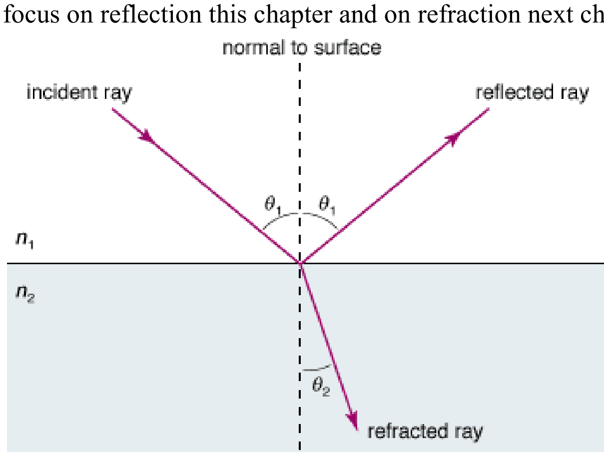
Ray model of light

- Waves are often approximated as rays to predict the path with which they will travel. The **ray model of light** is based on the assumption that light travels in a straight line in a vacuum or uniform medium. A **ray** is a straight line that represents the path of a very narrow beam of light. **Ray diagrams** are drawings used to depict the path of light rays. Even though ray diagrams ignore the wave nature of light, they are useful in describing how light behaves at boundaries (reflection or refraction) and often used to locate the image formed by a mirror or a lens.



Behavior of light at a boundary

- Whenever light (or any wave) encounters a different medium one of three things can happen. The light can be ***absorbed*** by the new medium and turned into internal energy and/or heat, the light can be ***transmitted*** through the new medium, or the light can be ***reflected*** back into the original medium. In reality, what most often happens is a combination of the three fates. Good mirrors reflect about 90 percent of the incident light and absorb the rest. If the light is reflected the angle of the reflected ray will be equal to the angle of the incident ray. If the ray is transmitted into the new medium the ray may be bent or refracted. We will focus on reflection this chapter and on refraction next chapter.



When Light encounters Matter

- **The 3 possible "fates" to befall the energy of the light when it interacts with matter/substances:**
  1. **Reflected –** Reflection of the light bounces the energy back into the same medium that it came from.
  2. **Transmitted through –** The light can travel through the new material while undergoing varying degrees of interaction with the substances' molecules.
  3. **Absorbed –** The light energy can be completely absorbed into the molecules of the substance and turned into heat.

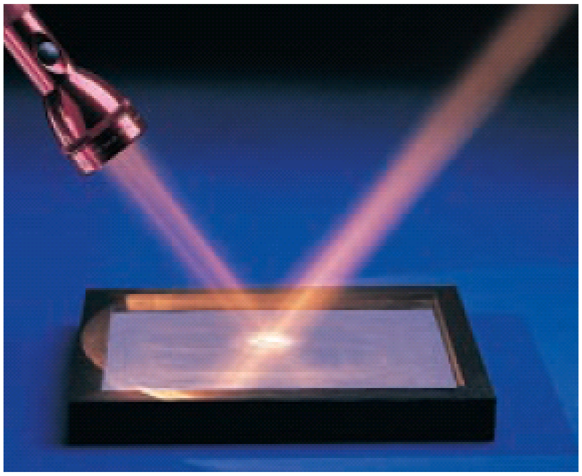
We can categorize substances according to how light interacts with that substance's molecules.

- **Opaque** objects absorb and/or reflect all light - light cannot get through.
- **Transparent** objects allows light to travel through in straight lines. Objects can be transparent to some colors or frequencies of light and opaque to others. Regular standard glass is transparent to visible light, but is opaque to UV and IR light.
- **Translucent** substances or objects scatter light in all directions as it passes through. Our atmosphere is translucent to visible light.

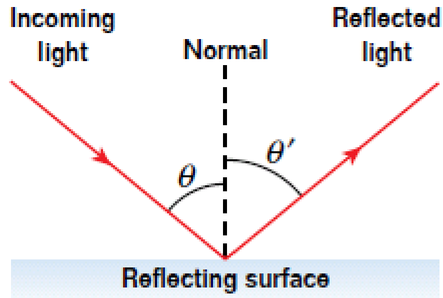
Reflection

- **Reflection** is the turning back of an electromagnetic wave at the surface of a substance. The **Law of Reflection** states that the angle of incidence = angle of reflection. Typically the angles are measured with respect to the normal. The **normal** is a line drawn ***perpendicular*** to the surface at the point of incidence.

http://www.physicsclassroom.com/Class/refln/u13l1c.cfm
http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/Reflection/Reflection.html



(a)



(b)

Figure 14-7
The symmetry of reflected light **(a)** is described by the law of reflection, which states that the angles of the incoming and reflected rays are equal **(b).**

- Reflection of rays off a surface will be regular or varied depending on the size of the irregularities of the surface relative to the wavelength of the light incident on the surface. **Specular (regular) reflection** occurs when light is incident on a "smooth" surface and the rays are reflected parallel to each other. **Diffuse reflection** occurs when light is incident on a "rough" surface and the rays are reflected in many different directions.

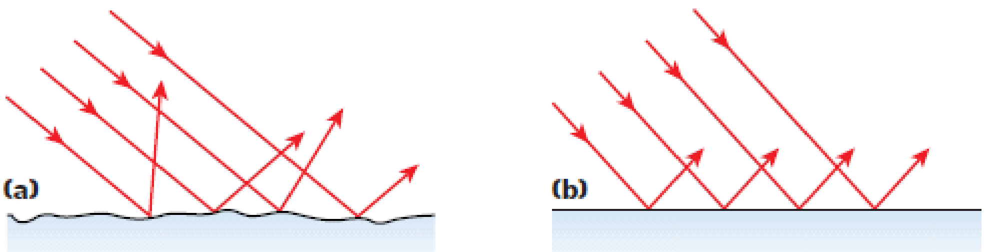


Figure 14-6
Diffusely reflected light is reflected in many directions **(a)**, whereas specularly reflected light is reflected in the same forward direction only **(b).**

Mirrors

- In analyzing mirrors we will focus on the types of images they produce. Images are formed at the point where rays of light actually intersect (**real image**) or from which they appear to intersect or come from (**virtual image**).
- *Three* characteristics are used in describing the image produced by a mirror –
  1. ***real or virtual,***
  2. ***orientation (inverted or upright), and***
  3. ***magnification (larger, smaller, or same size).***

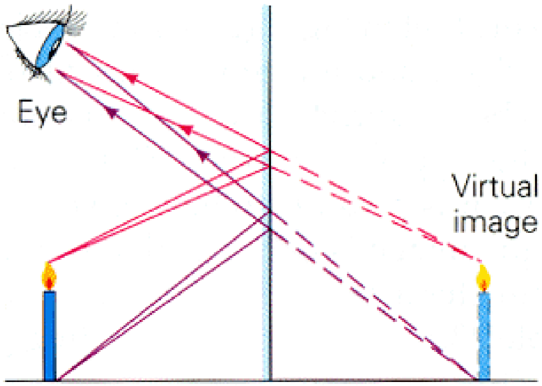
Virtual images will be upright and real images will be inverted.

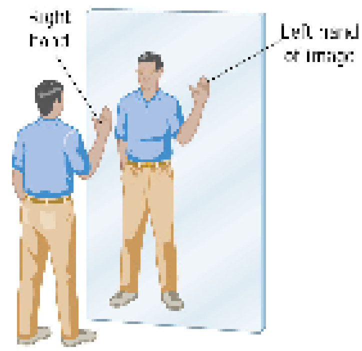
- **Magnification** is the ratio of the height of the image to the height of the object, which can also be calculated in terms of a ratio of the distances. If the image is larger than the object, the magnification will be greater than one. If the image is smaller than the object, the magnification will be less than one. If the image is the same size as the object, the magnification will be one.

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Flat Mirrors

- ***A flat mirror will always produce an upright, virtual, unmagnified image, that is left-right reversed.*** The ***distance*** from the object to the mirror ***is equal*** to the distance of the image to the mirror.

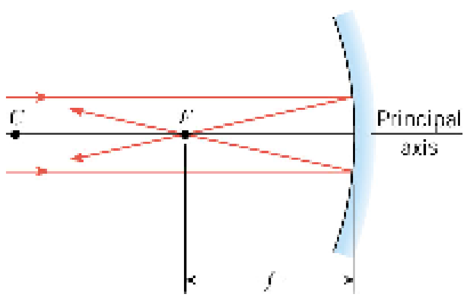


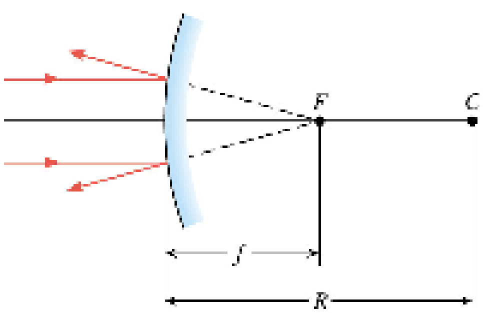


http://www.physicsclassroom.com/mmedia/optics/ifpm.cfm

Spherical Mirrors

- The type of image produced by a spherical mirror depends upon whether the mirror is concave (converging) or convex (diverging) and, for concave mirrors, whether the object is behind or in front of the focal point. The **focal point** is the point at which rays parallel to the principal axis intersect (converge) after being reflected. The **principal axis** is a line drawn perpendicular (normal) to the surface of the mirror and passes through the focal point and center of curvature of the mirror. **Focal length** is the distance from the focal point to the mirror along the principal axis.





The focal length is ½ the radius of curvature of the mirror.
f=R/2

http://www.glenbrook.k12.il.us/GBSSCI/PHYS/MMEDIA/optics/rdcma.html

Images produced by spherical mirrors

- To determine the type of image produced by a spherical mirror you can draw ray diagrams and/or use the mirror and magnification equations. You will have to know how to do both.

- **Four rules for finding images formed by spherical mirrors using *__ray diagrams__*. *(Note – You only need to draw two rays to determine the point at which the image will form.)***
  1. Incident rays parallel to the principal axis of a mirror are reflected through the focal point.
  2. Incident rays that pass through the focal point are reflected parallel to the principal axis.
  3. Incident rays that pass through the center of curvature are reflected back through the center of curvature.
  4. Incident rays drawn to the point of contact of the principle axis with the mirror will reflect at the same angle with which they hit (law of reflection).

- **Equations used for locating images and determining magnifications**
  - ***Mirror equation*** ***Magnification***

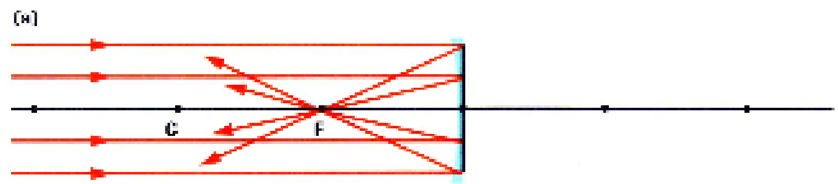
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad\qquad M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

- **Sign conventions for mirrors**
  - d_o is + (object is in front of mirror)
  - d_i is + if in front of mirror (real image)
  - d_i is – if behind mirror (virtual image)
  - r and f are + for concave mirror
  - r and f are – for convex mirror
  - M is positive, upright
  - M is negative, inverted
  - ***In this course -Virtual images are always upright.*** Since the distance for a virtual image is negative, the magnification will be positive and the image is upright. **Real images are always inverted.** Since real images have a positive distance, magnification will be negative and the image is inverted.

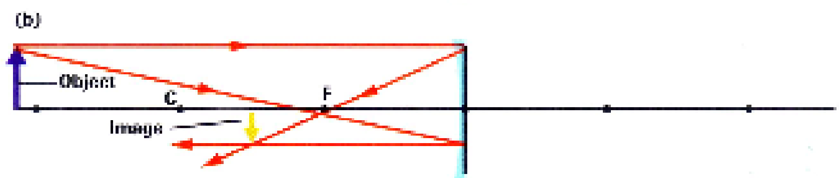
Concave (converging) mirrors

- The type of image produced by a concave mirror depends upon the location of the object relative to the focal point and center of curvature. Real images are formed if the object is beyond the focal point.

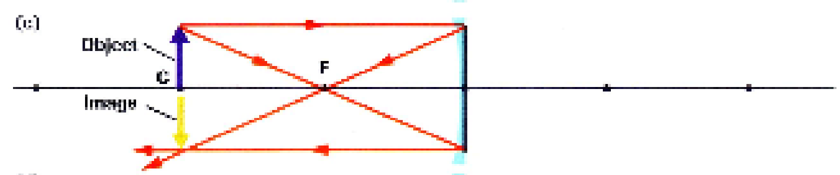
a. All incoming rays parallel to the axis will reflect through the focal point.



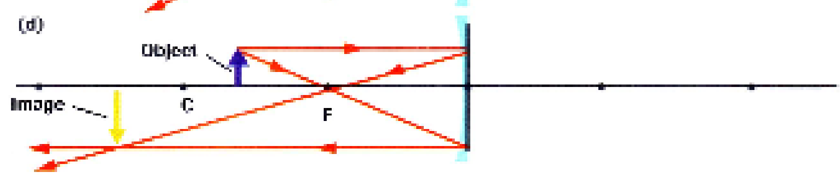
b. If the object is beyond the center of curvature, the image is inverted, real, and smaller.



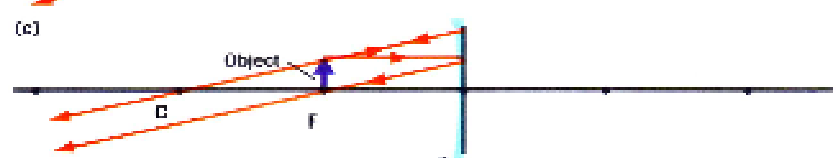
c. If the object is at C, the image will be real, inverted and the same size located also at C.



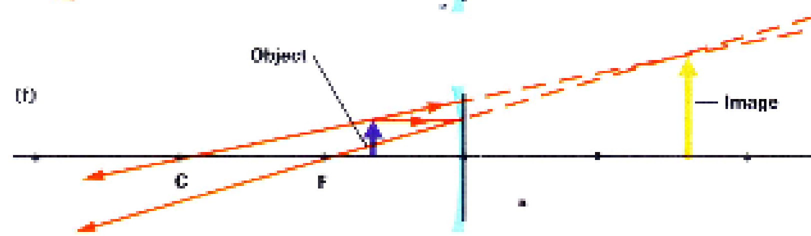
d. If the object is between the focal point and center of curvature, the image is inverted, real, and larger.



e. At the focal point no image is produced since all rays would reflect parallel.



f. If object is in front of focal point, the image is upright, virtual, and larger.



http://www.physicsclassroom.com/Class/refln/u13l3d.cfm http://www.glenbrook.k12.il.us/GBSSCI/PHYS/MMEDIA/optics/rdcma.html

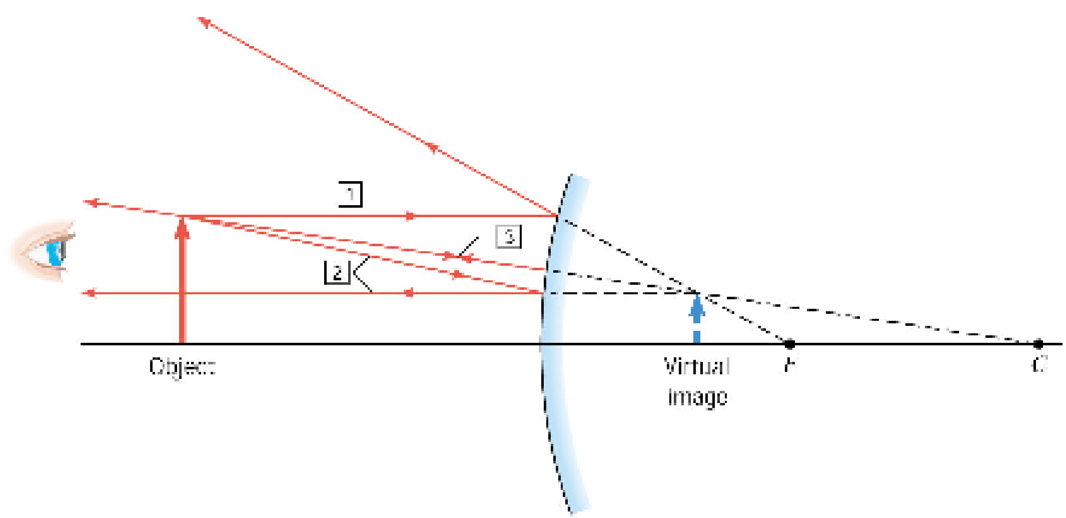
Example 1:

A concave spherical mirror has a focal length of 10.0 cm. Locate the image of a pencil that is placed upright 30.0 cm from the mirror. Find the magnification of the image. Draw a ray diagram to confirm your answer.

Object placed at:	**Image distance d_i**	**real or virtual**	**upright or inverted**	**larger or smaller**
$d_o > C$	+	real	inverted	smaller
$d_o = C$	+	real	inverted	same size
$f < d_o < C$	+	real	inverted	larger
$d_o = f$	No image	No image	No image	No image
$d_o < f$	-	virtual	upright	larger

Convex (diverging mirror) mirrors

- ***Convex mirrors always produce images that are virtual, upright and smaller.*** Since the mirror is convex the ***center of curvature is behind the mirror and so is the focal point.*** Both values are ***negative*** when used in the mirror equation.



Parabolic mirrors

- **Spherical aberration** is the inability of a spherical mirror to focus all parallel rays to a single point. Parabolic mirrors eliminate spherical aberration by making all parallel rays pass through focal point. Parabolic mirrors are used in a variety of common devices such as reflecting telescopes and flashlights because of their ability to focus the light more effectively than a spherical mirror.

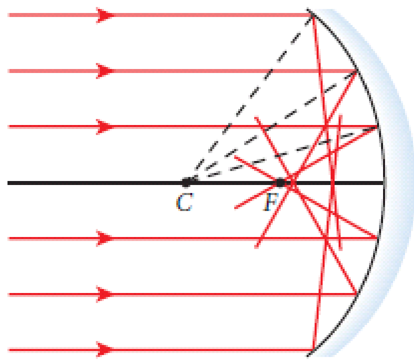


Figure 14-15
Spherical aberration occurs when parallel rays far from the principal axis converge away from the mirror's focal point.

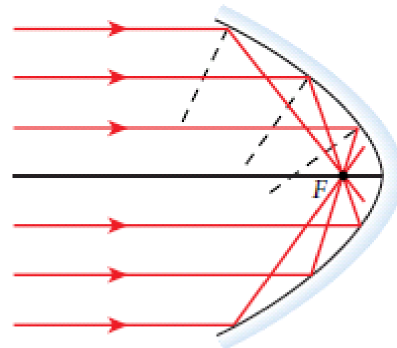
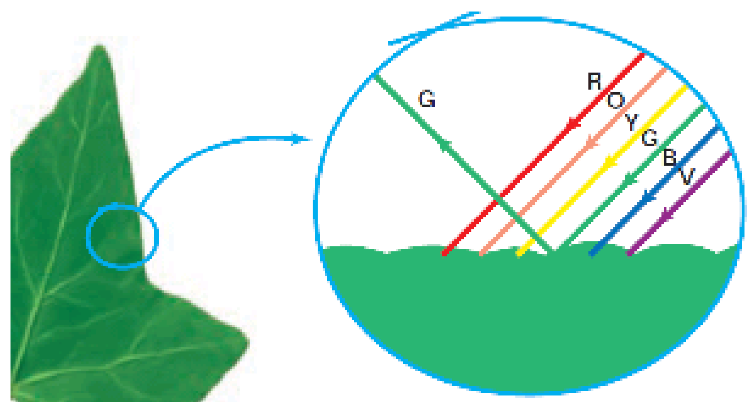


Figure 14-16
All parallel rays converge at a parabolic mirror's focal point. The curvature in this figure is much greater than it is in real parabolic mirrors.

Color

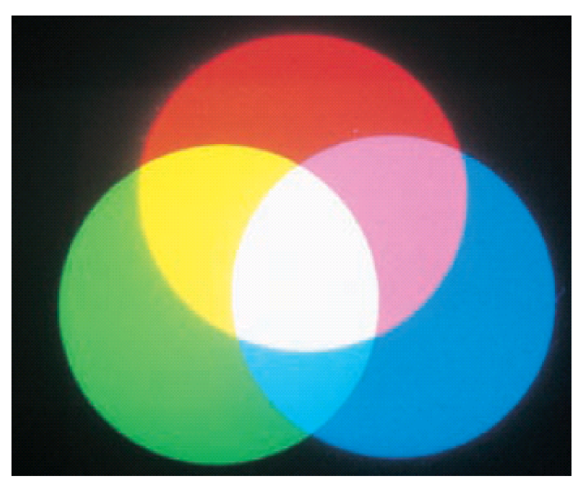
- The color of an object depends on:
  1. which wavelengths of light shine on an object,
  2. which wavelengths are absorbed,
  3. and which are reflected.

- If all wavelengths of incoming light are completely reflected by an object, that object appears the same color as the light illuminating it. An object of a particular color absorbs light of all colors except light whose color is the same as the object's color. As shown to the right, a leaf appears green under white light because the pigment in the leaf reflects only green light.

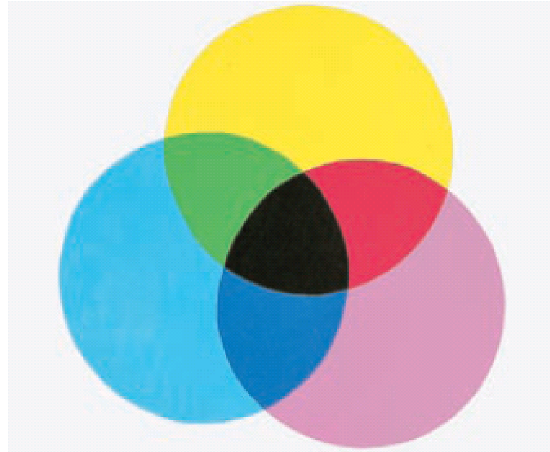


- Sunlight is composed of all colors of visible light. We call sunlight "white light" because when all wavelengths of light are present they produce white. White is not a color - it is the combination of all colors. Black is not a color either…it is the absence of light. An object looks black when it is absorbing all the light that hits it. When objects absorb light, they become warmer due to the absorption of energy.

  - **Color addition** produces colors by adding colors of light. The three additive primary colors of light are red, blue, and green and when they are mixed with equal intensity they produce white. The additive primary colors are used in color monitors and TV's to produce all the colors.
    http://mysite.verizon.net/vzeoacw1/coloradd.html



- **Color subtraction** produces different colors by mixing pigments. Pigments absorb or subtract light of certain wavelengths and reflect others. This is used in magazines, paints, and plastics. The primary colors of pigment (light subtraction) are magenta, cyan, and yellow. If you mix these together in the right amounts, you will get a pigment that will absorb all light and appear black. http://mysite.verizon.net/vzeoacw1/colorsub.html



Color phenomenon in nature
Atoms and molecules in substances vibrate and can resonate when light hits and interacts with them. This is what causes some wavelengths or frequencies to be absorbed by certain objects and determines which of the "three fates" will come to light that encounters matter.
If the light encounters solids or liquids and the light matches the natural frequency of the substance, the atoms will resonate, absorb the light and turn it into heat in the substance. In low-density gases, this resonance does not result in complete absorption and conversion to heat. This concept explains several natural phenomena:

- **Why is the sky blue? 3 important factors explain this**:
  1. Molecules in the atmosphere are very small molecules of nitrogen and oxygen and they resonate in the frequencies of violet and blue visible light.
  2. Since air or gas molecules are so far apart, their resonance does not cause them to absorb the light. Instead the vibrations just scatter out the violets and blues in all directions…including down to the surface and to your eyes.
  3. Violet is actually scattered out the most, but our eyes are not very sensitive to violet…Consequently we see a mostly blue sky!
- **Why are sunsets red? 2 important factors in this:**
  1. The sun's light must travel a much longer path through the atmosphere to get to you at sunset and all the atmosphere keeps scattering out more of the high frequency violets and blues as the light travels through.
  2. Once all the higher frequencies are scattered out, then all that is left to go straight through to you is the lower frequencies like the orange and reds. So you see an orange - red sunset!
- **Consider this - if our atmosphere was made up of molecules that resonate in long wavelengths of light, what color would our midday sky be? What would be the color of our sunsets and sunrises?**

- **Why is water greenish-blue (cyan)?**
  1. **Liquids produce a different effect than gases when they resonate with certain colors/frequencies of light.** Water molecules resonate with infrared and low frequency visible light (reds and oranges). When molecules in solids or liquids resonate with light, it results in those resonant wavelengths or colors being absorbed and/or scattered…after some depth through water all that is left to reach a receiver (such as your eyes) is the higher frequency blues and greens. Blue and green combine to make cyan. **If you were to take a red object deep under water - it would appear black because no red light would reach the object to be reflected to your eyes.**

Polarization of light waves

- Transverse waves can be polarized. **Linear polarization** is the alignment of a transverse wave along a single plane. Light can be linearly polarized using ***polarizing film*** or filters in such a way, as shown below, that only the waves vibrating along the axis of the filter will get through. ***Linear polarization of light gives experimental evidence that light is a transverse wave.*** Nature can produce polarized light by reflection or scattering. The glaring light produced from roads and bodies of water is polarized horizontally due to reflection. ***Polarizing sunglasses eliminate the glare by orienting the transmission axis vertically***. Polarized light and polarizing lenses are used in a variety of circumstances including creating a 3-D image from a specially created flat picture, analyzing metallic and plastic materials for stress points and weak spots in structures, eliminating glare from water or other vehicles when boating, fishing, or driving, and creating color in films that either reflect or transmit light.

Light Passing Through Crossed Polarizers

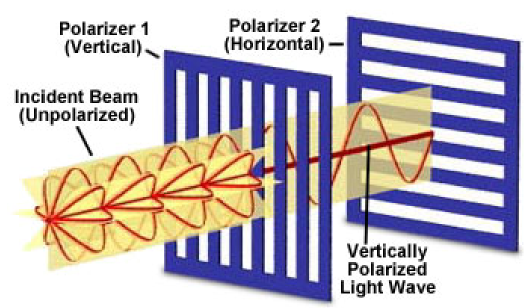


Figure 1

Physics textbook practice problems Ch. 14: pp. 550-552 #'s 6, 8-13, 16, 21, 24-31, 34, 36, 40, 41, 43, and 44 plus complete the worksheets on ray diagrams