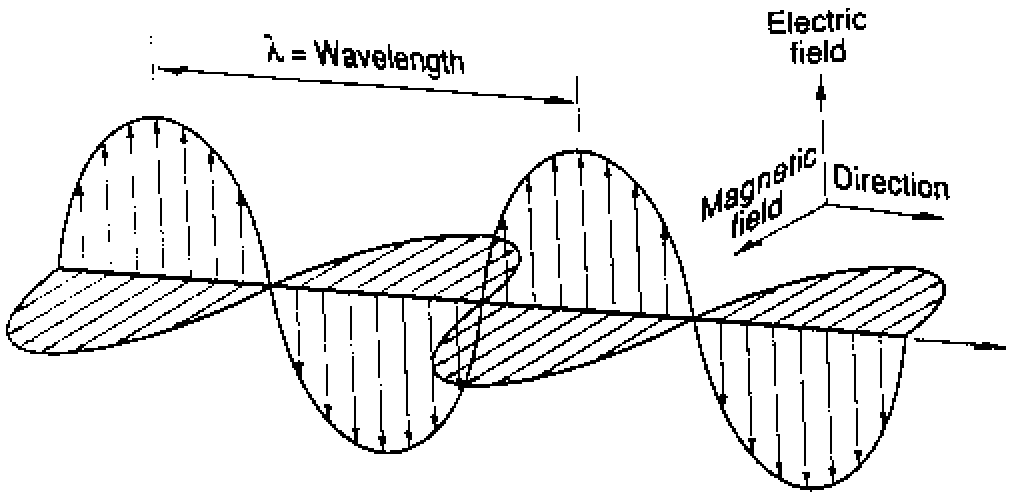
Characteristics of Light

The Nature of Light

*Light is electromagnetic energy that stimulates the photoreceptor cells in the retina of the eye. This form of energy is our most important means of learning about the nature of our environment. Visible light is only a tiny fraction of the mysterious essence we call "**radiant energy**."*

Electromagnetic Waves – the basic facts:

1. Waves that are composed of **oscillating electric** and **magnetic fields**.
2. These fields are **perpendicular to the direction** in which the wave moves.
3. The fields are at **right angles to each other**.
4. Electromagnetic waves travel at **c**. (**c** is the constant for the speed of light.)
5. Electromagnetic waves are distinguished by **differences in frequencies and wavelengths**.
6. Electromagnetic waves can **travel through space** (no medium is required).
7. Since electromagnetic waves are **transverse waves**, the level of energy is **constantly variable**.



imager from http://www.geo.mtu.edu/rs/back/spectrum/e_mag.gif

Examples: **1. radio waves** - travels through space, carries signals to radio or TV
2. light - travels through space, visible electromagnetic waves

What is light? How does light form?

The age-old question that scientists have debated: “Is light a wave or is it a stream of particles?”

Two scientifically acceptable models explain what light is:

1. **Wave model** – Light is composed of **transverse** waves that can move through space.

When light reaches a boundary, it does not simply stop. If the boundary is translucent or opaque, the light will reflect, refract or diffract.

Light can move through a lens and reflect off of a smooth surface. Light can also diffract when passing through a narrow opening. Unlike other forms of electromagnetic waves, light cannot penetrate objects that are not transparent or translucent.

2. **Particle model** – **Light** is composed of mass-less bundles of electromagnetic energy called **photons**.

The mass-less photons can knock electrons off of a metal plate, but not all visible light is capable of this task. Only high-energy **blue** and **violet** light can perform this task. Low energy **red** light does not have enough energy to knock electrons off of a metal plate.

Light waves – other general facts and properties:

1. the speed of light waves in a vacuum is 3×10^8 m/s
2. light speed slows in the presence of a liquid or gas (air)

It can be summarized that light is supported by both particle and wave theories but light is neither particle nor wave. Light propagates as waves and exchanges energy as particles. Light is light.

Source of light When an electron in atom moves to a higher energy level within the atom, it ***absorbs*** energy, if the electron moves to a lower energy level, the absorbed energy is ***released*** in the form electric and magnetic fields that composes electromagnetic waves. Light is composed of streaming ***photons***. **Photons** are the visible electromagnetic waves that stimulate the photoreceptor cells in the retina of the eye.

The atom is the source of all forms of electromagnetic emissions. Normally an atom is in ground state; electrons are at their lowest allowed energy levels. The lowest energy electrons are closest to the nucleus ant thus tightly bound. The electrons in the highest energy levels are furthest from the nucleus and can be easily excited to vacant higher energy levels. When an atom collides with another atom or with a free electron, **energy is absorbed** and the outer electrons can be excited to higher states of energy. If the atom **absorbs electromagnetic energy** the electrons can be excited to higher energy states. After a time of about 1×10^{-8} (0.00000001) seconds, the electron transfer to a lower energy state and a **photon** is released.

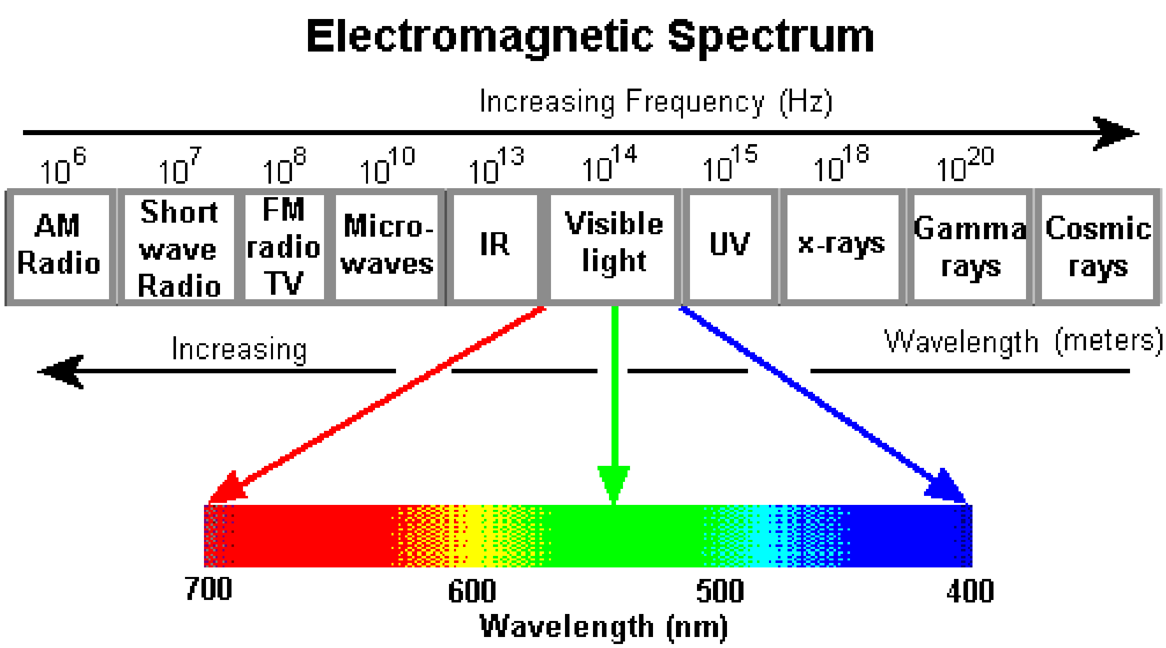
No Light: If the process is random, called **spontaneous emission**, then photon emissions are not correlated and light is incoherent.

Yes Light: If a continuous spectra of emission is present, then the photon emissions result in continuous bands of energy levels resulting in coherent light. The rate of vibrating electrons within the atom determines the ***frequency*** of electromagnetic wave:
1. The **slower** the vibration then the ***lower*** the frequency, the longer the wavelength
2. The **faster** the vibration, the ***higher*** the frequency, the ***shorter*** the wavelength.

The unit for wavelength (l) is ***meters***.

A brief tour of the electromagnetic spectrum

All electromagnetic waves are generated within the atom. The electromagnetic waves include low frequency radio waves such as KTRH at “740” (740 kHz) on the dial, channel 2 TV at 56 MHz, “The Point” at 106.9 MHz, microwaves for cooking, visible light waves, and x-rays for photographing broken bones.



Radio waves - This portion of the electromagnetic spectrum contains the ***lowest*** frequency radio waves and have the ***longest*** wavelength. These are used for local and long distant (DX) communications. Included are AM broadcast, short wave radio, TV and FM transmissions.

Microwaves - These electromagnetic waves are used for point-to-point communications, radar, and cooking food.

Infrared light waves - These electromagnetic waves are slightly ***longer*** than red light waves and thus not ***visible***. Light bulbs with a reddish glow emit IR (infrared) light to keep food warm. Cameras and film that detect IR are used to map object that release heat and weather patterns.

Visible light waves - The very short electromagnetic waves that are detected by photoreceptor cells in animals and provides energy for photosynthesis.

Ultraviolet light waves - These electromagnetic waves are slightly ***shorter*** than violet light waves. UV light waves can penetrate clouds and long exposure to UV light waves can cause ***sunburn***

X-rays - These electromagnetic wave are so short, they can pass through the human body. X-rays are used to produce photographs of bones or internal structures of other objects. They are used to check your baggage at airports.

Gamma rays - Gamma rays have the highest frequency and shortest wavelengths that are very penetrating and dangerous. Gamma rays can cause cancer but gamma rays are also used to kill ***cancer cells***.

Cosmic rays - includes x-rays and gamma rays that make up background radiation from the galaxy - nuclei that have been traveling so fast that the electrons have been striped away

Each of the above types of electromagnetic radiation travels at **c**. **c** is the constant in a formula that represents the speed of light, 3×10^8 m/s. the formula for velocity, frequency and wavelength is:

v = fl **v** - velocity **f** - frequency l - wavelength

Reflection of Light

The travel of light through a transparent substance is a straight line. When the ray encounters an opaque object, it cannot pass through, part of the energy is absorbed and the rest will be deflected. The change in direction is **reflection**.

Reflection - the turning back of an electromagnetic wave at the surface of a substance

Two types of reflection:
specular reflection - light rays are reflected of off a smooth shiny surface; ex. mirror - the irregularities on the surface are **smaller** than the wavelength of light.
diffuse reflection - light rays are scattered in many directions from an uneven surface; the surface irregularities are **larger** that the wavelength of light

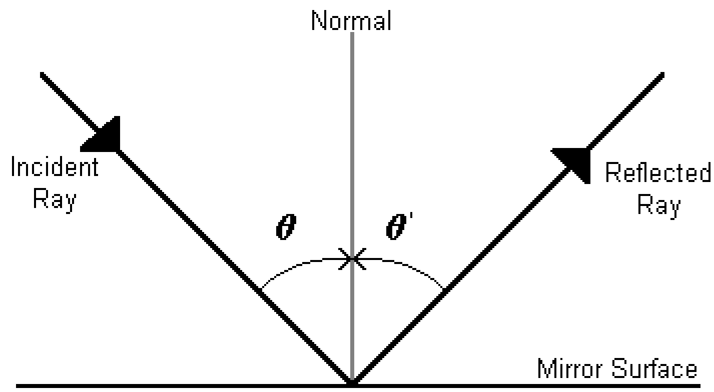
Reflections notes:
incident ray - incoming light ray
reflected ray - outgoing light ray
angle of incidence - angle between incoming light ray and the surface of contact
angle of reflection - angle between surface of contact and the outgoing light ray

Note that the angle of incidence and the angle of reflection are always equal.

Angle of incoming light ray = Angle of reflected light ray

The law of reflection simply stated: $q = q'$

A line perpendicular to the reflecting surface is referred to as the normal to the surface. The angle between the incoming ray and the surface equals **90**° **-** q and the angle between the reflected ray and the surface equals **90**° **-** q**'**. See the figure below.



Plane mirrors - The simplest mirror

An object is placed in front of the mirror. The light bounces off of the object in all directions. Some of the light will reflect off of the mirror. It appears that the object is located behind the mirror.

Object distance from the mirror is ***p***.
Image distance (distance the image appears to be behind the mirror) is ***q***.

Notes about the image of a plane mirror:
1. The object in front of the mirror will appear to be the same distance behind the mirror.
2. Image produced is upright
3. Image is the same size as the object.
4. This image is the **virtual image**. The virtual image can never be displayed on a physical surface.
5. This is referred to as ray tracing. Notice that the image formed by the flat mirror will appear to be reversed.

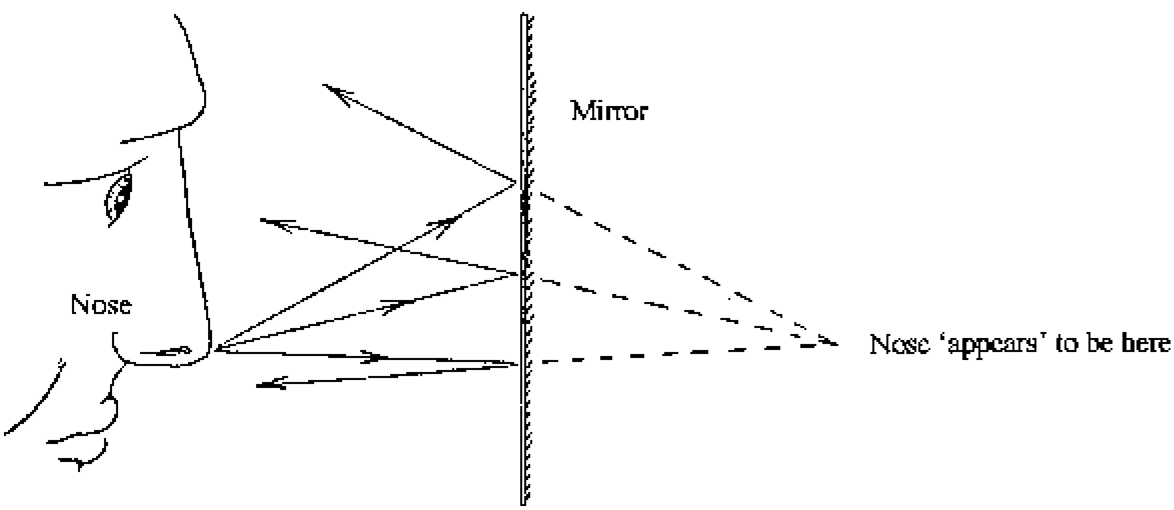


Image From http://www.le.ac.uk/se/centres/sci/selfstudy/ps80.gif

Spherical Mirrors - What happens when light reflects off a curved surface?

The image you see is located where the reflected light converges, or where the reflected light appears to diverge from.

Spherical Mirrors are:
1. **Concave** (curves in like a "cave")
   - **a.** the inside surface is reflective
   - **b.** can form either real or virtual images - depends on where the object is relative to the focal point.
   - **c.** light is focused to a point.

Uses: Satellite dishes, telescopes

2. **Convex** (curves out)
   - **a.** the outside surface is reflective
   - **b.** forms only virtual images
   - **c.** scatters light rays

Uses: in gas stations, rearview mirrors on vehicles

Note: **real image** - light rays from the object actual pass through, **always inverted**
virtual image - formed because light rays can be extended back to meet at the image position, **they don't actually go through the image position**.

Ray Diagrams - Used to determine where the image is located and to determine if the image is real or virtual. **Note:** For the mirror worksheet the four items of information required for each image are: 1. Orientation (upright or inverted) 2. Size (larger, smaller, same) 3. Location (between f and c, beyond c, etc.) 4 Type (real or virtual)

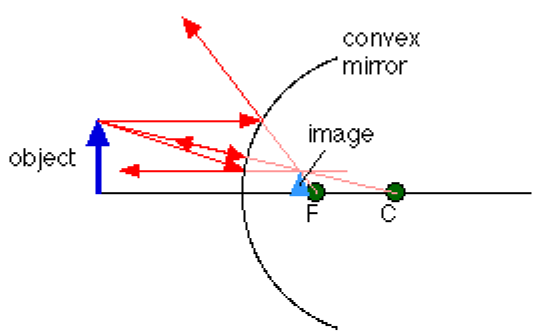
The Image will be located at the place where the rays intersect. There are only **three rays** needed that are easy to draw.

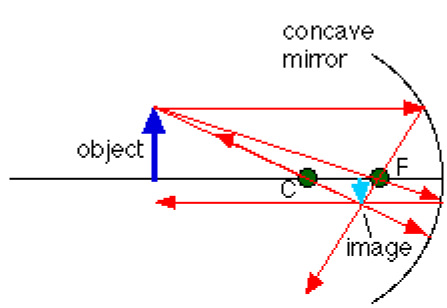
1. Parallel ray - **1.** A parallel ray is drawn from the tip of the object parallel to the principal axis to the mirror. **2.**It reflects off the mirror and either passes through the focal point (**f**) **(concave mirror)**, or can be extended back to pass through the focal point **(convex mirror).**

2. Chief ray - **3.** A ray is drawn from the tip of the object to the mirror through the center of the curvature(**C**). **4.** This ray will hit the mirror at a 90° angle, reflecting back in the direction from which it came. **5.** The chief and parallel rays meet at the tip of the image.

3. Focal ray - **6.** Is a mirror image of the parallel ray is drawn from the tip of the object through the focal point (**f**) to the mirror. **7.** The focal ray reflects off the mirror parallel to the principal axis.

Note: For a spherical mirror, C is at the radius of the sphere and F is half the distance from the sphere to the radius.





Images from: http://physics.bu.edu/~duffy/PY106/Reflection.html

Steps for analyzing mirror problems

There are basically three steps to follow to analyze any mirror problem, which generally means determining where the image of an object is located, and determining what kind of image it is (real or virtual, upright or inverted).

- Step 1 - Draw a ray diagram. The more careful you are in constructing this, the better idea you'll have of where the image is.
- Step 2 - Apply the mirror equation to determine the image distance. (Or to find the object distance, or the focal length, depending on what is given.)
- Step 3 - Make sure steps 1 and 2 are consistent with each other.

The mirror equation: $$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

p - distance from mirror to object
q - distance from mirror to image
f - focal length of mirror

Magnification - In many cases the height of the image differs from the height of the object (mirror has done some magnification).

The magnification equation: $$M = \frac{h_i}{h_o} = -\frac{q}{p}$$

h_i - image height
h_o - object height
M - magnification of plus/minus 1; this number has no units, it is a ratio

Sign conventions

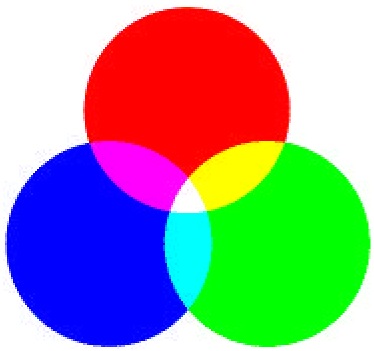
What does a positive or negative image height or image distance mean? To figure out what the signs mean, take the side of the mirror where the object is to be the positive side. Any distances measured on that side is positive. Distances measured on the other side are negative.

f, the focal length, is positive for a concave mirror, and negative for a convex mirror. When the image distance is positive, the image is on the same side of the mirror as the object, and it is real and inverted. When the image distance is negative, the image is behind the mirror, so the image is virtual and upright.

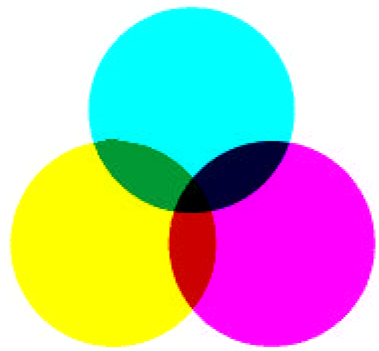
A negative **M** means that the image is inverted. Positive means an upright image

Color of Light and Pigments

A few basic light facts:
1. If all wavelengths of incoming light are completely reflected by an object, the object appears the same color as the light illuminating it. The object appears white.
2. An object of a particular color absorbs all colors of light except for the color of light of the object. The red rose will absorb all colors of light except red light.
3. An object that absorbs all colors (reflects none) will appear black.



RGB - Additive



CYM - Subtractive

Additive color theory - White light is the sum of the three primary colors of light. Black is the absence of color.
Secondary (complementary) colors are produce from two-color overlap:

Blue + Green = Cyan
Red + Blue = Magenta
Green + Red = Yellow
Blue + Red + Green = White

By combining the primary colors in various unequal proportions can produce all other perceivable colors.

Additive lights are used in photography and producing the colors on monitors and in televisions.

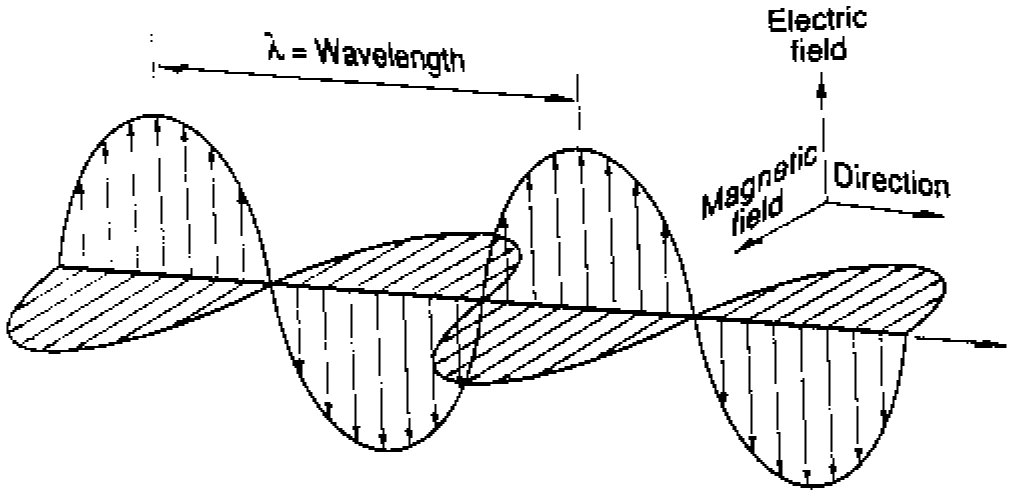
Subtractive Color Theory - Secondary colors are used as subtractive primaries. **Pigments** are examples of subtractive colors that reflect some wavelengths and absorb or subtract others.

Cyan + Yellow = Green
Cyan + Magenta = Blue
Magenta + Yellow = Red
Cyan + Magenta + Yellow = Black

By combining the pigments in various unequal proportions, the subtractive (absorption) of light will produce all other perceived pigments.

The subtraction or **absorption** of light is used for producing paints, photographs and the dyes for clothing.

Polarization



Remember this image from the beginning? It shows that the electric field and magnetic field are perpendicular to the direction of the wave and that these two fields are at right angles to each other. Since **light** naturally **oscillates in random directions**, it is **unpolarized**.

Why would we want to polarize light? Polarized light reduces the glare. It makes it easier to see when driving and skiing. Polarized light can also increase the contrast in photos, the white clouds and blue sky become much more distinct. In optical mineralogy polarized light is used to help identify mineral specimens.

Light oscillates in random directions. By aligning the electric fields of all the light waves and aligning all the magnetic fields of all the light waves, so they are respectively vibrating in the same direction, the light is **linear polarized**.

Two methods of polarizing light:

1. Transmission - Certain transparent crystals can polarize light. This occurs due to the crystal structure (arrangement) of the atoms or molecules in the crystal. This effect is similar to a rope vibrating through the slats in a picket fence. The waves can only vibrate in one direction, the direction of the slit through the crystalline structure. Refer to figure 14-24 in the Holt textbook. If you place a second picket fence at right angles to the first fence, the wave cannot randomly vibrate. The rope will move only in one direction. If another crystal is placed adjacent to the first but at right angles, the light wave will move in only one direction. A classic example is a polarizing filter that can be placed on a camera lens.

2. Reflection and scattering - When light is reflected at a certain angle off a surface, the light is completely polarized parallel to the reflecting surface. An example is the horizontally polarized light that reflects off the car hood and water. This is the polarized light that causes the glare. The microscopic vertical slit in “polarized” lens of glasses reduces or eliminates the glare of the light.