

# UNIT 12

## LIGHT and OPTICS

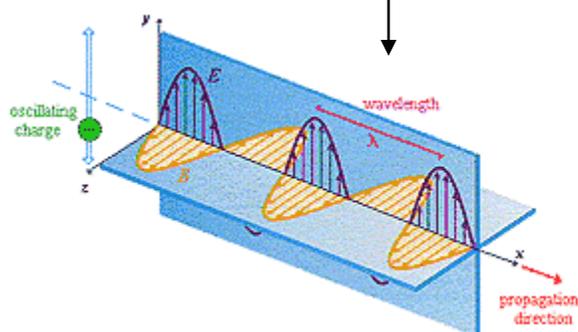
### What is light?

Light is simply a name for a range of electromagnetic radiation that can be detected by the human eye.

Color	Wavelength interval	Frequency interval
violet	~ 430 to 380 nm	~ 700 to 790 THz
blue	~ 500 to 430 nm	~ 600 to 700 THz
cyan	~ 520 to 500 nm	~ 580 to 600 THz
green	~ 565 to 520 nm	~ 530 to 580 THz
yellow	~ 590 to 565 nm	~ 510 to 530 THz
orange	~ 625 to 590 nm	~ 480 to 510 THz
red	~ 740 to 625 nm	~ 405 to 480 THz

### What characteristic does light have?

Light is **electromagnetic radiation** and has a dual nature consisting of both particles (photons) and waves that result in a changing electric and magnetic field which propagate through space, forming an **electromagnetic wave**. Light is a transverse wave.



**Amplitude** - Brightness of the light.

**Wavelength** - color of the light.

**Angle at which it is vibrating** - called polarization.

**Speed** – All light waves travel at the speed of light, 299,792,458 meters per second or 186,282 miles per second.

**Frequency** - The frequency (number of wavelengths per second) of a light wave may be calculated using the equation:

$$c = f\lambda$$

$c$  = speed of light ( $3 \times 10^8$  m/s)

$f$  = Frequency (hz)

$\lambda$  = wavelength (m)

**What factors affect the brightness of a source of light?**

The brightness of light is measured as light intensity. The units are watts/meter<sup>2</sup> (W/m<sup>2</sup>). The equation used is:

$$I = p/4\pi r^2$$

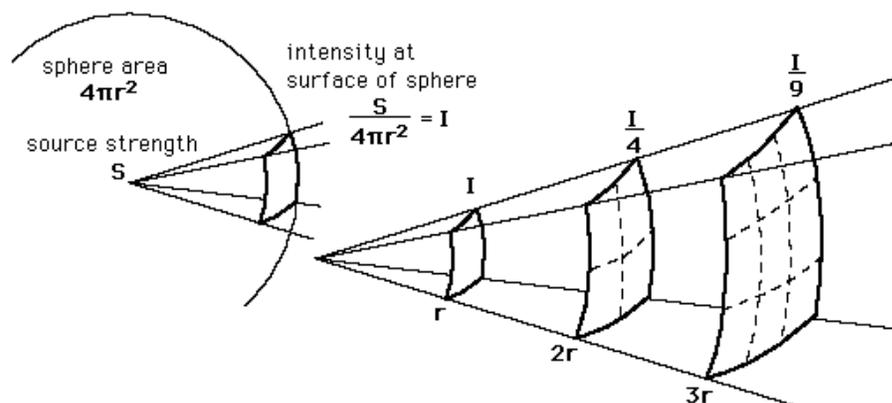
$I$  = Intensity of Light (W/m<sup>2</sup>)

$p$  = power of light source in watts

$r$  = distance from the light source

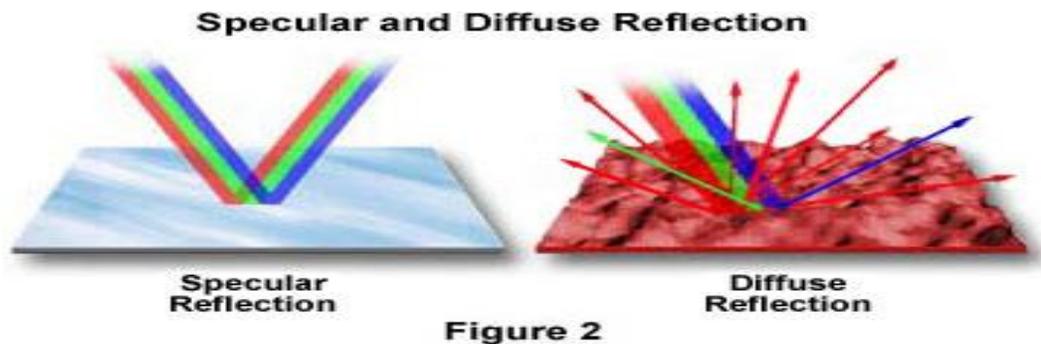
The Brightness of light is affected by:

- 1) The power of the light source in watts.
- 2) The distance from the source in meters. **Brightness decreases as the square of the distance from the source.**
- 3) The intervening medium.



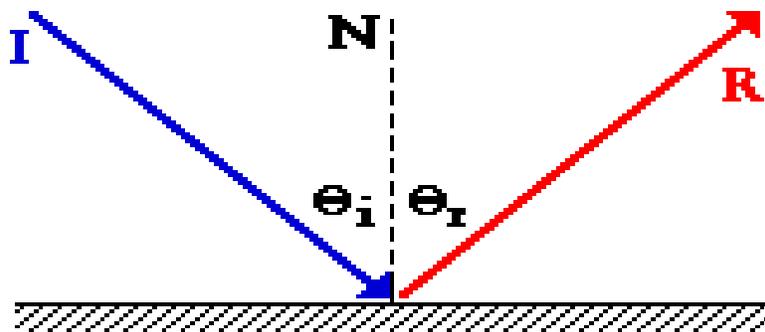
### When is reflected light considered specular and when is it considered diffuse?

- **Reflection** is the change in direction of an electromagnetic wave at a surface that causes it to move away from the surface.
- The texture of a surface affects how it reflects light.
  - **Diffuse reflection** is reflection from a rough, texture surface such as paper or unpolished wood.
  - **Specular reflection** is reflection from a smooth, shiny surface such as a mirror.



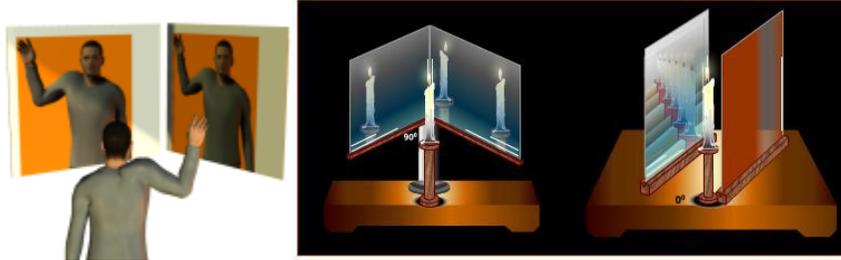
### What is the law of reflection?

- The **law of reflection** states that the angle between an incident ray of light(I) and the normal to the mirror's surface (N) equals the angle between the normal (N) and the reflected light ray(R).
- **Angle of incidence** -the the angle between a ray that strikes a surface and the line perpendicular to that surface at the point of contact.
- **Angle of reflection** -the angle formed by the line perpendicular to a surface and the direction in which a reflected ray moves.
- **The angle of incidence and the angle of reflection are always equal.**



### How does the number of images depend on the angle between two plane mirrors?

In this section we deal with plane mirrors. These are mirrors that are flat. Flat mirrors form **virtual images** that are the same distance from the mirror's surface as the object is. As the angle between two mirrors is increased and decreased, the number of reflected images increases and decreases. At some angles, you will see all complete images. At other angles, you will see some complete images and some parts of images. **A virtual image can never be displayed on a physical surface.**



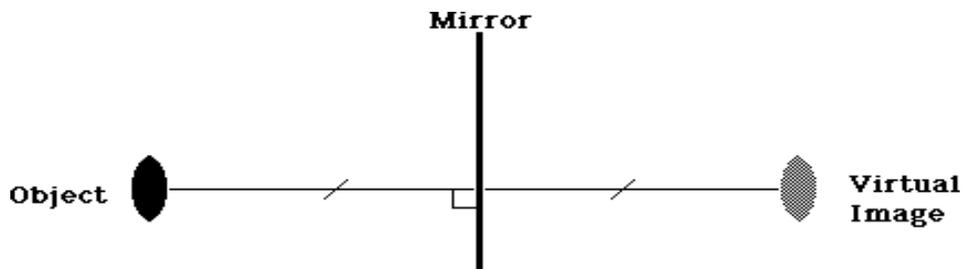
### What is an image and how does it differ from an object/source of light?

An **image** is an optically formed reproduction of an object, such as one formed by a lens or mirror

### What is the difference between real and virtual images?

There are two types of image

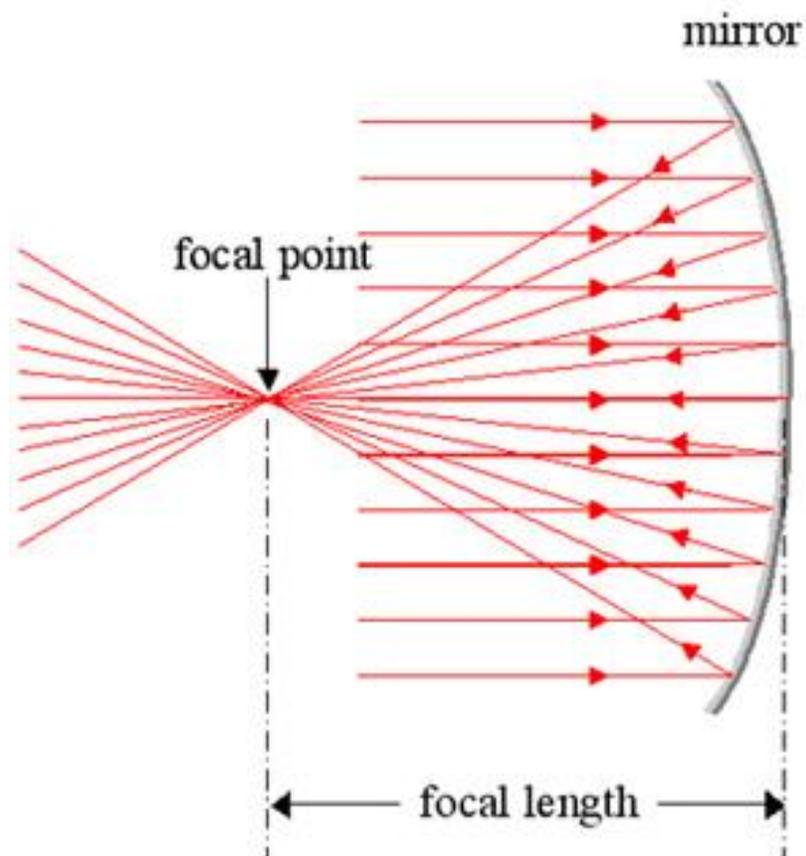
- Real Image** -This is one through which the light rays actually pass and which can be formed on a screen. Examples of real images are the image formed on the film in a camera or on the retina of your eye.
- Virtual Image** -This is one through which the rays do not pass; they only appear to come from it. Examples of virtual images are the image formed by a magnifying glass when used to look at a small object and that in a plane mirror. **For a real object, the image produced by a plane mirror is virtual and the same distance behind the mirror as the object is in front of it. (see Figure 2).**



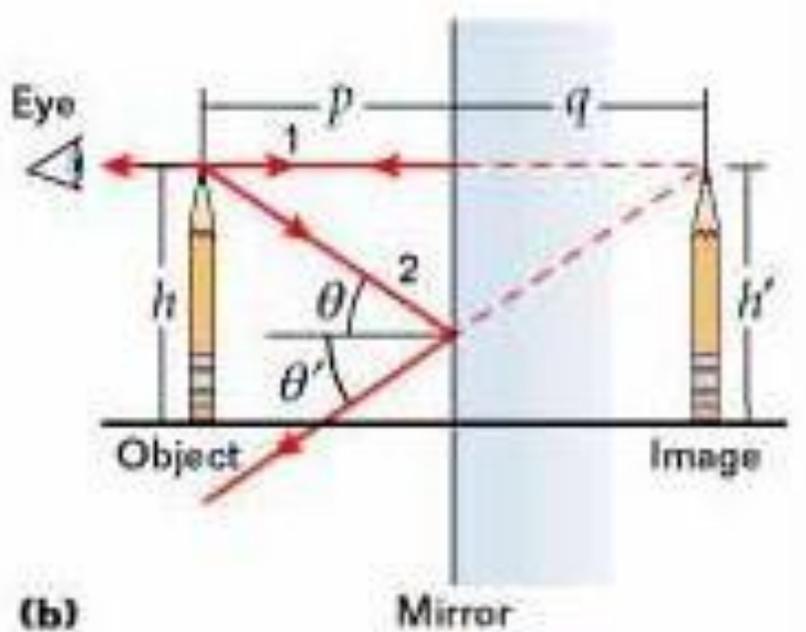


How can focal point be found using ray diagrams?

A **focal point** is the point on the axis of a lens or mirror to which parallel rays of light converge or from which they appear to diverge after refraction or reflection.



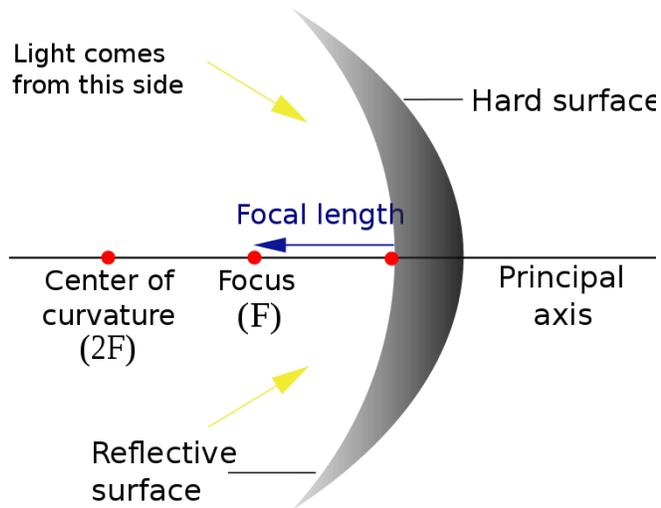
A ray diagram is used to locate the image formed by a mirror using geometry



What shapes can optical devices have and how does the shape affect the position, location, orientation and size of the image?

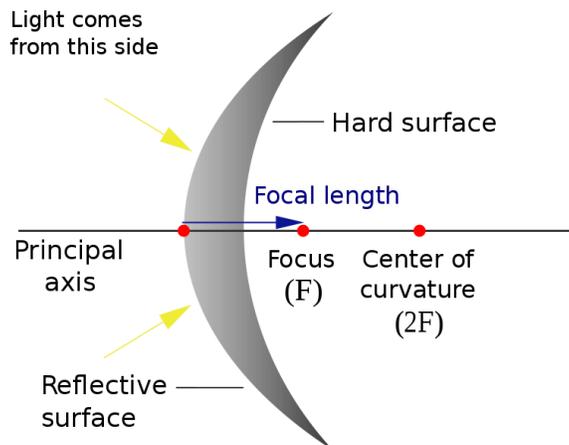
1. Concave Spherical Mirror:

- An inwardly curved, mirrored surface that is a portion of a sphere.
- Converges incoming light rays
- Objects close to mirror appear larger than the object
- Objects far away from the mirror appear smaller than the object
- Forms real images in front of the concave mirror.
- Used whenever a magnified image is needed (dressing room mirror)
- Principal axis- A line that extends infinitely from the center of the mirror's surface through the center of curvature.



## 2. A convex Spherical mirror:

- An outwardly curved, mirrored surface that is a portion of a sphere.
- Diverges incoming light rays.
- Forms a virtual image that appears behind the mirror
- Used on a car's passenger side view mirror
- Image appears smaller than the object
- Also called a diverging mirror



## 3. Parabolic Mirror

- A reflective device used to collect or project energy such as light.

- The parabolic reflector transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. Conversely, a spherical wave generated by a point source placed in the focus is transformed into a plane wave propagating as a collimated beam along the axis.

- Parabolic reflectors are used to collect energy from a distant source (for example incoming star light) and bring it to a common focal point thus correcting spherical aberration found in simpler spherical reflectors.

- Since the principles of reflection are reversible, parabolic reflectors can also be used to project energy of a source at its focus outward in a parallel beam used in devices such as spotlights and car headlights.



### What is the difference between real and virtual images?

#### Real Image:

- Any time the light rays' energies are capturable.
- The image would be at the focus point of a **concave mirror** and **convex lenses**
- You can put your hand or a piece of paper at the focal point and see the image imprinted on it, or in the case of sunlight, get burned from the energies.

#### Virtual Image :

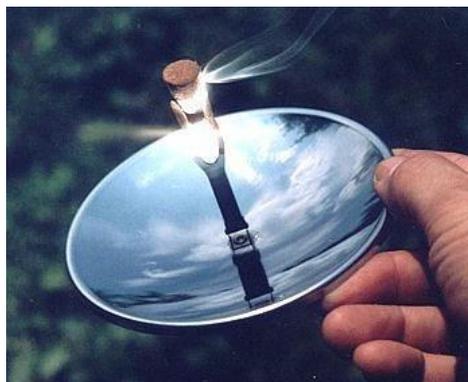
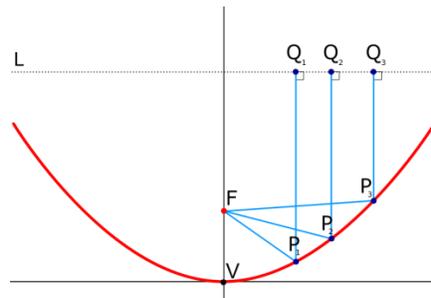
- **flat** and **convex mirrors** and **concave lenses** do not bring the energies together.
- The image you see of yourself in your bathroom mirror appears to be behind the glass. This makes it a virtual image, not a real one. You see it, but it isn't really there.

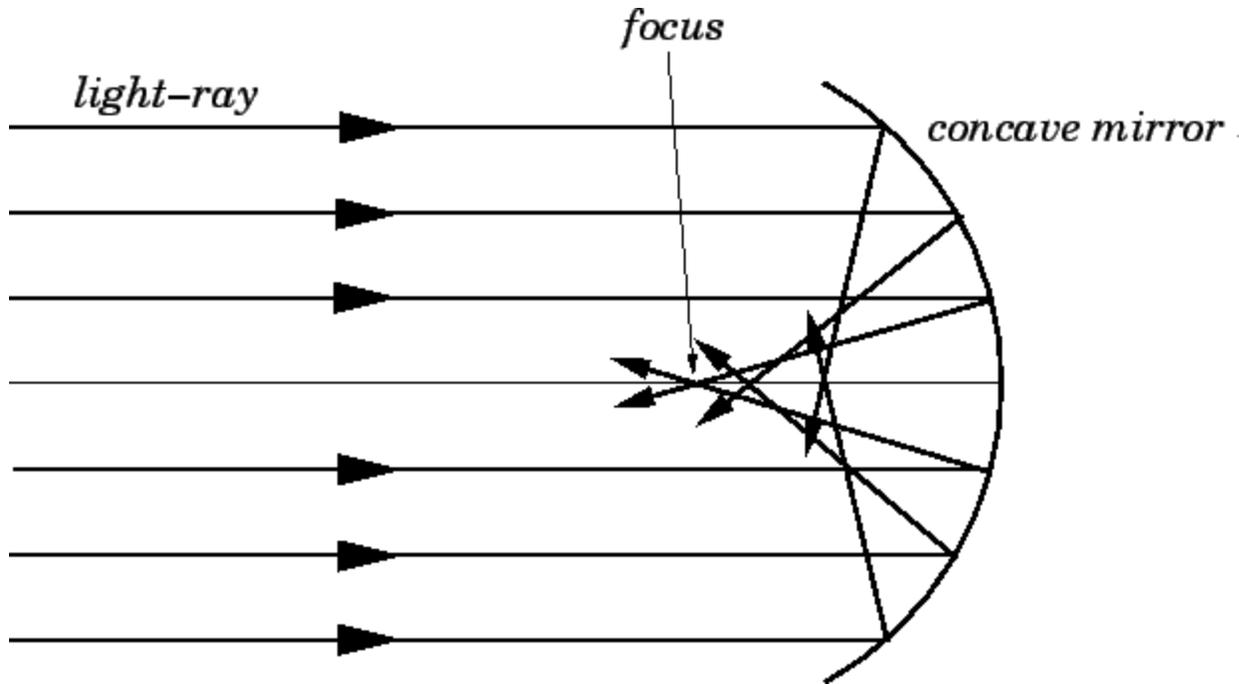
- Images can be bigger or smaller than the real object it is viewing.
- Images can be right side up upside down.

### What is the difference between parabolic and spherical mirrors?

A **parabolic reflector (or dish or mirror)** is a reflective device used to collect or project energy such as light, sound, or radio waves. Its shape is that of a circular paraboloid, that is, the surface generated by a parabola revolving around its axis. The parabolic reflector transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. Conversely, a spherical wave generated by a point source placed in the focus is transformed into a plane wave propagating as a collimated beam along the axis.

Parabolic reflectors are used to collect energy from a distant source (for example sound waves or incoming star light) and bring it to a common focal point, thus correcting spherical aberration found in simpler spherical reflectors. Since the principles of reflection are reversible, parabolic reflectors can also be used to project energy of a source at its focus outward in a parallel beam, used in devices such as spotlights and car headlights.

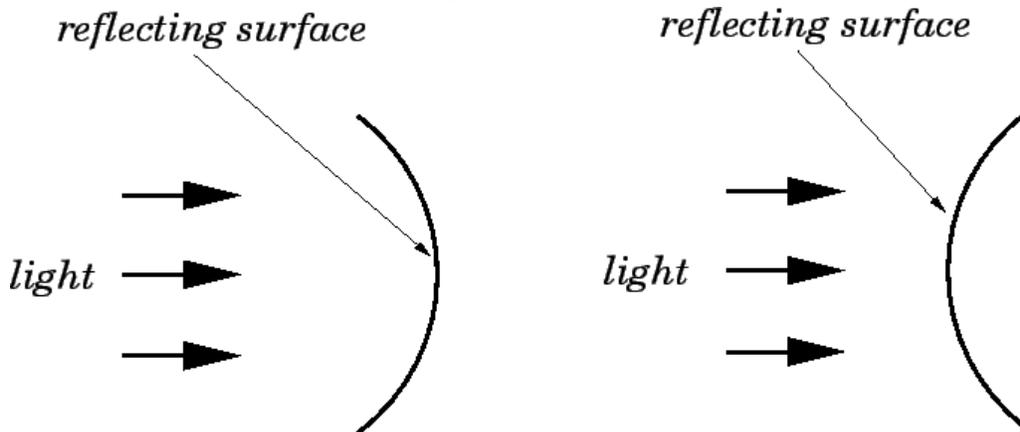




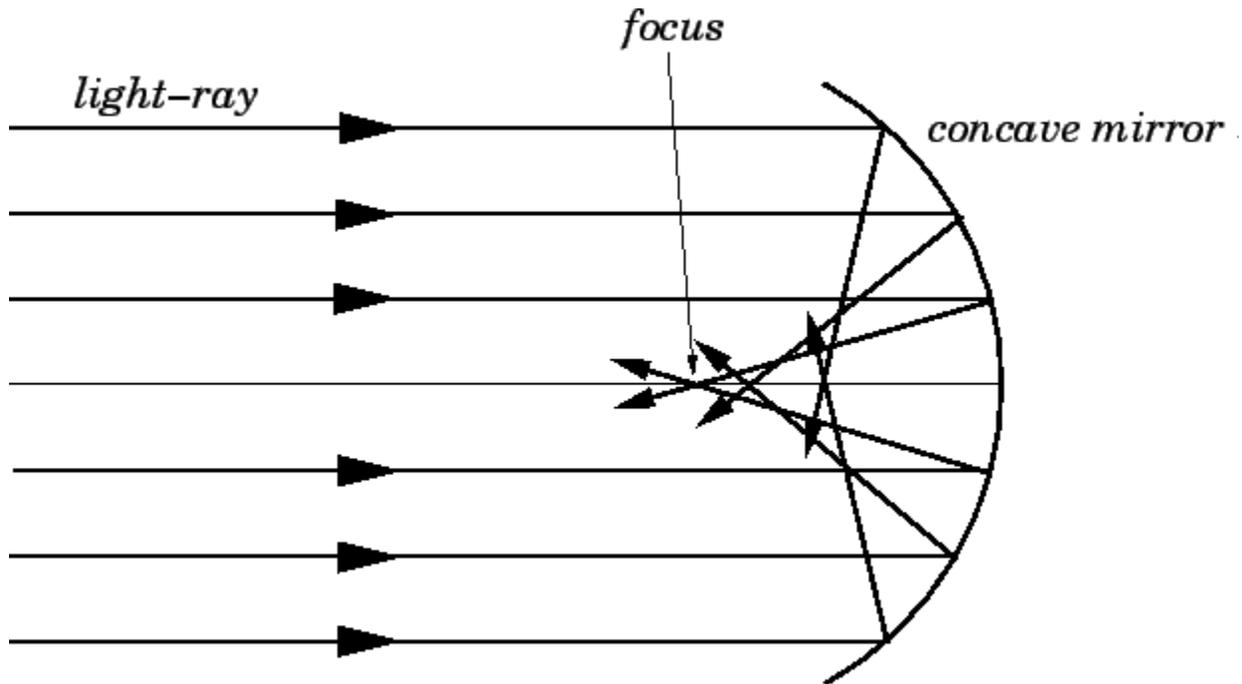
**Figure 70:** *Spherical aberration in a concave mirror.*

A **spherical mirror** is a mirror which has the shape of a piece cut out of a spherical surface. There are two types of spherical mirrors: **concave**, and **convex**. The most commonly occurring examples of **concave mirrors** are shaving mirrors and makeup mirrors. As is well-known, these types of mirrors magnify objects placed close to them.

The most commonly occurring examples of **convex mirrors** are the passenger-side wing mirrors of cars. These type of mirrors have wider fields of view than equivalent flat mirrors, but objects which appear in them generally look smaller (and, therefore, farther away) than they actually are.



**Figure 68:** A concave (left) and a convex (right) mirror



**Figure 70:** Spherical aberration in a concave mirror.

**What are the different types of optical devices and what characteristics of light do each use to produce images?**

An optical device is a device that creates, manipulates, or measures electromagnetic radiation.

**What is Snell's Law?**

The bending of light as it travels from one medium to another is called refraction. As a light ray travels from one medium into another medium where its speed is different, the light ray will change its direction unless it travels along the normal.

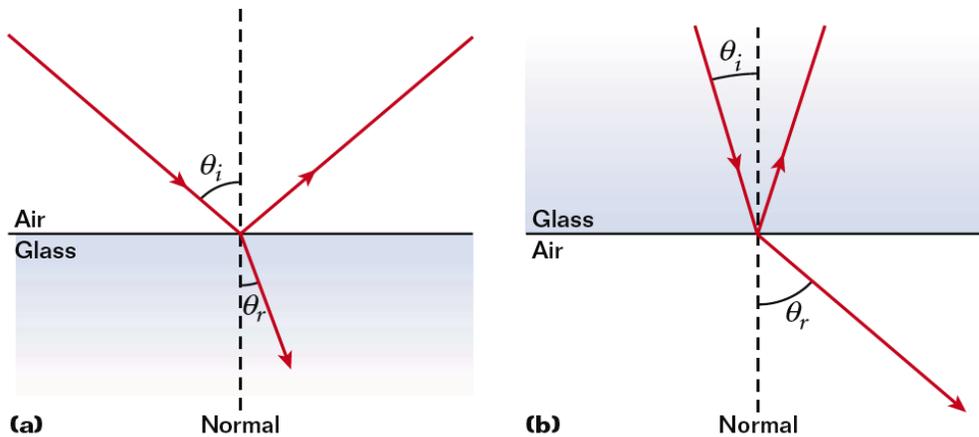
Refraction can be explained in terms of the wave model of light. The speed of light in a vacuum,  $c$ , is an important constant used by physicists. Inside of other mediums, such as air, glass, or water, the speed of light is different and is usually less than  $c$ .

The Law of Refraction-The index of refraction for a substance is the ratio of the speed of light in a vacuum to the speed of light in that substance.

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

$$\text{index of refraction} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in medium}}$$

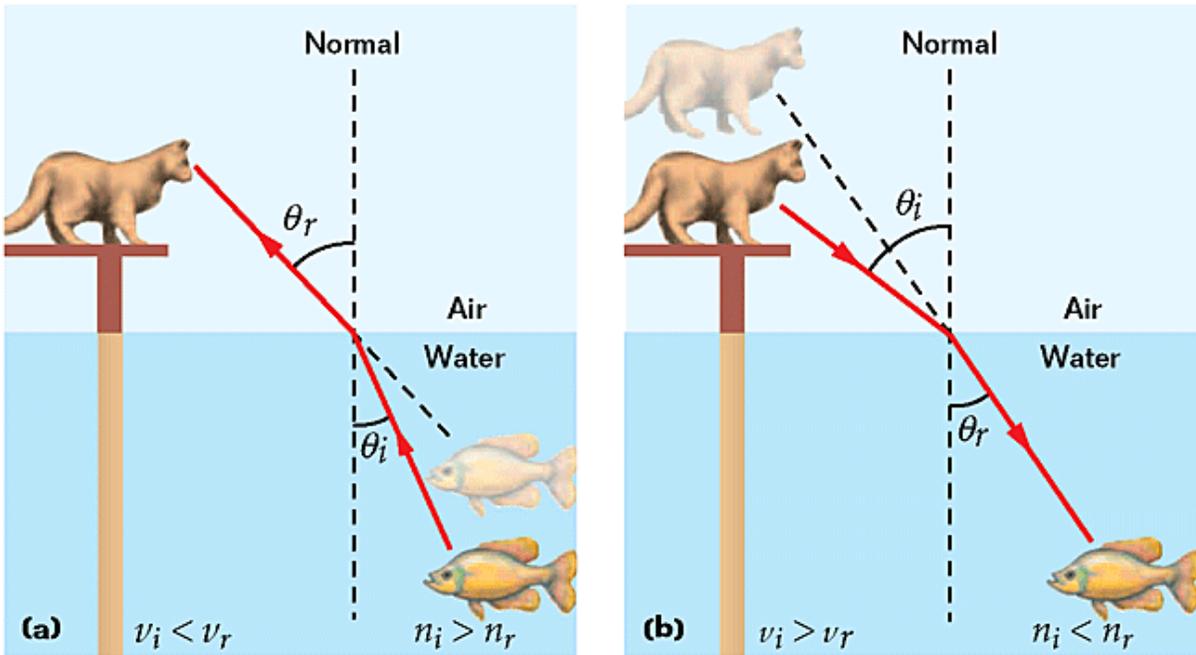
- When light passes from a medium with a smaller index of refraction to one with a larger index of refraction (like from air to glass), the ray bends toward the normal.
- When light passes from a medium with a larger index of refraction to one with a smaller index of refraction (like from glass to air), the ray bends away from the normal.



- **Objects appear to be in different positions due to refraction.**
- **Snell's Law determines the angle of refraction.**

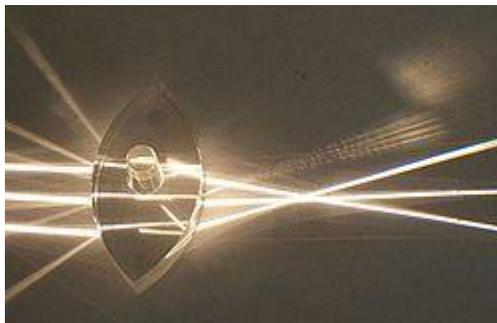
$$n_i \sin \theta_i = n_r \sin \theta_r$$

index of refraction of first medium  $\times$  sine of the angle of incidence =  
 index of refraction of second medium  $\times$  sine of the angle of refraction

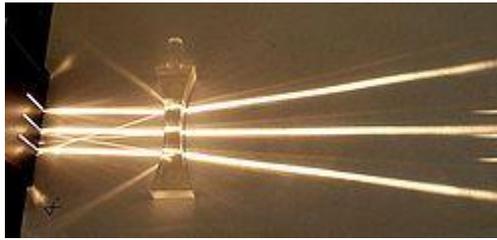


**What is the difference between convex and concave lenses?**

1. **Lens** – A transparent object that refracts light rays, causing them to converge or diverge to create an image.
  - a. **Converging lens(CONVEX)** – Thicker in the middle. Bend light inward. Produce real or virtual images. Light rays converge (Magnifying glass, human eye)



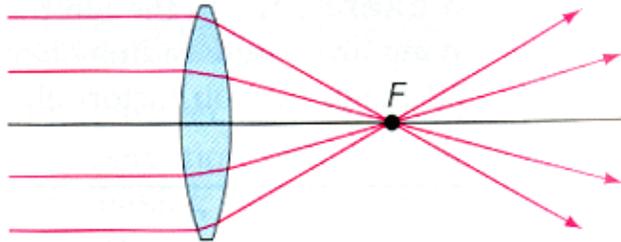
- b. **Diverging lens (CONCAVE)** – Thicker at the edge. Bends light outward. Produce virtual image only. Light rays diverge. Reduces the size of the object.



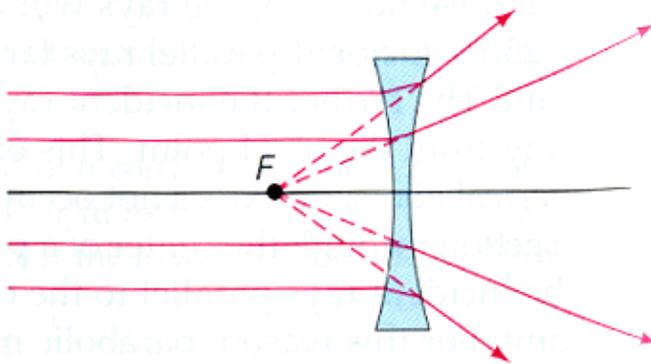
2. **Focal point-**

- a. The focal point of a converging lens is the point where the image of an object at an infinite distance from the lens is focused.
- b. Light rays diverge after passing through a diverging lens. In this case, the focal point is defined as the point from which the diverging rays appear to originate.

3. **Focal length** – The distance from the focal point to the center of the lens.



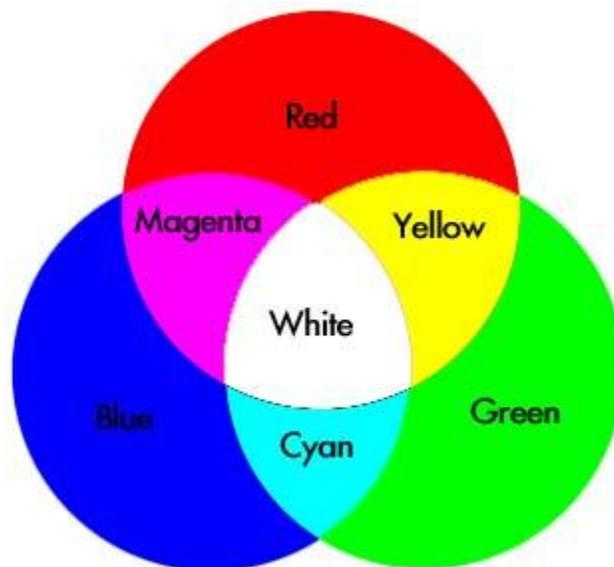
Converging lens



Diverging lens

### How are colors related to light?

1. There are three things that can happen to a light wave.
  - a. Reflected
  - b. Absorbed
  - c. Transmitted
2. What happens to light is determined by the object that the wave hits. This will give the object its color.
  - a. Black object -All the wavelengths of light hitting that object are absorbed; no light is reflected.
  - b. Solid objects, for the most part, will reflect light.
  - c. Transparent objects will transmit light through them.
3. Additive primary colors -**red**, **green**, and **blue** produce white light when combined.
  - a. Light of different colors can be produced by adding light consisting of the primary additive colors (**red, green, and blue**).

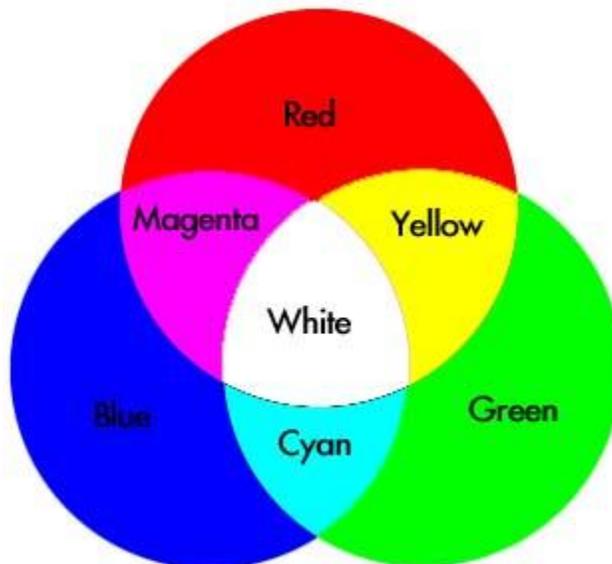


### What affects the observed color of an object?

**Pigment color**- An artist's traditional color wheel has 12 colors: 3 primary, 3 secondary, and 6 tertiary. Some materials let certain colors pass through them, and absorb other colors. These materials are called dyes or pigments. The primary colors of pigment are red, blue, and yellow. Mixing these primary colors of pigment gives us the three secondary colors: red+blue=violet, red+yellow=orange, and yellow+blue=green. Then, the primary colors mixed with the secondary give us the tertiary. They are: red- violet, red-orange, yellow-orange, yellow-green, blue-green, and blue-violet.

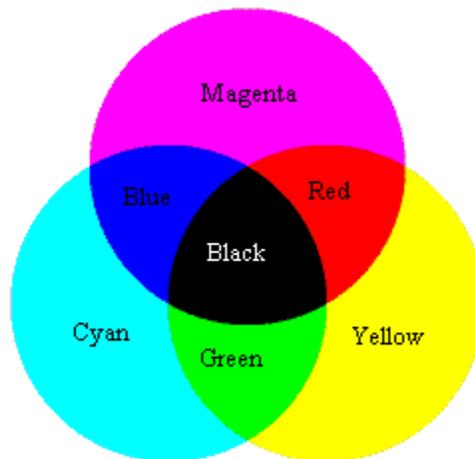
**Light Color**-The primary colors of light are red, blue, and green, and the secondary are yellow, cyan, and magenta. It is very important to know that mixing pigment and mixing light are very different. Red and green paint, for example, make brown paint, but red and green light make yellow light. When beams of light are mixed without any absorption, an additive process occurs. The more we mix the beams, the closer they get to being white light. However, when we put light through a color filter, a subtractive process occurs. Some wavelengths of light are being absorbed (subtracted) and we only see the wavelengths that are selectively given off. The Additive and Subtractive Models are explained further below.

**Additive Color**- As stated previously, the primary colors of light are red, blue, and green. These occur in the Additive Color (RGB) Model, so named because black is the base and light is "added" to eventually get to white, which is all of the colors together. Additive colors are seen in televisions, nature, and the computer screen you are looking at right now. Amazingly enough, colors are perceived in our eyes and brains by a three-color code; three different particles in the retina are sensitive to—you guessed it—red, blue, and green. Just as any color of the spectrum can be made by mixing the three primary colors, so do our own eyes discern the various colors by sensing different wavelengths with these three receptors. Additive primary colors produce white light when combined. Light of different colors can be produced.



**Subtractive Color (cyan, magenta, and yellow)** - A subtractive color model explains the mixing of paints, dyes, inks, and natural colorants to create a full range of colors, each caused by subtracting (that is, absorbing) some wavelengths of light and reflecting the others. The color that a surface displays depends on which colors of the electromagnetic spectrum are reflected by it and therefore made visible.

In most color printing, the primary ink colors used are cyan, magenta, and yellow. Cyan is the complement of red, meaning that cyan acts like a filter that absorbs red. The amount of cyan applied to a paper will control how much red will show. Magenta is the complement of green, and yellow the complement of blue. Combinations of different amounts of the three inks can produce a wide range of colors; this is how artwork reproductions are mass-produced, although an under-toning of black ink is usually used as well. This mixture is called CMYK.



Pigments can be produced by combining subtractive colors (magenta, yellow, and cyan).by adding light consisting of the primary additive colors (red, green, and blue).

### **What is polarization?**

Light has properties both as a particle and as an electromagnetic wave. Its electromagnetic wave properties allow it to become polarized. Since light waves have the ability to vibrate in multiple directions, it is possible to shut out some of these axes, thus producing polarized light. Light can be polarized via a variety of techniques.

The simplest way to polarize light is via the use of a Polaroid filter. A Polaroid filter is made up of material which can block one of the axes of light oscillation (again, either up and down or left and right). As a result, a Polaroid filter removes half of the light's waves. As a result, the polarized light has only had the intensity of its unpolarized counterpart, and only vibrates in a single plane (either up and down or

left and right). If light is passed through two filters that block out a different axis, no light will shine through.

Light can also be polarized via other means. When light reflects off of non-metallic surfaces, polarized light will emerge. If the polarization is extreme, "glare" will be observed. When light passes from one material to another, it is called refraction, which will also cause some polarization of the light. Additionally, when light travels through a medium it will hit the atoms and "scatter," causing other waves to be set off. These waves will interfere with the light on certain planes, causing it to polarize. Light can be polarized by reflection and scattering.

