

TOPIC 3

PROPERTIES OF WAVES INCLUDING LIGHT AND SOUND

WHAT IS WAVE MOTION?

The wave motion is a means of transferring energy from one point to another without there being any transfer of matter or substance between these points. Waves may be classified as mechanical waves and electromagnetic waves.

Mechanical Waves:

- Mechanical waves (example water waves, sound waves, waves in stretched springs) require a material medium for travel.
- When a wave travels from one point A to point B, it is because of a disturbance of some kind at A has caused the particles of the medium to move. This particle drags its neighbor with it, so that it too becomes displaced and has a similar effect on next particle, and so on until the disturbance reaches at point B.
- There are two types of mechanical waves depend upon how the particles of the medium move. These are transverse waves and longitudinal waves. In transverse waves the direction of movement or disturbance of the particles in the medium is at right angle to the direction of the waves. However in longitudinal wave the direction of disturbance of particles in the medium is in the same direction that the waves travel.

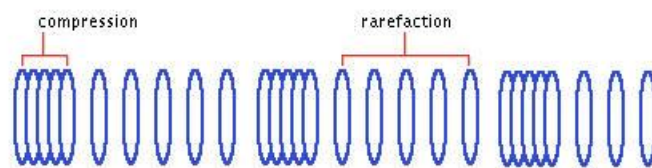


Figure 1: Longitudinal Wave

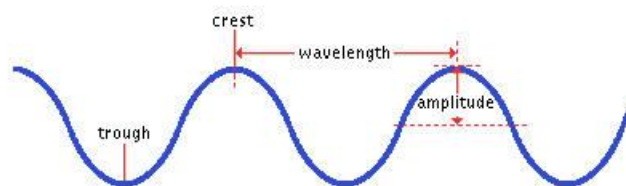
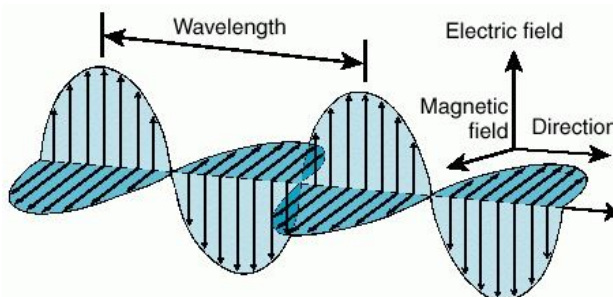


Figure 2: Transverse Wave

Electromagnetic waves:

Electromagnetic waves (for example light waves, radio waves, x-rays etc) can travel through the space with the constant speed without the presence of any medium. They are comprised of electric and magnetic field oscillating perpendicular to the direction of waves. More detailed explanation on electromagnetic waves is in last section.

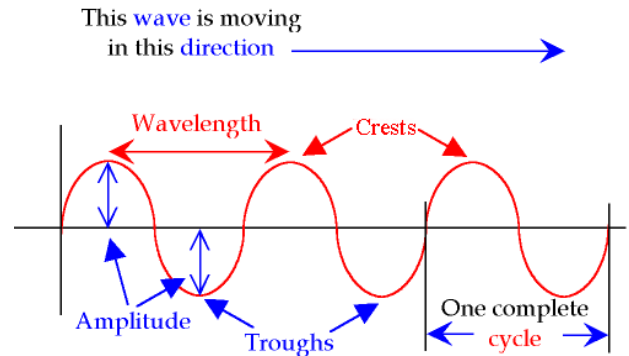


Wavelength (λ):

The wavelength of a wave, represented by the Greek letter λ (lambda), is the distance between the two successive crests or troughs.

Frequency (f):

The frequency f is the number of complete waves generated per second. The unit of frequency is 'cycle per second' or 'hertz (Hz)'.

Speed of wave motion (v):

The speed v of the wave is the distance moved in the direction of travel of the wave by a crest or any point on the wave in 1 second.

Amplitude (a):

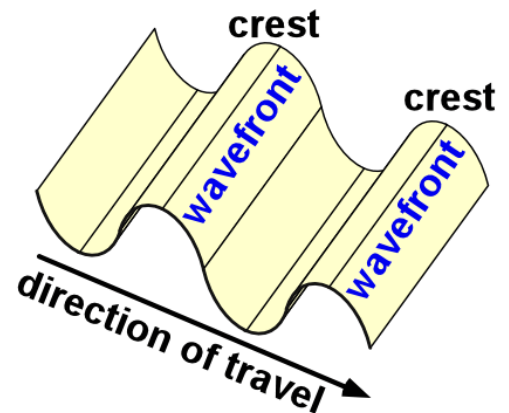
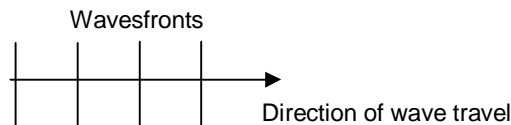
The amplitude ' a ' is the height of a crest or the depth of trough measured from the center of undisturbed position.

Time period (T):

It is the time taken for a wave to complete one cycle or one wave.

Wavefronts:

The wavefronts are represented by straight lines and can be thought as the crests or troughs of the waves. They are at the right angle to the direction of waves.

Wave equation:

The higher the frequency (f) of a wave the smaller its wavelength (λ). It is true for all types of waves and the relation between them is called wave equation which is

$$\text{speed of wave} = \text{frequency} \times \text{wavelength}$$

$$v = f\lambda$$

$$T = \frac{1}{f}$$

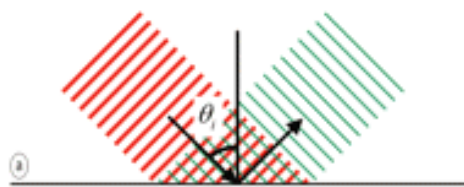
where T is the time period of the wave.

Reflection of plane waves:

Most common example of reflection of wave is echo that is when you hear two sounds in an empty room. It is reflection of sound waves. When the sound waves fall on a hard surface at an incident angle θ between the direction of travel of the waves and the normal of the surface than it will reflect with the same angle in opposite direction. The incident angle i° is always equal to reflected angle r° .

$$\angle i^\circ = \angle r^\circ$$

Other examples are reflection of light rays from the mirror or radar.

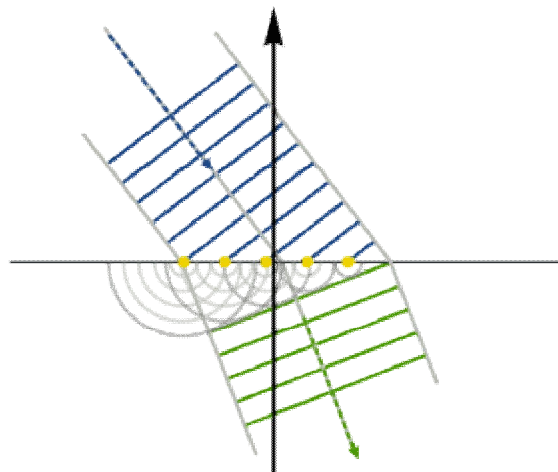


Refraction of waves:

Refraction is the bending of waves towards the normal when they enter from lighter medium to denser medium i.e. the angle of incidence is more than the angle of refraction. In the example of water waves, when straight waves pass from deep to shallow region, their wavelength becomes shorter. It means that, although the wavelength λ has altered, the frequency f has remained same. Since the velocity $v=f\lambda$, it means that the waves travel more slowly in shallow region than in deep.

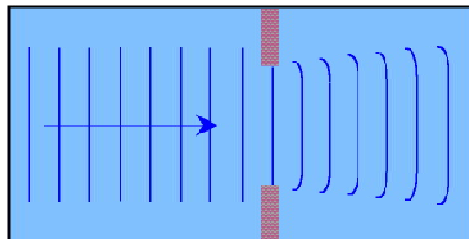
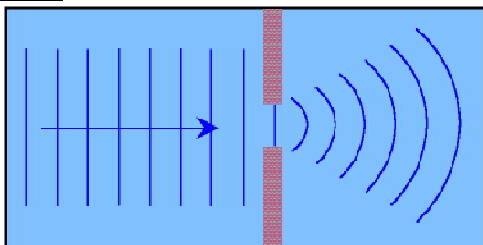
$$\angle i^\circ > \angle r^\circ$$

when the incident medium is less denser than the reflected medium.

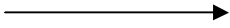
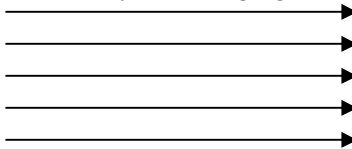


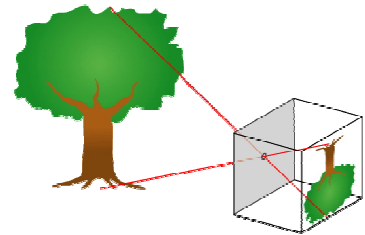
Diffraction of waves:

When straight waves are incident on a small opening formed between two bars placed in the path of waves, then the wavefronts emerge with a circular shape and waves spread out in all directions from the opening. The spreading of waves at the edges of obstacles is called diffraction. The extent of diffraction depends on the width of the gap compare to the wavelength. If the width of the gap is approximately equal to the wavelength then the diffraction is most noticeable. In the process of diffraction the wavelength, speed and frequency of the wave remain same.



LIGHT WAVE:

- Light waves travel in straight lines.
 - A ray is the direction of the path taken by light waves and represented in diagrams by a straight line with an arrow on it.
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- A beam is a stream of light energy and may be represented by a number of rays which may be diverging, converging or parallel.
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- Light waves are electromagnetic waves and can travel without the presence of any medium.
 - Why shadows formed? Because the object is opaque, light travels in straight line and light waves have shorter wavelength. For example in pin hole camera.
 - Speed of light is much faster than the speed of sound. For example in thunder we see the lightening first and then we hear the sound.



REFLECTION OF LIGHT:

- When the light waves called incident rays strike on a silver shiny surface eg plane mirror, they bounce back at the same angle. The bounced ray is called reflected ray.
- Plane mirror can be formed by a thin silver coating at the back of a transparent glass sheet and then painting the surface for protection.
- The perpendicular to the plane mirror where incident ray strikes is called NORMAL.

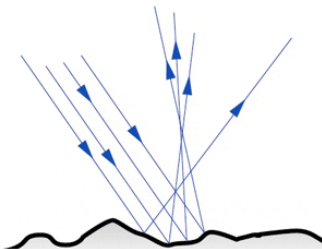
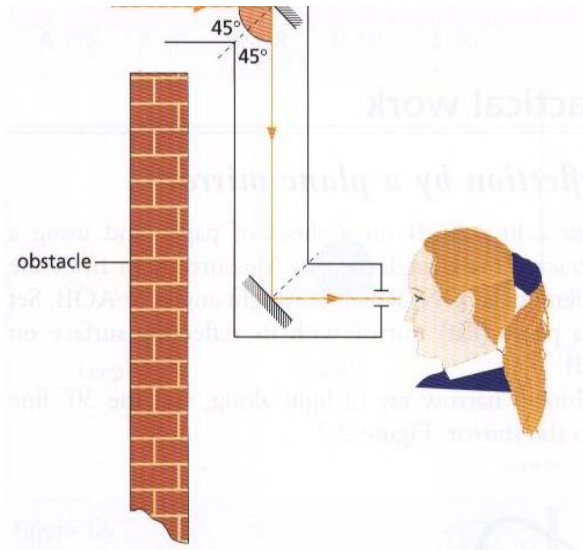
Laws of Reflection:

The Angle of incidence equals the angle of reflection or

$$\angle i^o = \angle r^o$$

The incident ray, the reflected ray and the normal all lie in the same plane.

Reflection is irregular or diffuse when waves strike on the surface that is not perfectly smooth like mirror.



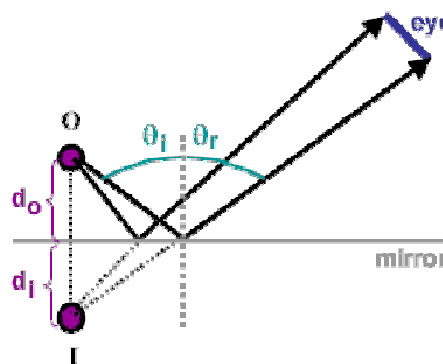
Real and virtual images:

1. A real image is one which can be produced on a screen and is formed by rays that actually pass through the lens or refracting material. The real images are inverted.
2. Virtual images are formed by the intersection of imaginary rays. They cannot be projected on a screen and only produced by rays which seem to come from the image but do not pass through it. Virtual images are always erected (upright). The image in the plane mirror is virtual image. In optics, a virtual image is an image in which the outgoing rays from a point on the object never actually intersect at any point.

Properties of the image in plane mirror:

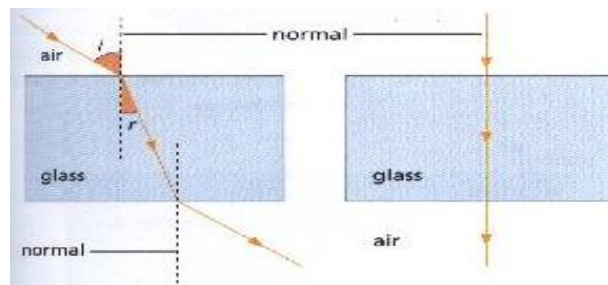
The image in the plane mirror is:

- a. as far behind the mirror as the object is in front and the line joining the object and image is perpendicular to the mirror,
- b. the same size as the object,
- c. virtual,
- d. laterally inverted (right side left)



REFRACTION OF LIGHT:

- The bending of light when it passes from one material (medium) to another is called refraction.
- A ray of light is bent towards the normal when it enters from lighter medium (eg air) to denser medium (eg glass).
- The angle between the incident ray and normal is called incident angle.
- The angle between the refracted ray and normal is called refracted angle.
- When light passes from lighter medium to denser medium the speed and wavelength decreases and frequency remains constant and opposite is true when light goes from denser to lighter medium.
- A ray of light traveling along the normal is not refracted.



Laws of refraction:

- The incident and refracted rays are on opposite sides of the normal at the point of incidence and all three are in same plane.
- The ratio of sine of angle of incidence to sine of angle of refraction is constant for a given pair of media. It is called refractive index of the medium (This law is called Snell's law presented by Willebrord Snell, Professor of mathematics in 1621)

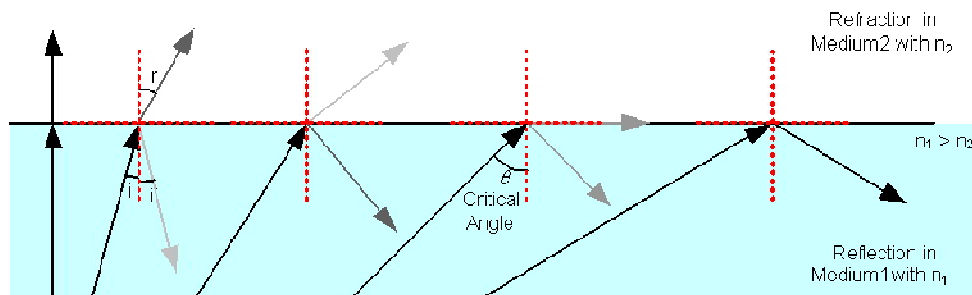
Use simple experiment with optical pins to find the position of refracted image through a transparent glass slab. Show the angle of incidence and angle of refraction.

Refractive index:

- Speed of light in air or vacuum is 3×10^8 m/s.
- Speed of light in glass is 2×10^8 m/s.
- The value of constant $\frac{\sin i}{\sin r}$ for a ray of light passing from one medium to another is called refractive index (n) of the second medium (r) with respect to the first (i).
- *Refractive index of glass is $n = \frac{\sin i \text{ in air}}{\sin r \text{ in glass}}$*
- Another definition of refractive index in terms of speed of light wave is
- *Refractive index of glass is $n = \frac{\text{speed of light in air}}{\text{speed of light in glass}}$*
- Common refractive indices with respect to vacuum or air are:

Medium or material	Refractive index (n)
Air	1.0008
Water	1.330
Glass	1.510
Diamond	2.417
Ruby	1.760

Total Internal Reflection:



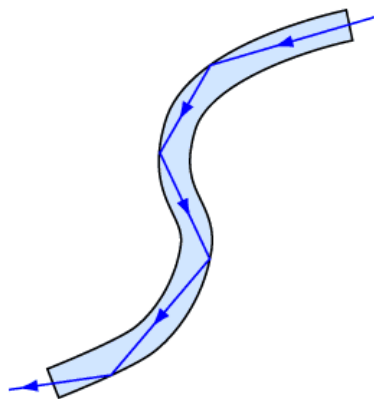
Consider a ray of light passing from glass to air. If the ray is along the normal then it will not refract. When the angle of incidence is small; we get a weak internally reflected ray (light grey) and strong refracted ray (dark grey). As we increase the angle of incidence, the angle of refraction also increases. At the same time the intensity of reflected ray gets stronger and intensity of refracted ray weaker. At

certain angle of incidence the angle of refraction becomes 90° . The incidence angle at which the angle of refraction is 90° is called critical angle of incidence, c .

Since it is impossible to have an angle of refraction greater than 90° , it follows that for all angles of incidence greater than the critical angle c the incident light goes through the process called total internal reflection. Fiber optic cables and mirage are good examples of total internal reflection.

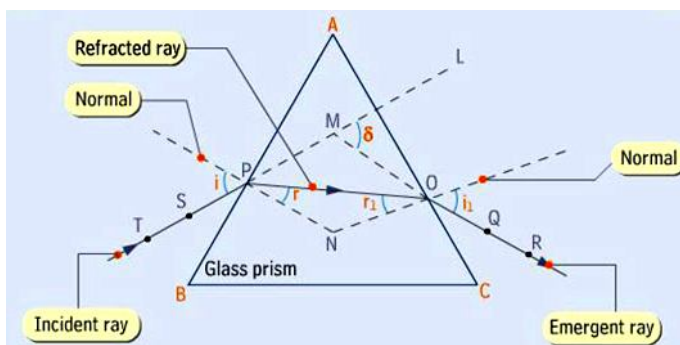
Fiber optic cable:

Fiber optic or optical fiber are flexible strands of glass that conduct and transmit light using total internal reflection. When the ray of light enters the fiber strikes on the inner wall of the cable with angle of incidence θ greater than the critical angle of the glass the ray goes through total internal reflection and reflects back into the glass with the same angle of reflection. The continuous reflection of ray inside the fiber transmits the light signal from one end of fiber to other end. The common use of optical fiber is in digital data communication and medical research.



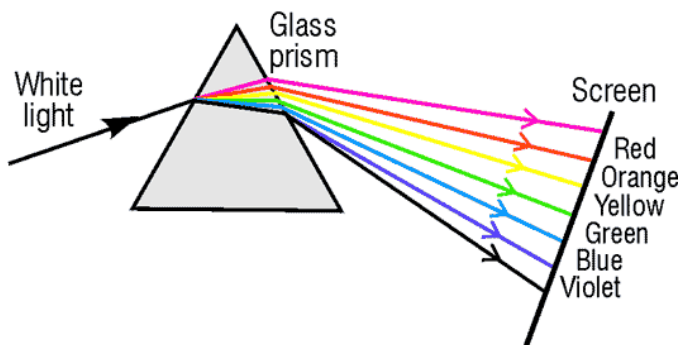
Refraction by a prism:

In a triangular glass prism the bending of a ray due to refraction at the first surface is added to the deviation at the second surface and deviation does not cancel out as in parallel sided glass. The angle δ is called the angle of deviation.



Dispersion of light:

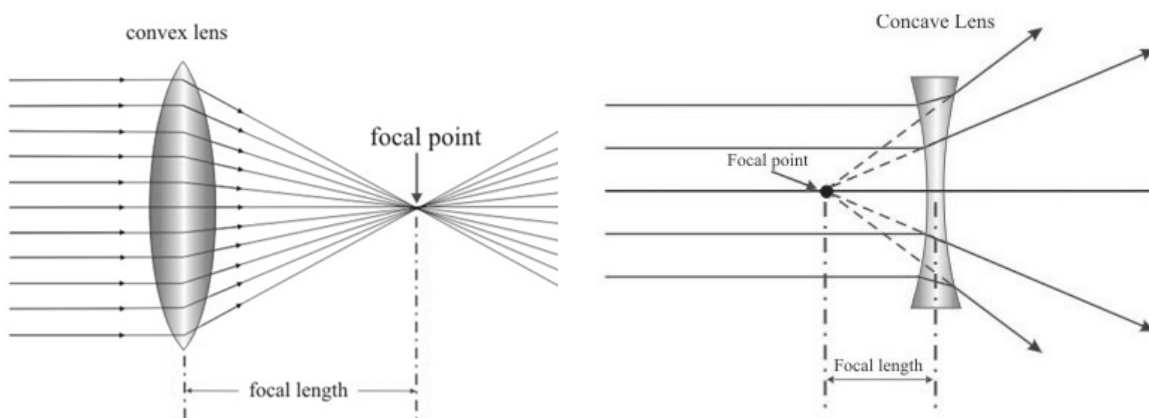
When white light falls on a triangular glass prism, a band of colors called a spectrum is obtained. The effect is called dispersion. It arises because white light is a mixture of seven colors which the prism separates because the refractive index of glass is different for each color or wavelength of light and it is greatest for violet light.



LENSES:

Lens is a transparent refracting medium bounded by two regular shaped surfaces such as spherical, plane or cylindrical. They are divided into two types

1. Convex or converging lens is thicker at the middle than the edges.
2. Concave or diverging lens thicker at the edge than at the centre.



Principal axis:

The straight line passing through the centre of the lens is called principal axis.

Aperture

The diameter of the lens is called aperture of the lens.

Optical centre:

A point inside the lens situated on the principal axis is called optical centre. The rays passing through the optical centre are not deviated.

Focal point or Focus:

A point at which incident rays parallel to the principal axis of a lens converges or appear to diverge after refraction is called focus of the lens.

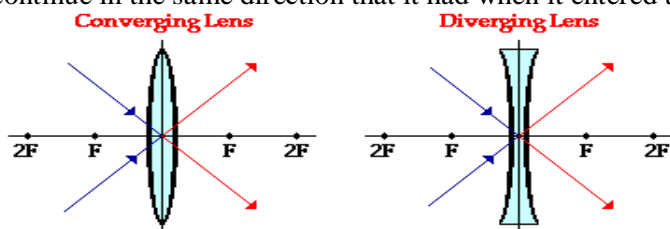
Focal length:

The distance from the optical centre to the focus is called focal length of the lens.

Refraction Rules for a Diverging Lens¹

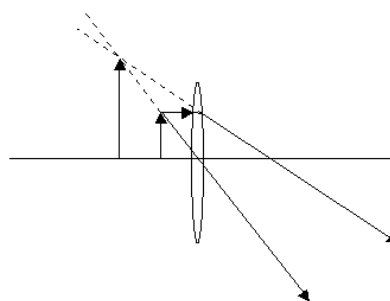
- Any incident ray traveling parallel to the principal axis of a diverging lens will refract through the lens and travel *in line with* the focal point (i.e., in a direction such that its extension will pass through the focal point).
- Any incident ray traveling towards the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.

- An incident ray which passes through the center of the lens will in affect continue in the same direction that it had when it entered the lens.



Convex lens as magnifying glass:

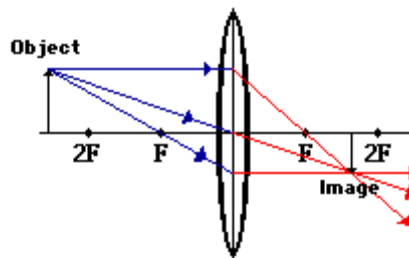
When the object is very far from the lens it will produce a small and inverted image but when the object is placed close to the lens between the focal point and the centre of the lens, the image produce is very large and virtual. The position of the image can be achieved by drawing the ray diagram. When two rays originating from an object and after passing through the lens they do not meet at any point. The position and size of the image can be found by drawing two rays back tracing without bending until they meet. The point where they meet is the top of the image. The size of image will be larger than the size of object. It will produce the image at the same side as the object and it will be a virtual image.



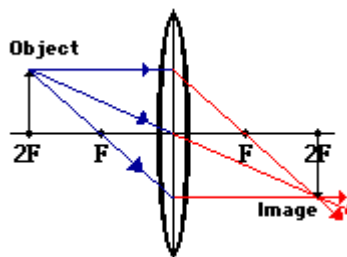
Ray diagrams for converging lens:

The position of image formed by object placed at various positions from the lens. Parallel rays of light are refracted through the focus F . The rays of light pass through the center of the lens travel straight on.

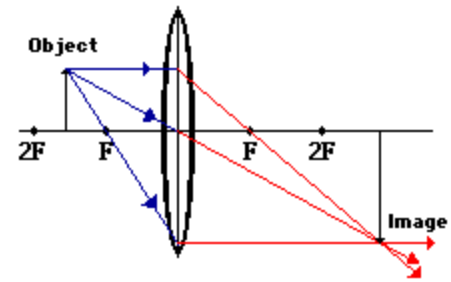
1. If an object is outside $2F$ then the image will be between F and $2F$. It is inverted, small, diminished and real.



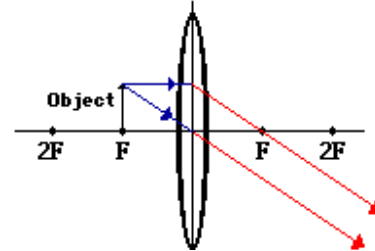
2. If an object is on F then the image will be on F as well. It is inverted, same size and real.



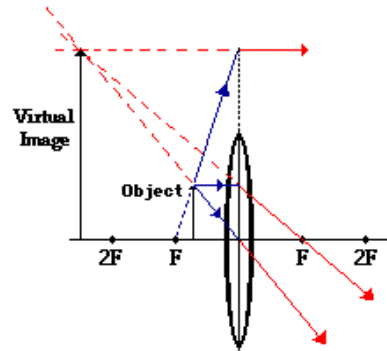
3. If an object is between F and $2F$ then the image will be outside $2F$. It is inverted, magnified and real.



4. If an object is placed on F then no image will be formed.



5. If an object is placed between F and the lens the image appeared to be at the same side of the lens. It is upright, magnified and virtual. In this way we can use the convex lens to see the magnified image of an object.



ELECTROMAGNETIC WAVES:

Electromagnetic waves consist of electric and magnetic fields oscillating perpendicular to the direction of waves. Based on their frequency and wavelength they are of different types, for example radio waves, micro waves, infrared, visible light, ultra violet, x-rays and gamma rays, however they all travel with same speed in vacuum, 3×10^8 m/s. Electromagnetic waves travel fastest in vacuum and presence of medium reduces its speed. The single name given to all the electromagnetic wave is electromagnetic spectrum.

Electromagnetic spectrum

The range of wavelengths for electromagnetic waves from the very long to the very short is called the Electromagnetic Spectrum:

Radio and **TV** waves are the longest usable waves, having a wavelength of 1.5 km or more. They are used for television and radio transmission.

Microwaves are used in telecommunication as well as for cooking food.

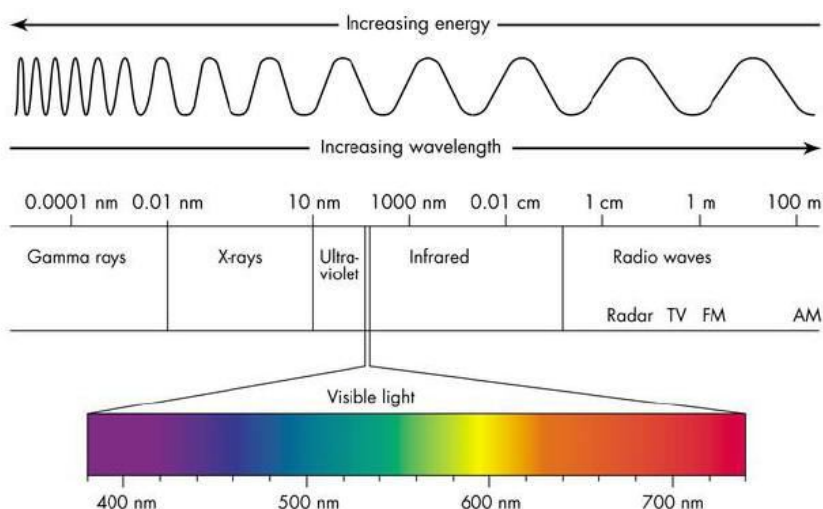
Infrared waves are barely visible. They are the deep red rays you get from a heat lamp. They are also used in remote controls.

Visible light waves are the radiation you can see with your eyes. Their wavelengths are in the range of 10^{-7} meters.

Ultraviolet rays are what give you sunburn and are used in "black lights" that make object glow. These are also used as disinfectant and for killing microorganism.

X-rays go through the body and are used for medical purposes.

Gamma rays are dangerous rays coming from nuclear reactors and atomic bombs. They have the shortest wavelength in the electromagnetic spectrum of about 10^{-13} meters.



Safety issues concern to use of microwave and X-rays

²It is known that microwave radiation can heat body tissue in the same way it heats food. Exposure to very high levels of microwave radiation can cause a painful burn. The lens of the eye is particularly sensitive to intense heat, and exposure to high levels of microwaves can cause cataracts. Likewise, the testes are very sensitive to changes in temperature. Accidental exposure to high levels of microwave energy can alter or kill sperm, causing temporary sterility. **These types of injuries can only occur if exposed to large amounts of microwave radiation**, much more than a leak from a microwave oven.

³For X-rays we should know the expected path of the main beam. Always keep all parts of your body outside of this path. Whenever possible, keep the safety doors to the instrument closed and latched. No unauthorized personnel may defeat or override any safety features on the X-ray generators, the safety enclosures, or tube shields and shutters without the permission of the lab director. No user may employ any power or hand tool on any part of the X-ray generator, detector, or low temperature device without express instructions from the lab director.

² <http://environmentalhealthandsafetyoffice.dal.ca/files/microwave.safety.pdf>

³ <http://xrayweb.chem.ou.edu/notes/safety.html>