Optics

Objectives

After going through this module, the learners will be able to:

- Understand the scope of study of optics
- Know our plan to cover ray optics and wave optics
- Recognize 'light facts'
- Distinguish between macroscopic and microscopic interaction of light with obstacles in its path

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Sources of light
- Light facts
- Light and electromagnetic waves
- Ray optics and wave optics
- Summary

Unit Syllabus

Chapter–9: Ray Optics and Optical Instruments Unit Syllabus

Ray optics: Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical; fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification, power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light: blue color of sky and reddish appearance of the sun at sunrise and sunset Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers.

Chapter 10 Wave Optics

Wave optics: wavefront and Huygens's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygens's principle. Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope. Polarisation, plane polarised light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

Unit Wise Module Distribution **15 Modules**

Module 1	• Introduction • How we will study optics-plan • Light facts • Ray optics, beams • Light falling on surfaces of any shape texture • Peculiar observations
Module 2	• Reflection of light • Laws of reflection • Reflection of light by plane and spherical surfaces • Spherical Mirrors aperture, radius of curvature, pole principal axis • Focus, Focal length, focal plane • Image – real and virtual • Sign convention • The mirror equation, magnification • To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror • Application of mirror formula
Module 3	• Refraction of light • Optical density and mass density • Incident ray, refracted ray emergent ray • Angle of incidence, angle of refraction angle of emergence To study the effect on intensity of light emerging through different colored transparent sheets using an LDR

	• Refractive index • Oblique incidence of light, Snell's law • Refraction through a parallel sided slab Lateral displacement, factors affecting lateral displacement • To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab • Formation of image in a glass slab
Module 4	• Special effects due to refraction • Real and apparent depth • To determine the refractive index of a liquid using travelling microscope • Total internal reflection • Optical fibers and other applications
Module 5	• Refraction through a prism • Deviation of light -angle of deviation • Angle of minimum deviation • Expression relating refractive index for material of the prism and angle of minimum deviation • To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation • Dispersion, spectrum
Module 6	• Refraction at spherical surfaces • Radius of curvature • Refraction by a lens • Foci, focal plane, focal length, optical center, principal axis • Formation of images real and virtual • Lens maker's formula • Lens formula and magnification • Sign convention • Application of lens formula • Power of lens

	• Combination of thin lenses in contact

Module 7	• To study the nature and size of image formed by a
	  ○ convex lens
	  ○ ii) concave mirror using a candle and a screen
	• To determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v
	• To determine the focal length of a convex mirror using a convex lens
	• To find the focal length of a concave lens using a convex lens
	• To find the refractive index of a liquid by using a convex lens and a plane mirror

Module 8	• Scattering of light – • Blue color of sky • Reddish appearance of the sun at sunrise and sunset • dust haze
Module 9	• Optical instruments • Human eye • Microscope • Astronomical telescopes reflecting and refracting • Magnification • Making your own telescope
Module 10	• Wave optics • Wave front • Huygens's principle shapes of wave front • Plane wave front • Refraction and reflection of plane wavefront using Huygens's principle • Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light

	• Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or colored fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

Words You Must Know

Let us remember the words we have been using in our study of Science courses upto secondary stage.

- **Speed/velocity of light:** The distance light can travel in a unit of time through a given substance. Light travels through a vacuum at about 186,000 miles, or 300,000 kilometers per second.
- **Incident ray:** An incident ray is a ray of light that strikes a surface. The angle between this ray and the perpendicular or normal to the surface is called the angle of incidence.

- **Reflected ray:** The reflected ray corresponding to a given incident ray, is the ray that represents the light reflected by the surface.
- **Refracted ray:** A *Ray* that undergoes a change of velocity, or in the general case, both velocity and direction, as a result of interaction with the material medium in which it travels.
- **Normal at the point of incidence:** At the point of incidence where the ray strikes the mirror, a line can be drawn perpendicular to the surface of the mirror. This line is known as a normal line.
- **Regular reflection:** When a beam pass of parallel light rays is incident on a smooth and plane surface, the reflected rays will also be parallel.
- **Diffused reflection:** When a beam of parallel light rays is scattered in all directions. Therefore the parallel rays incident on the surface will reflect in different directions.
- **Converging rays:** *Converging rays* are rays of light, which proceeding from different points of an object, tend toward a single point.
- **Diverging rays:** The point of intersection is the image point of the top of the object. The three refracted rays would appear to diverge from this point. This is merely the point where all light from the top of the object would appear to diverge from after refracting through the double concave lens.
- **Reflection of light:** When *light* falls on a surface, the direction of the ray is changed. This change in direction is known as *reflection of light*.
- **Refraction of light:** The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media.
- **Laws of reflection:** The law of reflection states that the incident ray, the reflected ray, and the normal to the surface of the mirror at the point of incidence, all lie in the same plane and the angle of reflection is equal to the angle of incidence.
- **Snell's law:** This law states that the ratio of the sines of the angles of incidence and sine of the angle of refraction of a wave are constant, when it passes between two given media.
- **Plane mirror:** A *plane mirror* is a *mirror* with a *flat* (*planar*) reflective surface. For light rays striking a *plane mirror*, the angle of reflection equals the angle of incidence
- **Spherical mirror- concave and convex:** The reflecting surface of the concave mirror is bulged inwards. But the reflecting surface of the convex mirror is bulged outwards.

- **Spherical lens-convex and concave:** A Convex Lens is thicker in the center, causing rays of light which are originally parallel to meet at a single point called the focal point and a Concave Lens is thinner in the middle, causing the rays of light to appear to originate from a single point.
- **Prism:** a *prism* is a transparent optical component with flat, polished surfaces that refract light. At least two of the flat surfaces must have an angle between them.
- **Superposition of waves:** whenever two (or more) *waves* travelling through the same medium at the same time. The *waves* pass through each other without being disturbed. The net displacement of the medium at any point in space or time is simply the sum of the individual *wave* displacements.
- **Diffraction:** It is *defined* as the bending of light around the corners of an obstacle or aperture into the region of geometrical shadow of the obstacle.
- **Light as electromagnetic wave:** Maxwell described light as a propagating wave of electric and magnetic fields. More generally, he predicted the existence of electromagnetic radiation: coupled electric and magnetic fields traveling as waves at a speed equal to the known speed of light.
- **Scattering:** Change in the direction of motion of a particle because of its collision with another particle.

Introduction

Welcome to the course on optics! This module is an outline of how we will proceed in our study of light.

In your previous courses you have studied light and its nature in the context of vision, shadow, and image formation by mirrors and lenses. The description was for very specific cases.

We studied the phenomenon of reflection. The way light changed its direction on reflection and formed images in mirrors and shiny polished surfaces. We also studied the phenomenon of refraction, the change in speed of light when it travels from one transparent medium to another. The important effect is bending of light when it travels from a rarer to denser or vice versa. We also studied the passage of light through lenses, glass blocks and triangular prisms. Many of the explanations were given satisfactorily using ray diagrams. The ray always indicates the direction of light propagation; hence it is a straight line with an arrow.

We learnt about the speed of light in vacuum and that it is a universal constant.

In your lesson on electromagnetic waves you learnt that light is part of the electromagnetic spectrum.

In **our present course**, we will attempt to understand the behaviour of light a little more in detail. We will study **ray optics,** which will give a **macroscopic view,** in which light beams emanating from a source may be represented by rays.

We will next study **wave optics**, in this we will be considering light as waves or their wave like behaviour, we will use this idea to understand the phenomenon of **diffraction and interference**.

We will use the wave nature to further our understanding of the phenomenon of **Polarisation of light**, which confirms the transverse nature of electromagnetic waves.

The course will help you understand the behaviour of light, as it interacts with the real world. Many of the ideas will appear similar to what you have learnt in your earlier courses, but now you are ready for deeper understanding and more explanations.

Sources of Light

We recognize the sources of light as natural and artificial. The sun is the biggest light source for our planet earth.

Natural

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Artificial

https://upload.wikimedia.org/wikipedia/commons/4/43/Candle_%28Slava_celebration%29.jpg

https://c1.staticflickr.com/5/4143/4747872021_cd8c1ee91b_b.jpg

https://upload.wikimedia.org/wikipedia/commons/1/13/India_Gate%2CDelhi.jpg

The world around us is full of colors, which makes us see the different colors around us. At day break, we are enthralled by the beauty around us. To see vivid colors of different objects in the same sunlight is an amazing experience.

Candy

https://c.pxhere.com/photos/c1/0a/focus_candies_sweets_food_candy_dessert_sugar_tasty-614912.jpg!d

What makes flowers, candies and sweets have different colors?

A bunch of fresh flowers

https://cdn.pixabay.com/photo/2016/05/03/18/46/flowers-1369831_960_720.jpg

Happiness of Holi colors

https://g4.nh.ee/images/pix/fd27f58bf34124b171-77474628.jpg

The effect of light from day break to setting in at night provides us with questions about behaviour of light when it interacts with surfaces big and small, the lighting up of water bodies, rooms in our homes, so many experiences that we have everyday.

Shallow sea bed , sunlight penetrates the sea usually up to 1 km

http://static2.blog.corriereobjects.it/wfprwpc/sociale/wp-content/blogs.dir/196/files/2016/06/barrieracorallina-632x373.jpg?v=1465599866

Empty classroom

https://upload.wikimedia.org/wikipedia/commons/b/b5/Classroom_in_Tbilisi_State_University_%28Tbilisi_day%29_%28A%29.jpg

Light Facts

Light-The natural agent that stimulates sight and makes things visible.

Optics is the branch of Physics which involves the behaviour and properties of light, including its interactions with matter and the construction of instruments that use or detect it.

Progress in electromagnetic theory in the 19th century led to the discovery that **light** waves were in fact electromagnetic radiation.

Nature has endowed the **human eye (retina)** with the **sensitivity to detect light** electromagnetic waves within a small range of the electromagnetic spectrum.

Light and Electromagnetic spectrum

You have studied the production and salient properties of electromagnetic waves in your earlier module of physics 3 course.

In the entire electromagnetic spectrum known to us, there is a **small segment**, which we can **detect with our eyes.** The spread of wavelengths ranges from **10^{-12} m to 10^{3} m.** It is the study of behaviour of these wavelengths that makes up our optics course.

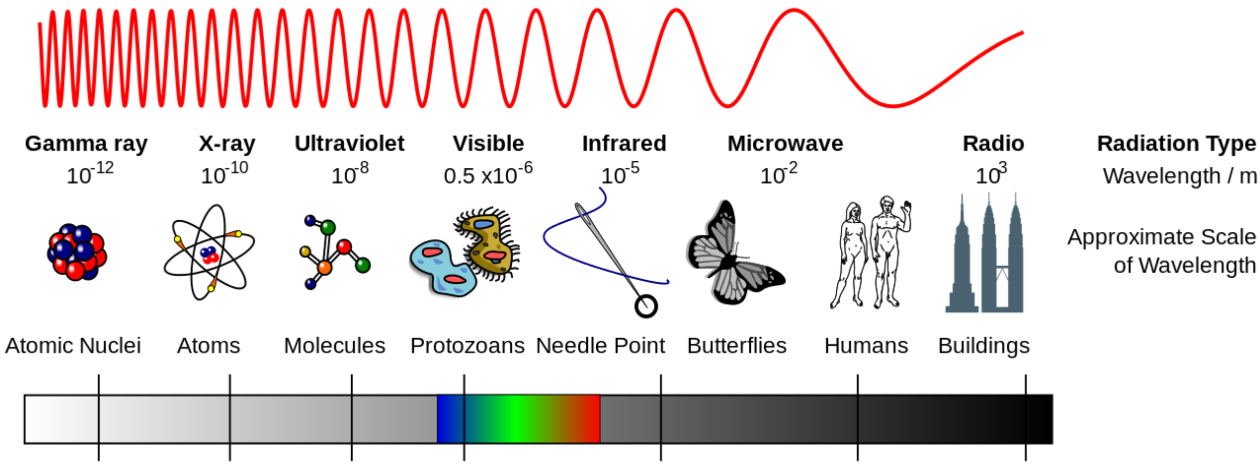
The approximate scale of the wavelength is shown in comparison to real life objects to interpret it. The wavelength of microwaves used for mobile phones are comparable to the size of the tip of a needle point.

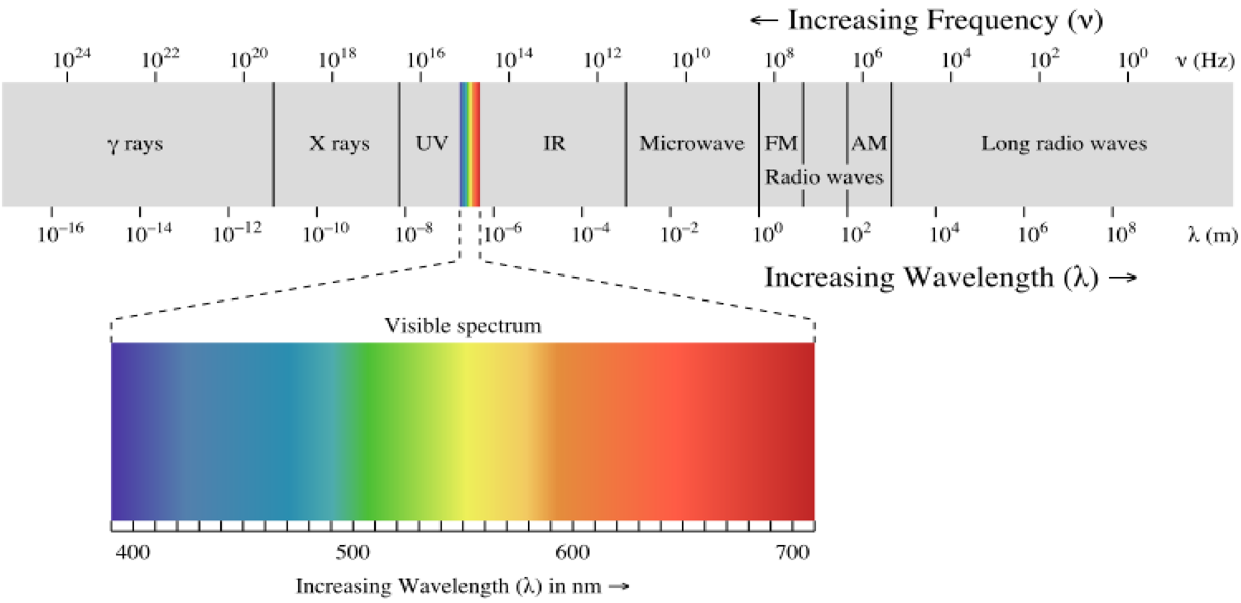
Generally, the wavelength is expressed in **Nanometre (10^{-9} m)**, **instead of metre.**

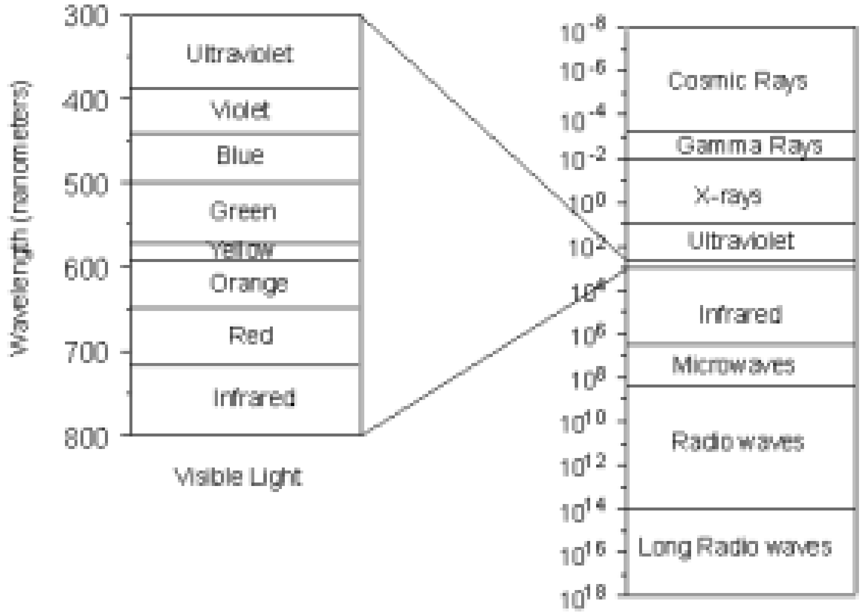
The electromagnetic spectrum can be divided into several bands based on the wavelength. As we have discussed before, visible light represents a narrow group of wavelengths between about 380 nm and 730 nm.

Electromagnetic radiation belonging to the region of the spectrum (wavelength of about 400 nm violet to 750 nm red (nanometre) is called light.

Notably, it is mainly through light and the sense of vision that we know and interpret the world around us.







Our eyes interpret these wavelengths as different colors. If only a single wavelength or limited range of wavelengths are present and enter our eyes, they are interpreted as a certain color.

If a single wavelength is present, we say that we have **monochromatic light**. Laser light. If two or more wavelengths make up the light it is called **polychromatic** light.If all wavelengths of visible light are present, our eyes interpret this as **white light**. If no wavelengths in the visible range are present, we interpret this as **dark**.

Speed of light in a vacuum, **299,792,458 metre per second, is one of the fundamental constants of nature.**

The sun is the main source of light and heat for living things on earth. It provides the energy that green plants use to create food, which releases energy into the living things that digest them.

There are **two things** that we can intuitively mention about light from common experience. First, that it travels with enormous speed and second, that it travels in a straight line. It took some time for people to realize that the speed of light is finite and measurable. Its presently accepted value in vacuum is $c = 2.99792458 \times 10^8$ m s^{-1}.

For many purposes, it suffices to take $c = 3 \times 10^8$ m s^{-1}.

The speed of light in vacuum is the highest speed attainable in nature to date. As we have said, the intuitive notion that light travels in a straight line seems to contradict what we have learnt in an earlier module, that light is an electromagnetic wave, made up of waves of wavelength belonging to the visible part of the spectrum.

How to reconcile the two facts?

The answer is that the wavelength of light is very small compared to the size of ordinary objects that we encounter commonly (generally of the order of a few cm or larger). In this situation, as you will learn, a light wave can be considered to travel from one point to another, along a straight line joining them. That is why it is treated as geometrical optics.

The path is called a ray of light, and a bundle of such rays constitutes a beam of light.

We will consider the phenomena of reflection, refraction and dispersion of light, using the ray picture of light. Using the basic laws of reflection and refraction, we shall study the image formation by plane or spherical reflecting and refracting surfaces. We will then go on to describe the construction and working of some important optical instruments, including the human eye.

We can now sum up our guiding principles for study of optics in the subsequent modules.

- **Light** is a transverse, electromagnetic wave that can be **seen by humans and living things**.
- **Light travels in a straight line** and formation of shadows and images can be explained easily.
- The **wave nature of light** was first illustrated through experiments on **diffraction and interference.**
- Like all electromagnetic waves, light can **travel through a vacuum.**
- The transverse **nature of light** can be demonstrated through **polarization.**

In 1678, Christiaan Huygens (1629–1695) published Traité de la Lumiere, where he argued in favour of the wave nature of light. His student Thomas Young (1773–1829) studied the famous Young's Double slit experiment.

The primary properties of light (visible electromagnetic radiation) are

Speed

- The speed of light in a vacuum is a universal constant in all reference frames.
- The speed of light in a vacuum is fixed at 299,792,458 m/s by the current definition of the meter.
- The speed of light in a medium is always slower than the speed of light in a vacuum.

- The speed of light depends upon the medium through which it travels. The speed of anything with mass is always less than the speed of light in a vacuum.

Intensity

- The candela is the luminous intensity, in a given intensity direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.
- Intensity is the absolute measure of a light wave's ability to illuminate a surface.
- Brightness is the relative intensity as perceived by the average human eye.

Frequency

- The frequency of a light wave is related to its colour, and hence its origin. This cannot change even if the speed of light changes as in the case of refraction

$$V = f \lambda$$

  The wavelength of a light wave is inversely proportional to its frequency.
- Light is often described by its wavelength in a vacuum.
- Light ranges in wavelength from 400 nm on the violet end to 700 nm on the red end of the visible spectrum.
- Frequency cannot change but wavelength changes as light travels from one medium to another.

Eye

- Detects the light and gives the sense of vision
- The distance of distinct vision is different for different eyes. For normal human eyes it is 25 cm.
- Defects of human vision can be corrected by using suitable lenses.

Other species and vision (this is given just for fun)

- Falcon can see a 10 cm small object from a distance of 1.5 km.
- Fly's Eye has a flicker fusion rate of 300/s. Humans have a flicker fusion rate of only 60/s in bright light and 24/s in dim light. The flicker fusion rate is the frequency with which the "flicker" of an image cannot be distinguished as an individual event. Like the frame of a movie… if you slowed it down, you would see individual frames. Speed

it up and you see a constantly moving image. Octopus' eye has a flicker fusion frequency of 70/s in bright light.

- Penguin has a flat cornea that allows for clear vision underwater. Penguins can also see into the ultraviolet range of the electromagnetic spectrum.
- Sparrow Retina has 400,000 photoreceptors per square mm.
- Reindeer can see ultraviolet wavelengths, which may help them view contrasts in their mostly white environment.

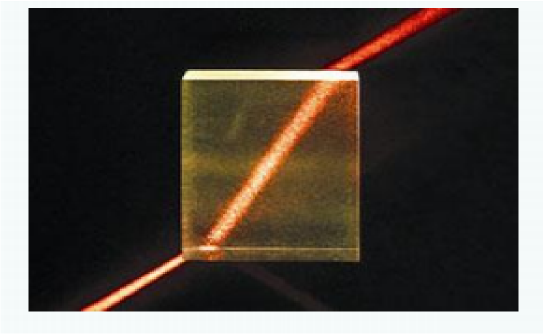
Ray Optics and Wave Optics

The ray, in **ray optics,** is an abstraction useful for approximating the paths along which light propagates under certain circumstances. When light falls on an interface /or surface, the phenomenon of reflection and refraction takes place. These follow certain rules or laws.

If the interface is between two transparent mediums, refraction takes place. Refraction is basically the change in speed of light when it travels from one transparent medium to another transparent medium. The effect of bending of light either towards the normal or away from the normal at the point of incidence, depends upon the pair of medium (the optical densities of the pair of medium) and the passage from rarer to denser medium and from denser to rarer medium.

We may have observed the bending of a pencil when half of it is immersed in water.

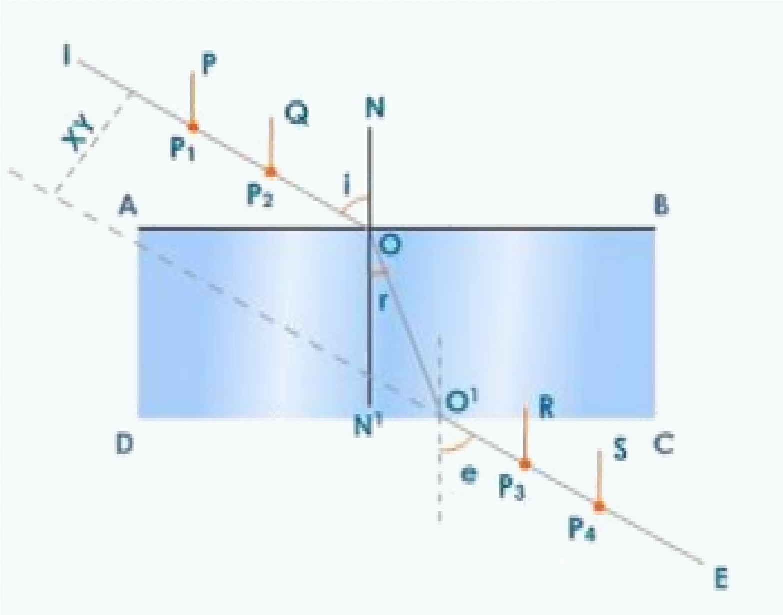
Or a laser beam through a rectangular glass slab.



Or

the experiment in the laboratory where you traced the path of light through a rectangular glass slab or an equilateral faced glass prism. This you may have done by placing the slab /prism on a white sheet on a horizontal wooden board and using pins.

If a ray of light is made to pass through a rectangular glass slab it bends towards the normal. The reason is that its speed decreases while travelling through a denser medium as compared to the air. And as the refracted ray incidents on the other (rear) surface of the slab, it bends away from the normal since it is travelling from denser to rarer medium.P Q R S is the ray through the glass slab.

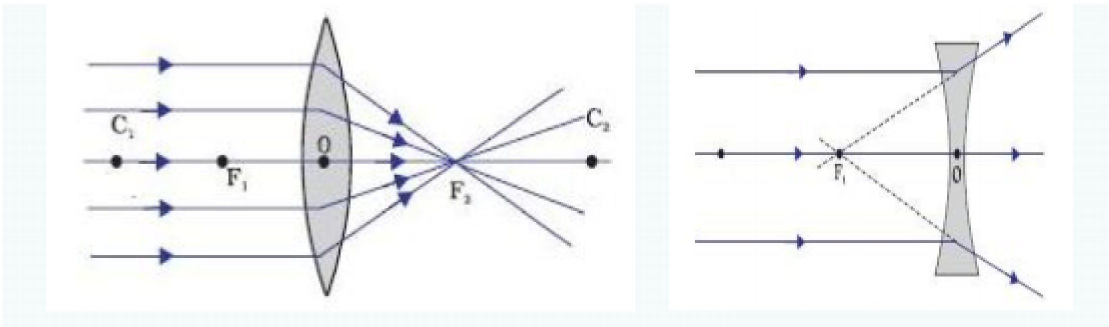


You also used ray optics to explain formation of images in spherical mirrors and lenses.

Have you ever noticed how your hand looks bent as you dangle it in the water from the edge of a pool? Or in a transparent bucket filled with water

Ever thought of reasons

- Why do fish seem to change position as we look at them from different viewpoints in an aquarium?
- What makes diamonds sparkle so much?
- What makes a parallel beam of light converge, or diverge depending upon the shape of the glass lens?



You may even recall the formation of images by lenses. These and many more situations of propagation of light through homogeneous, heterogeneous mediums that light travels in a straight line, it can retrace its path, light rays may intersect at points after reflection or refraction creating images of the object from where the rays emanated. You could also explain the formation of virtual images where light seems to come from after reflection or refraction.

All the considerations were taking light in a macroscopic way

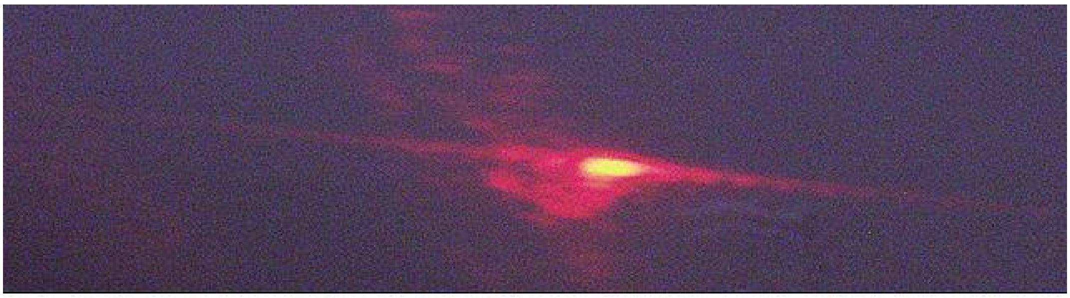
So we see that in your previous lessons in science courses you have studied about the macroscopic phenomena like rectilinear propagation of light, reflection and refraction of light etc. and the study of formation of images in mirrors and lenses.

We also studied that light is an electromagnetic wave. This wave originates from atoms. The vibration of electrons with sufficient energy between different energy states results in radiation of energy from the atom. The frequency of electromagnetic waves lies in the region of visible range. This means it can be detected by human eyes.

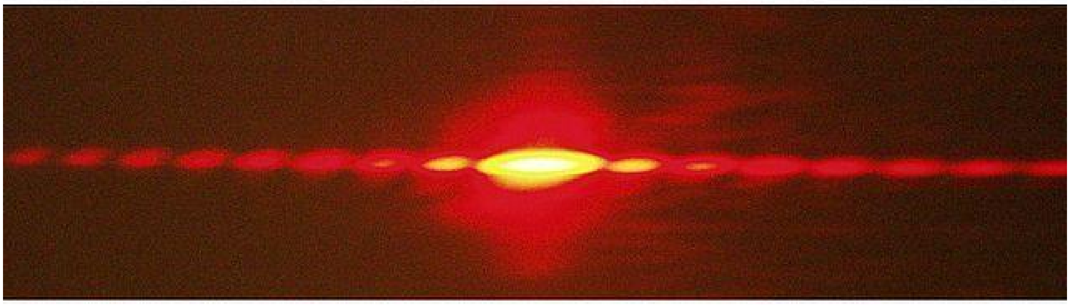
Light is an electromagnetic wave, we need to apply the ideas of wave propagation in order to explain phenomenon of

- **interference,**
- **diffraction and**
- **polarization**.

Just to help you realize the difficulty by limiting our study in optics to ray optics alone. The patterns shown for- what would happen if a small single slit is illuminated by light, ray optics must give a single slit on any screen placed in the path of light emerging from the slit. But in reality we see a bunch of bright spots. These could not be explained by just ray optics. Also ever thought about how sun glasses make it easier for us to go out in bright sunlight?



Pattern produced from a single slit.



Pattern produced from a double slit.

https://upload.wikimedia.org/wikipedia/commons/thumb/1/10/Single_%26_double_slit_experiment.jpg/640px-Single_%26_double_slit_experiment.jpg

So we will study this unit in two parts

The first nine modules are on ray optics and explain the various phenomena related to light as it encounters boundaries. The material of the boundaries is described by opaque, transparent or translucent.

The subsequent six modules are dedicated to treating light as waves and hence explaining the phenomenon of interference, diffraction and polarization. These could not be explained by ray optics. However, the phenomenon of reflection and refraction can be explained using wave optics, and this encourages us to say microscopic properties of light need wave optics while macroscopic properties can be explained by ray optics.

Summary

- Our world is visible due to light
- Eyes are natural detectors of light
- Light is refracted or reflected when it falls on surfaces
- The path of light is represented by rays,
- Light follows laws of reflection and refraction
- Macroscopic effects of reflection and refraction, e.g. convergence and divergence of parallel beam of light, formation of images due to reflection and refraction can be explained by ray optics
- The wave-like properties of light as observed in the phenomenon of interference, diffraction and polarization can only be explained by taking a microscopic view of optics. Hence we study light as ray optics and wave optics