Nature & Propagation Of Light

The branch of optics that deals with production, emission & propagation of light its nature and the study of phenomena of interference, diffraction and polarization is called wave optics.

Nature and source of light

A. Newton's Corpuscular Theory

The first scientific attempt to explain the nature of light was made by Newton's in 1678. according to the theory, light consists of tiny light elastic particles called corpuscles. They are massless, emitted by objects such as lamp, candles. They travel all direction in straight lines with velocity of light. Different colours are due to the different size of corpuscles. The phenomena of refraction was explained by stating that these corpuscles

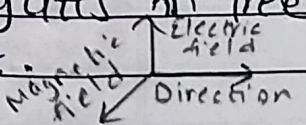
are attraced by the material of denser medium. This theory is based on the fact that the speed of light must be greater in the denser medium.

B. Huygen's Wave Theory

- In 1690, Dutch physicist proposed that light propagates from the source in the form of wave.
- For the propagation of wave medium is necessary. He assumed that all space including vacuum is filled with massless, colourless, invisible medium called ether.
- In 1801, Young experimentally showed that two light beam interfered with each other in the same way as two sound wave.

C. Electromagnetic theory

- Maxwell in 1860, theoretically proved that light gets propagated in the form of electromagnetic wave consisting electric & magnetic field mutually perpendicular to each other.
- The electromagnetic waves propagates in free space with the velocity of light.



D) Quantum theory

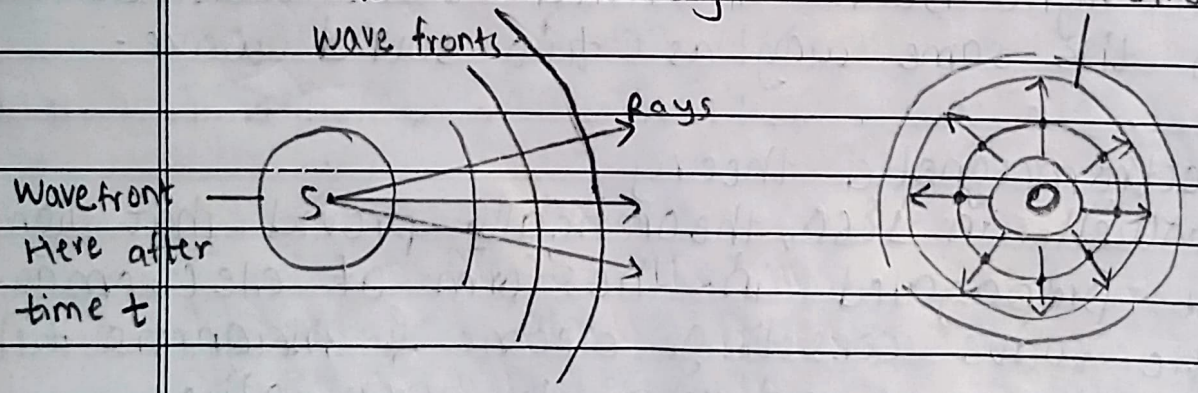
- In 1905, Einstein proposed new theory called quantum theory.
- According to this theory, light is transmitted as tiny packets of energy called photons.
- Energy of each photon; $E = hf$, h = Plank's constant

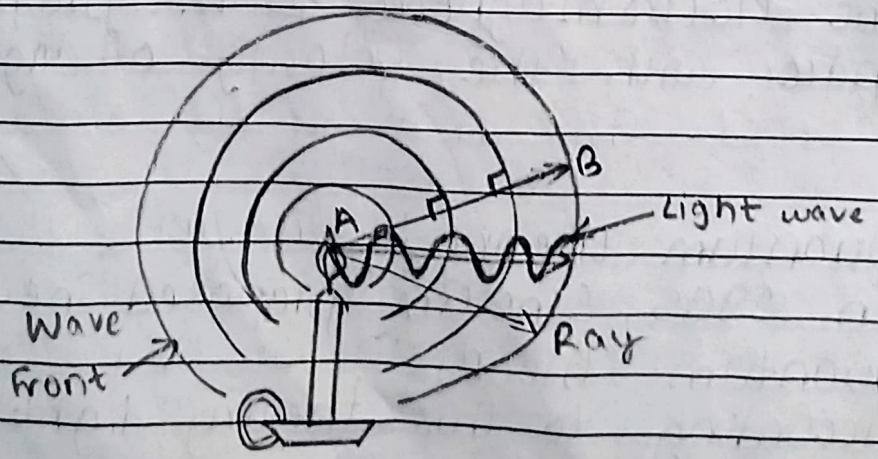
E. Duel Nature of Light

- From the discussion various theory of light can exist in particle form as well as wave form
- In 1924, French scientist De-Broglie suggested that every morning particle is associated with a wave which controls the particle in every aspect.

Wavefront

- A wave front at any instant is defined as the locus of particles of medium vibrating at the same phase.
- An imaginary line perpendicular to wave front is called ray.





Wave fronts Propagating from a Point Source

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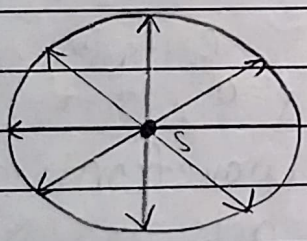
Types of Wavefront

Depending upon the nature of source of light

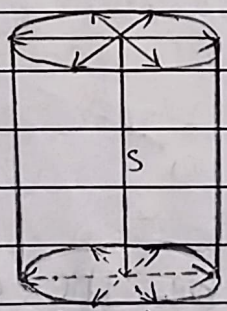
1) Spherical wavefront: If the source of light is point source then wavefront is spherical. A point source emit waves which spread in all direction.

2) Cylindrical wavefront: When a source of light is linear in shape (like a slit), all points equidistance from linear source lie on the surface of cylinder. Such wavefront is cylindrical wavefront.

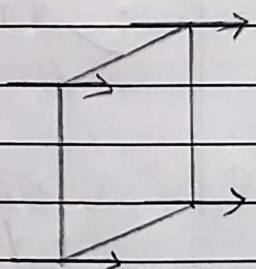
3) Plane wavefront: For any kind of source (point or line) the wavefront appears as plane if source lies at infinity.



Spherical wavefront



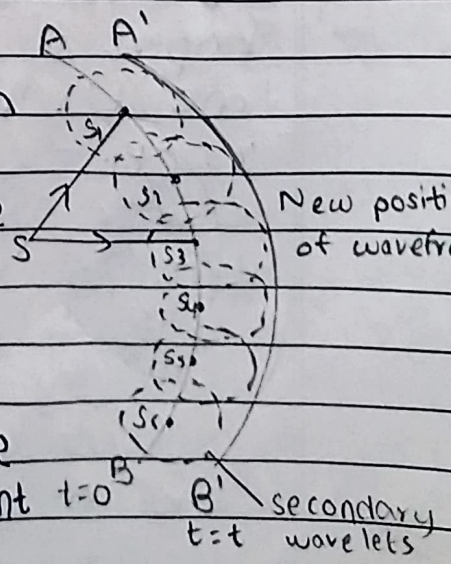
Cylindrical wavefront



Plane wavefront

Huygen's Principle

- If the present shape & position of a wavefront is known, its shape & position at any time in future can be determined by Huygen's Principle.

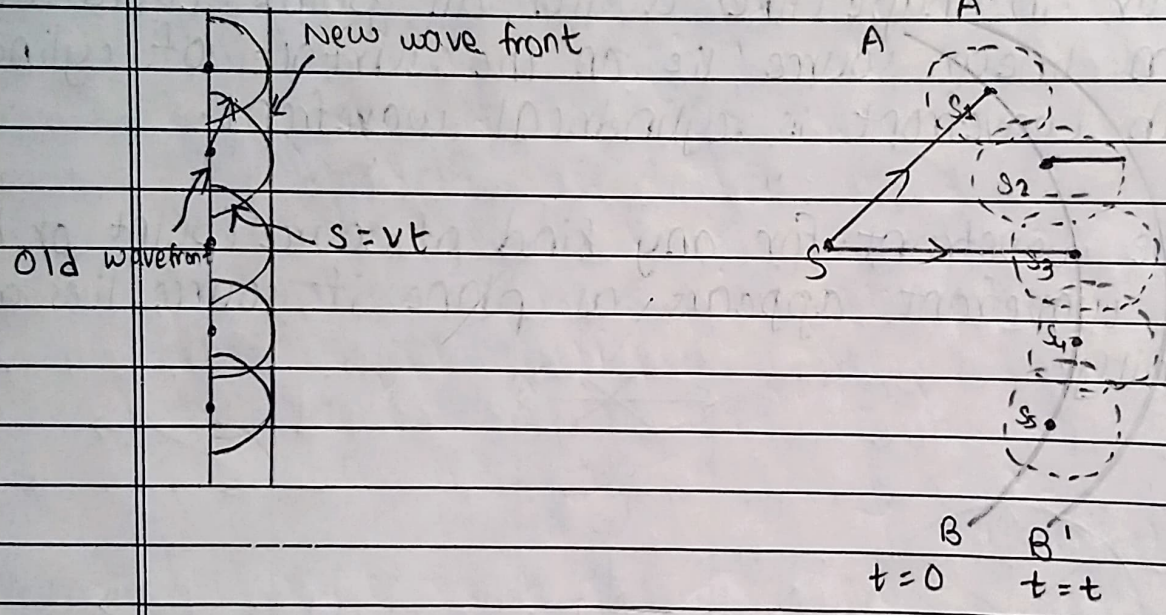


- According to Huygen's Principle

* Every point in a given wavefront

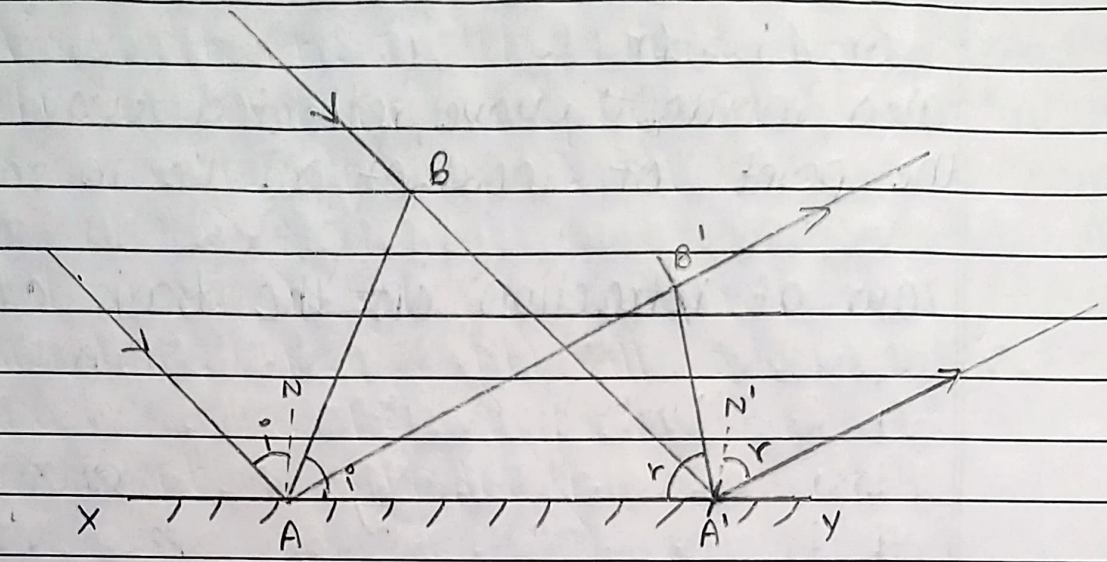
acts as a source of new disturbance. The new disturbance travels in all direction with speed of light. They are called secondary wavelets.

* The tengencial envelope to all secondary wavelets at a given time gives new wavefront.



Let AB be the given wavefront at time $t=0$. Every points on AB acts as source of new disturbance. The tengencial envelope A'B' to all secondary wavelets gives the shape & position of new wavefront after time 't'. The radius of each wave let is $r = ct$.

Law of Reflection on the basis of wave theory



Consider a plane wavefront AB incident on a plane reflecting surface XY at an angle of incidence. If point A of the wavefront reached the surface at first, after some time 'or' 't' B will reach at A'.

$\therefore t = \frac{}{BA'}$ is the time at which B will reach A'. v is the velocity of wave.

From Huygen's principle, every point of the wavefront AB is source of secondary wavelets. At time 't' the wavelet that had emerged from A has travelled distance $AB' = BA'$. With A as the center & AB' is radius draw a circle This circle represents section of spherical wavelets in plane of paper. So, envelop of wavelets is reflected wavefront A'B' at time 't'.

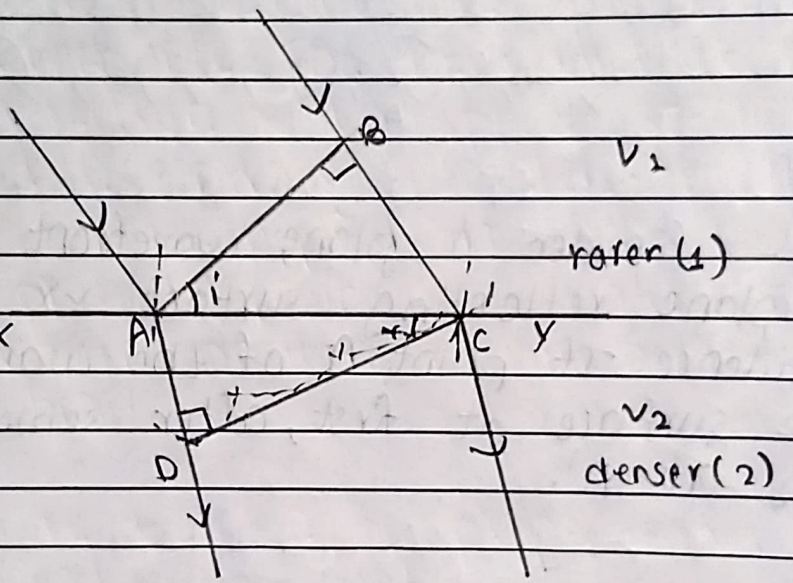
$\therefore \Delta ABA'$ and $\Delta AB'A'$ are congruent

$\angle BAA' = \angle BA'A$

or, $\angle i = \angle r$

Also, incident wave, reflected wave & normal at the point of incident, all lie in same plane.

Laws of refraction on the basis of wave theory



Consider a section of a plane wavefront AB incident on the plane refracting surface XY separating two different media (1) & (2).

Let v_1 & v_2 be the velocity of incident wave & refracted wave ($v_1 > v_2$).

The first point on boundary to be hit by incident wavefront. A & last is C.

From Huygen's Principle, every point between A & B in turn becomes a source of secondary spherical wavelets.

Let 't' be the time taken by disturbance at B to reach C.

$\therefore BC = v_1 t$ — (1)

During this time the secondary wavelet created at A has travelled distance $AD = v_2 t$ in medium (2). With A center & AD as radius draw a circle. This circle represents secondary spherical wavefront at time 't' that had emerged from A, 't' second earlier.

Thus envelop to wavelets is refracted wavefront CFD.

In ΔABC, $\sin i = \frac{BC}{AC}$

In ΔACD, $\sin r = \frac{AD}{AC}$

$$\text{or, } \frac{\sin i}{\sin r} = \frac{BC}{AC} \times \frac{AC}{AD}$$

$$\text{or, } \frac{\sin i}{\sin r} = \frac{v_1 t}{v_2 t}$$

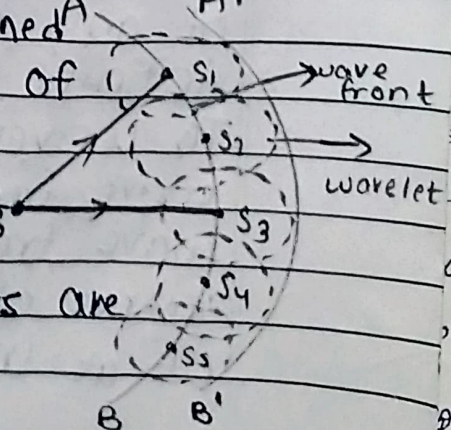
$$\text{or, } \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

$\therefore \frac{\sin i}{\sin r} = \mu$ this is Snell's law.

Short Questions

1) Distinguish between wavefront & wavelet?

2) Wavefront at any instant is defined as the locus of the particles of the medium vibrating in the same phase. Every point on the wavefront acts as a source of a disturbance, these points are called wavelets.



The wavelets may originate form the primary as well as secondary source of light & wavefronts are obtained by the tengencial envelop of the wavelets.

2) State Huygen's principle - Does it apply to sound waves in air?

→ According to Huygen's principle every point in a given wavefront acts as a souree of new disturbance. The new disturbance travels in all direction with speed of light. They are called secondary wavelets. Yes, Huygen's principle can be applied to sound wave in air. If the present position & nature of wavefront in air known, position of wave front is known after sometime.

3) Differentiate between a plane wave front & a spherical wave front.

Plane wave-front	SN	Spherical wave-front
It is plane in shape.	1)	It is spherical in shape.
It is produced by a source of light of any shape at infinite distance.	2)	It is produced by a point source of light at finite distance.
To convert spherical wave front into plane wave front. a point source of light is ke- ot at the focus	3)	To convert plane to spherical wave front: convex lens is placed in the path of plane wave front.

What is meant by wave front & wavelets?

→ Wavefront: It is the locus of the particles of the medium vibrating in the same phase.

Wavelets: They are the secondary waves which are produced when each point of the wave front acts as the new source of wave represented by small circles.

4) Differentiate wave front & wavelet?

→

Wave front	Sl.	Wavelet
Wave front is the locus of the particles of the medium vibrating in the same phase.	1)	Wavelet are the secondary waves which are produced when each point of the waves front acts as the new source of wave represented by small circles.
The locus of wavelets equi distant from source of light is taken as wave front.	2)	Every point on the wave front acts a source of disturbance, called wavelets.
Different types of wave front may originate depending upon nature & distance of source light: spherical, cylindrical & plane wave fronts.	3)	The wavelets may originate from the primary as well as secondary source of light.

6) If light travels from one medium to another,

its velocity changes? Is it due to change in frequency or wavelength? Explain.

→ Yes, there will be change or variation in velocity & wavelength of light during refraction. The velocity of light in any medium depends on the refractive index of the medium & it varies from one medium to another medium. But, the frequency is the fundamental property of any waves & it does not change even when the wave travels in any medium. It is equally true for all types of waves as light waves or sound waves.

7) A normally incident wave front does not deviate, when it travels from one medium to another. Explain.

→ According to the law of refraction, when light is normally incident on a plane surface which does not deviate i.e, not deviate towards or away from normal. As a result, incident wave front does not deviate when it travels from one medium to another.

8) What is Huygen's principle?

→ Huygen's principle is a geometrical method for determining the position & shape of a given wavefront at any time in the future if we know its present position.

9) When monochromatic light incidents on a surface, the reflected wave will have same frequency, why?

→ Since, frequency is fundamental or empirical parameter of a wave & it doesnot change with medium, but only depends upon nature of source. So, the velocity of light wave during its propagation changes on changing wavelength while passing from one medium to another medium. Due to this reason, when monochromatic light incidents on a surface, the reflected & refracted wave will have same frequency.

10) Which of the parameters, wavelength, frequency, speed or amplitude change in reflection?

→ In reflection, the amplitude will be changed, but parameters like wavelength, frequency, speed remains unchanged.

11) Does the energy of light change when it travel from one medium to another? Give reason.

→ NO, when light passes from one medium to other its speed changes & wavelength changes but its frequency remains same & amplitude does not change. The energy of wave depends on the amplitude. That's why, the energy of light does not change when it travels from one medium to another.