Lecture 2

2.1 Nature of Light:

Attempts to explain the nature of light have been going on for quite sometime. All what was known for fact is that: Everyday experience shows that the propagation of light is instantaneous; for when we see a piece of artillery fired at great distance, the flash reaches our eyes without lapse of time; but the sound reaches the ear only after a noticeable interval.
In the following some lights are shed on the different theories, which have been trying to explain the nature of light.

1. **Corpuscular or Newton theory**:

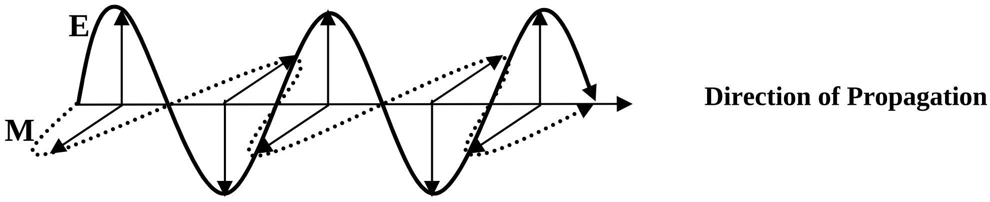
   Newton in his theory proposed that light is composed for many very tiny particles, which go together. So, the theory attributed particle nature to light, but failed to explain some physical wave phenomena such as diffraction, interference, and polarization.

2. **The wave theory of Hygen.**

   Hygen proposed that light has wave nature. He had to attribute elastic wave properties, well known waves and ever studied at that time, to light. A medium was then proposed and assumed to fill the whole space and attain properties of elastic solid to allow waves to propagate through. This was termed "luminiferous ether". No one at that time could ever imagine a wave to propagate without a medium to support the motion and to determine the velocity of propagation. The ether was assumed to be the only medium at absolute rest. A motion of any other object can perfectly be obtained in relation to ether. The ether had to be composed of two bizarre characteristics. On one hand, ether had to be the stiffest medium ever known to allow light waves with the maximum known speed to propagate through. The stiffer the medium, the greater the velocity of the waves which propagate through. So, ether had to be very resilient. On the other hand, ether did not impede objects penetrating it. Though **Hygen** succeeded to explain phenomena of diffraction, interference and polarization, he could not identify the nature of the assumed ether.

3. **Electromagnetic Wave Theory of Maxwell**

   Maxwell in 1864 developed a unified theory of electromagnetics in which light is considered of being composed of a time-varying electric field perpendicular to a time-varying magnetic field.



Time-Varying electric and magnetic fields perpendicularly in space.

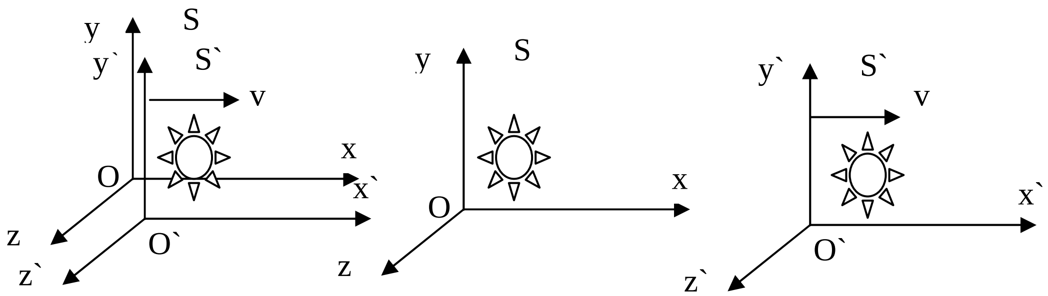
In 1887 **Hertz** succeeded to experimentally generate EM waves by means of an oscillatory electric current and confirmed what Maxwell had predicted theoretically. Later on, **Einstein** proved that no medium is necessary for EM waves to propagate, unlike mechanical waves.

4. **Quantum theory**

Light waves are now regarded as EM waves composed of pulsating amount of energies known as photons. The amount of energy a photon carries depends on the frequency of the light wave. These photons are referred to as quanta indicating that light energy is no longer regarded as continuum. Light waves propagate in vacuum.

2.2 Light Waves and Classical Relativity

Now let us consider a light burst be flashed and being monitored by two observers O and O`. The question now is whether the observer O` be able to predict the equation of the light wave as seen by O or not. In other words, would Maxwell's equations take on different forms in different inertial frames?



O coincides O` after a time duration t

Wave front in S: $x^2 + y^2 + z^2 = c^2 t^2$ **(1)**

While in S`** **:** $x`^2 + y`^2 + z`^2 = c^2 t`^2$ **(2)

Using Galilean Transformation:

$x` = x - vt, \quad y` = y, \quad z` = z, \quad and \quad t` = t$

Maxwell's equation as transformed in S` becomes:

$$(x - vt)^2 + y^2 + z^2 = c^2 t^2 \quad \textbf{(3)}$$

It is clear now that equation (3) is not equal to equation (1) which leads one to think of one out of three possible reasons :

1. Maxwell equation may possess different mathematical form in different inertial frame of reference.
2. The speed of light is not a constant, it can be assumed dependent on space-time coordinates in such a way making equation (3) be rewritten as :

$$x^2 + y^2 + z^2 = c^2t^2 + 2xvt - v^2t^2$$
$$= c^{`2}t^2$$

3. Galilean transformation is not a good one and some other transformation should be thought of.

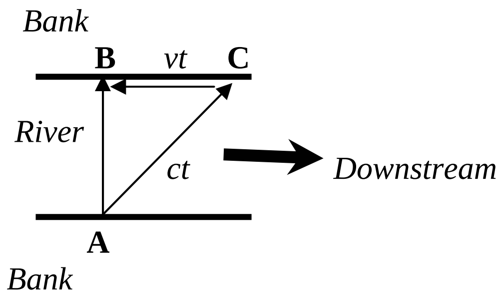
2.3 If Light is a wave!! What is waving?

Having established that light is a wave, though, we still haven't answered one of the major objections raised above. Just what is waving? We discussed sound waves as waves of compression in air. Actually, that is only one case---sound will also travel through liquids, like water, and solids, like a steel bar. It is found experimentally that, other things being equal, sound travels faster through a medium that is harder to compress---the material just springs back faster and the wave moves through more rapidly. For media of equal springiness, the sound goes faster through the less heavy medium, essentially because the same amount of springiness can push things along faster in a lighter material. So when a sound wave passes, the material---air, water or solid---waves as it goes through. Taking this as a hint, it was natural to suppose that light must be just waves in some mysterious material, which was called the ether, surrounding and permeating everything. This ether must also fill all of space, out to the stars, because we can see them, so the medium must be there to carry the light. (We could never hear an explosion on the moon, however loud, because there is no air to carry the sound to us.) Let us think a bit about what properties this ether must have. Since light travels so fast, it must be very light, and very hard to compress. Yet, as mentioned above, it must allow solid bodies to pass through it freely, without ether resistance, or the planets would be slowing down. Thus we can picture it as a kind of ghostly wind blowing through the earth. But how can we prove any of this? Can we detect it?

2.4 Michelson-Morley Experiment:

A challenge Michelson set himself, after his success in measuring the speed of light accurately, was to detect and determine the relative velocity of ether. Naturally, something that allows solid bodies to pass through it freely is a little hard to get a grip on. But Michelson realized that, just as the speed of sound is relative to the air, so the speed of light must be relative to the ether. This must mean, if you could measure the speed of light accurately enough, you could measure the speed of light traveling upwind, and compare it with the speed of light traveling downwind, and the difference of the two measurements should be twice the wind speed. Unfortunately, it wasn't that easy. All the recent accurate measurements had used light traveling to a distant mirror and coming back, so if there were an ether wind along the direction between the mirrors, it would have opposite effects on the two parts of the measurement, leaving a very small overall effect. There was no technically feasible way to do a one-way determination of the speed of light. At this point, Michelson had a very clever idea for detecting the ether wind. As he explained to his Children (according to his daughter), it was based on some swimming race puzzle.

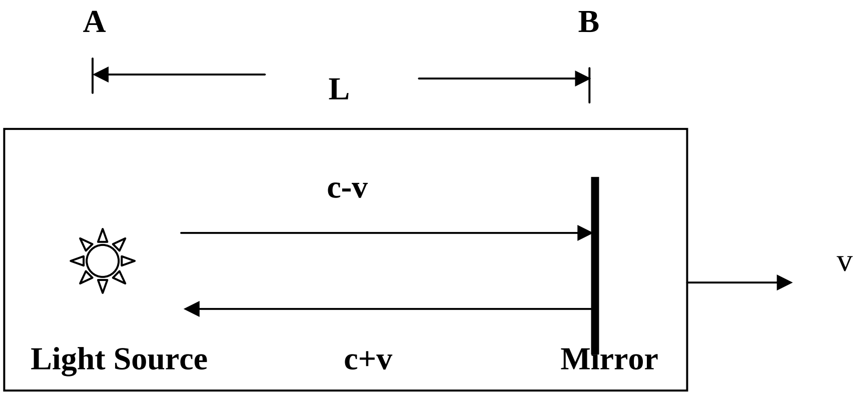
Suppose we have a river of width w (say, 100 feet), and two swimmers who both swim at the same speed v feet per second (say, 5 feet per second). The river is flowing at a steady rate, say 3 feet per second. The swimmers race in the following way: they both *start at the same point on one bank. One swims directly across the river to the closest point on the opposite bank, then turns around and swims back. The other stays on one side of the river, swimming upstream a distance (measured along the bank) exactly equal to the width of the river, then swims back to the start. Who wins? Let's consider first the swimmer going upstream and back. Going 100 feet upstream, the speed relative to the bank is only 2 feet per second, so that takes 50 seconds. Coming back, the speed is 8 feet per second, so it takes 12.5 seconds, for a total time of 62.5 seconds.*



Swimmer A has moved ct relative to the water, and been carried downstream a distance vt .

The swimmer going across the flow is trickier. It won't do simply to aim directly for the opposite bank-the flow will carry the swimmer downstream. To succeed in going directly across, the swimmer must actually aim upstream at the correct angle (of course, a real swimmer would do this automatically). Thus, the swimmer is going at 5 feet per second, at an angle, relative to the river, and being carried downstream at a rate of 3 feet per second. If the angle is correctly chosen so that the net movement is directly across, in one second the swimmer must have moved four feet across---the distances covered in one second will form a 3,4,5 triangle. So, at a crossing rate of 4 feet per second, the swimmer gets across in 25 seconds, and back in the same time, for a total time of 50 seconds. The cross-stream swimmer wins. This turns out to true whatever their swimming speed. (Of course, the race is only possible if they can swim faster than the current!)

Michelson and Morley set up an experiment to measure the velocity of earth with respect to ether. They found that the earth's speed v relative to the ether appears only in order of v^2/c^2. Such measurements determine the time it takes a light pulse to travel to and from a mirror.



Ether

Assume that the light source and the mirror move with a velocity v relative to the ether which is considered to be at rest. The taken by the ray to travel from A-to-B is $\frac{L}{c-v}$ and that taken from B-to-A is $\frac{L}{c-v}$. Then the round trip time can be written as:

$$t_{ABA} = \frac{L}{c-v} + \frac{L}{c+v} = \frac{2Lc}{c^2 - v^2}$$

$$= \frac{2Lc}{c^2} \frac{1}{1-\frac{v^2}{c^2}} = \frac{2L}{c}(1-\frac{v^2}{c^2})^{-1}$$

For v much smaller than c, which is true as the orbital velocity of earth around the sun is negligible as compared to the velocity of light, and using the binomial expansion:

$$(1+x)^n = 1 + nx + \frac{n(n-)}{2!}x^2 + \dots\dots\dots\dots \qquad x < 1$$

$$\therefore t_{ABA} \cong \frac{2L}{c}(1+\frac{v^2}{c^2})$$

Calculations: Take the orbital speed of earth around the sun to be $v = 3\times10^4 m/s$ and the speed of light as $c = 3\times10^8 m./s$.

$$\therefore \frac{v}{c} = 10^{-4} \qquad and \qquad \frac{v^2}{c^2} = 10^{-8}$$