The search for the absolute in the physical realm: a note on the theory of light and relativity

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Based on our current understanding of modern physics "Everything is relative, nothing is absolute" seems to be an agreed up on conclusion, or is it? What do we mean by relative? What do we mean by absolute? If absolute is reference frame independent, then modern physics has found one - the speed of light. This is one of the most interesting journeys of man's search for meaning and order in the physical realm. In this short note the writer presents the historical developments of the exploration.

Light and seeing

The precursors of scientific investigation of the behaviour of light and its propagation was mainly in connection with seeing. The Greek geometers tried to study the geometrical properties of seeing. Euclid [1] thought that there was something that goes out of the eyes and impresses on the object of seeing for seeing to happen. Claudius Ptolemy [2], the author of Almagest (the well-known book of earth centred astronomy), believed, like Euclid, that seeing is because of some sort of ray that goes out of the eye. He further studied the path breaking when light propagates from air to water and he measured the breaking angle. The Euclidean scientific error that concluded that seeing is due to rays that come out of the eyes was later corrected by the well-known Arab polymath, Al Hazen [3]. Al Hazen studied the nature of the eye and concluded that seeing was due to the projection of the image of the outside world on to the retina of the eye in a manner very close to what modern science would tell us. That is, seeing happens when light reflected from objects penetrates the eye and the eye further sends the signal to the brain. What Alhazen missed was that the image formed on the retina is in fact an inverted image of the object of sight. This was later discovered by Kepler [4].

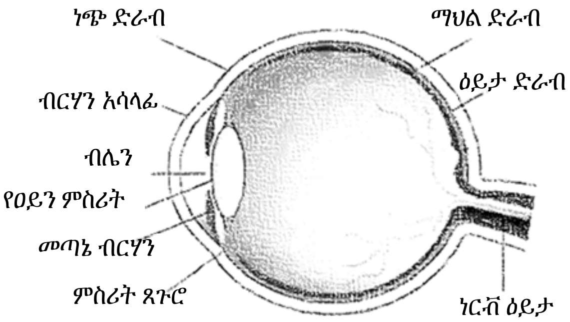

Figure 1: Different parts of the human eye

Light follows the path that takes it the least time to travel

Light bounces off reflective surfaces. The law of reflection says that the angle of incidence and the angle of reflection are equal. The Greek mathematician, Hero [5], could find the law reflection stating that light follows the shortest path. Consider the illustration in Figure 2. Let DF be a mirror. Let a light ray emitted from A be reflected off the mirror surface at C and pass through B. Let B' be the image of B. Construct straight line BB crossing the mirror at D'. According to the property of mirror image BD and B'D are equal. Therefore, BC and B'C are equal and further AB and AB' are equal. ACB' is straight line and hence the shortest distance between A and B'. If a light ray emitted from A makes an incidence at any other point than C, it would have to travel a longer distance than ACB. This will obviously lead us to the law of reflection, i.e., the angle of incidence is equal to the angle of reflection.

In addition, light changes its course when moving from one medium into another if the two have different refractive indices, for instance from air to water. A stick partly in air and partly in water looks broken (bent) when the surrounding is illuminated. This Optical illusion is due to the property of refraction. Claudius Ptolemy [2] and Al Hazen [3] studied the refraction of light from air to water and tried to measure the angle of refraction. However, it was the Dutch mathematician, Willebrord Snellius [6] which is credited with finding the law of refraction. Snell's law of refraction says that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant and that constant is the refraction index. This law cannot be readily inferred from the shortest path principle. In fact, if light was to follow the shortest path it would have continued to travel in a straight line irrespective of changes in the type of medium it is propagating through. But, it does not. It was Fermat [5] that found a principle that explains both the refraction and the reflection properties of light. Fermat stated that light travels in the path that takes it the least amount of time. It is called Fermat's least[1] time principle. It is perplexing that light "sniffs" the path that takes it the least amount of time when traveling from one medium to another.

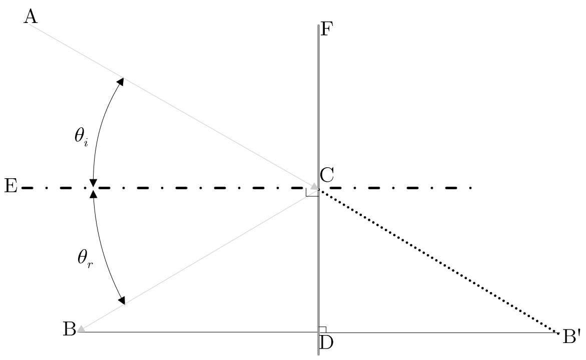

Figure 2: Geometric representation of reflection of light from a level mirror.

[1]More generally, it is the weaker form – the stationary principle that is used.

Light behaves both as particle and as wave

It was Newton [7] that found out that white light is a mixture of different colours using light prism. He also speculated that light was composed of particles (corpuscles). Others, such as Hooke speculated that light is a wave like sound is. The controversy seems to get resolution when Thomas Young [8] demonstrated the interference behaviour of light by passing light through two adjacent holes. This would demonstrate the wave nature of light. In his celebrated paper, on photoelectric effect [9], Einstein considered discrete energy packets called photons, which are particle like. Modern science acknowledges that light behaves both as wave and as particle.

The speed of light in a vacuum is finite

Galileo Galili [10] tried to measure the speed of light. The distance between the source of light and the receiver was too small to do an accurate measurement in Galileo's experimental setup. But, Galileo understood the speed of light was finite from observing the fact that the spread of lightning, although swift, takes some fractions of seconds. The first cunning attempt to measure the speed of light was due to Ole Rømer [11]. Rømer investigated the astronomical data for the times of eclipse of one of Jupiter's moons, Io. Rømer, after investigating the data, recognized that the time for the eclipse of Io took longer time when the earth was on the other side of the sun relative to Jupiter. Knowing the size of earth's orbit and the time difference for the observation of Io's eclipse, Rømer could compute the speed of light. Rømer didn't disclose what that number was although he used it successfully for winning a bate in the prediction of the time of Io's eclipse. The number was later computed by Christiaan Huygens [12]. Huygens, using Rømer's procedure, computed the speed of light to be thirty-one thousand miles per second. This is less than the modern value due to the inaccuracy in the then estimated size of the earth's orbit and the then data for the time of Io's eclipse. Using the same procedure and better data, Joseph Delambre could compute the speed of light to be three hundred thousand kilometres per second. This value is reasonably close to the modern value.

Light is an electromagnetic wave

Aristotle [13] wrote that Democritus of Abdera believed that nature was composed of small indivisible units, which Democritus called Atoms. Those who then believed, like Democritus or following Democritus, in the existence of such fundamental units of nature were called Atomists. The existence of such units was a mere speculation until John Dalton [14] proved the existence of such fundamental particles. But, they were not indivisible as the name Atom suggests. The 18th century and the 19th century scientific developments contributed a lot to the understanding of the structure of these basic units of nature. It is discovered that atoms have negatively charged particles swirling around a dense nucleus. It was later discovered that the nucleus of an atom contains neutral particles and positively charged particles respectively called neutrons and protons. Long before the contents of atoms were known, there was some understanding that certain objects could be made to posses an attractive power by rubbing them against fur or hair and that their attractive force decreases with distance. The objects are then said to be charged. It was later discovered that the force of attraction is directly proportional to the magnitude of the charge and inversely proportional to the square of the distance from the charged object [14]. Furthermore, it was discovered that charges could be set in motion in a form of what is called electric current. Indeed, natural phenomena such as lightning and shocks from electric eel are manifestations of this same phenomenon.

On the other hand, man has discovered that certain types of minerals possess a property of attracting metallic substances. These materials were called load stones. Load stones became useful materials as direction pointers, especially for water transport. Direction pointers made of such materials could always point towards north. Such materials had their particles arranged in such a way that they manifest a strong field – capable of a spooky action at a distance which is called magnetic field. It was later discovered that a magnetic field could be produced around a wire that carries current. Faraday [15] speculated that magnetic fields can be wave like and their action at a distance could take time. Maxwell [16] synthesized the works of Faraday, Coulomb [14], Biot, Savart and Ampere into what are known as Maxwell's laws of electromagnetism. Maxwell could then identify light to be an electromagnetic wave whose speed in a vacuum is given by the permittivity and permeability of free space. It was a surprising discovery. However, despite their success in explaining electromagnetic waves Maxwell's laws could not be in accordance with the principle of relativity when they are transformed according to the Galilean transformation that held good for the Newtonian mechanics. That is, Maxwell's laws of electromagnetism could change their form depending on the speed of the reference system, contrary to Newton's laws of motion, when a Galilean transformation is applied to them. (The Galilean transformation says that all inertial reference systems measure the same duration regardless of their speed.) But, the principle of relativity says that the laws of physics are the same in all inertial frames of reference.

All inertial frames of reference measure the same speed of light

In the early 1850's the French physicist, Hippolyte Fizeau [17], developed an experimental setup for observing the relative speed of light when propagating through a water flowing through a tube. If the light beam followed Galilean transformation, it would have arrived at its receiving end faster when propagating in the same direction as the flowing water (with a speed equal to the sum of the speed of the light beam in water and that of the water) and slower when propagating against the flow of water (with a speed relative to the stationary receiver equal to the difference of the speed of light beam in water and that of the water in the tube.) But, Fizeau's [17] experiment implied that the propagation of light did not follow the Newtonian superposition of velocities the Galilean transformation. Fizeau's experiment was later refined and repeated by other researchers and the result was accepted. Fizeau's [17] experiment casted doubt on whether the classical Galilean transformation holds good for the propagation of electromagnetic waves.

In the 19th century, physicists in general accepted light is an electromagnetic wave. They speculated that light propagated in a certain medium like other types of waves do. The medium of propagation was named luminiferous aether (modified from the so-called aether from Aristotle's meta physics.) Michelson and Morley [19] devised an experiment to put the hypothesis to a test. Michelson and Morley's experimental setup has some likeness with finding out which of the two swimmers of the same speed arrives first if one swims across the river and the other swims along the river for the same distance as that of the river width and come back to their starting point. In this setup, it can be mathematically demonstrated that the swimmer that swims across the river will arrive first. If luminiferous aether plays the role of the river and has a certain speed of its own and if two light rays are made to do the race in the same manner as the swimmers, then one would expect that the two light rays would have arrived one latter than the other. This difference in the arrival time would have been detected by receiving both on a screen and observing the interference pattern. Michelson and Morley could not detect any interference pattern. They carried out the experiment in different setups by varying directions, locations and altitudes. But, they could not detect any difference in the time of arrival of the light rays. This experiment is known as the "famous failed experiment." But, this confirmed that the so-called luminiferous aether was nowhere to be detected and that the speed of light is a constant!

As the writer pointed out earlier, Maxwell's electromagnetic laws would not follow the principle of relativity under Galilean transformations. Lorentz [19] and others developed a new way of transformation such that the propagation of electromagnetic waves obeys the principle of relativity. The transformation is now called the Lorentz transformation. For reference speeds that are much smaller than the speed of light, the Lorentz transformation may be reasonably approximated by the Galilean transformation. The Lorentz transformation would imply something nonintuitive – namely length contraction and time dilation that can be observable at reference frame speeds closer to the speed of light. Neither time nor space are absolute, contrary to Newton's assertion. Whether we light torches or play Ping-Pong, we have no way of knowing whether we are in a moving frame of reference or in a stationary one as the laws of physics are the same in the stationary as well as the moving reference frame. But, Lorentz did accept the presence of luminiferous aether. The fate of Luminiferous aether changed from 1905, after Einstein [20] presented his paper on the electrodynamics of moving bodies (widely known as special theory of relativity.) Einstein postulated that the speed of light is the same in all inertial reference frames and from there on there was no need to postulate the existence of Luminiferous aether. All inertial frames of reference measure the same speed of light irrespective of their own velocity. This postulate is generally accepted in modern physics. What else can be absolute if this is not!

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