Light Speed

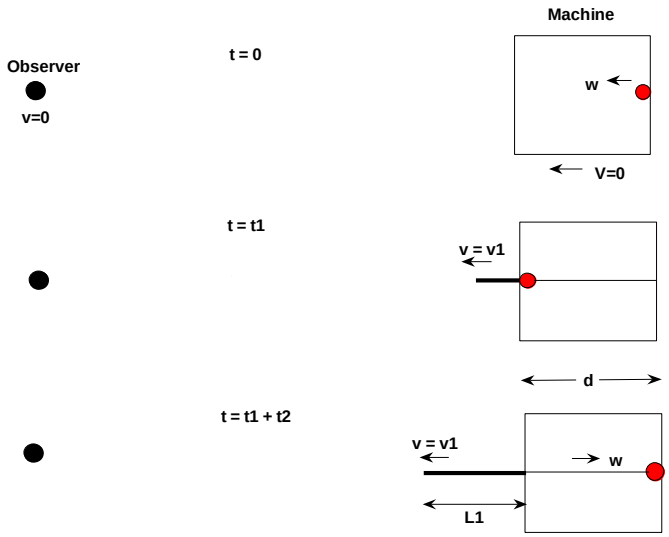
While hiking the lower hills of the math world, one may venture into the lower hills of the physics world. The flora and fauna can look quite similar while having a somewhat different appearance. The high peaks and cliffs of the physics world look more like those of the math world having little real look to them.

Forty years ago while taking a class in physics I asked the professor why the speed of light was the same for all observers. Of course, it was understood that I meant all observers moving in a straight line at a constant speed. The answer was that it was because of the curvature of space and time. I got an answer and was not going to show how unintelligent I was by displaying in any way my lack of understanding. So I asked no more questions. I knew if I asked later why space and time are curved the answer would be because the speed of light is the same for all observes. Two questions given and two scientifically intelligent answers returned. Those residing in the high mountain tops looking down have no problem with this. Those in the low hills straining to look up have a difficult time meshing the two questions and the two answers.

I have thought about the answer off and on over the forty years since the question was asked. No sleep was lost over it and it did not interfere with anything being taught, but it was not forgotten. How to approach the fact of light being the same speed for all observers was the sticking point. Investigating the speed of light by observation leads one into special relativity. The elegance of special relativity becomes the central theme. The speed of light appears relegated to being an axiom. Showing it is a constant in Maxwell's equations that are the same for all observers gives one a physical reason but it is still not satisfying. For low level day hikers something more is needed.

The speed of light being the same in any inertial reference frame was discovered by experiment, the famous Michelson Morley experiment. This strange property of light may not have been the conclusion at the time of the experiment but was the ultimate conclusion. Could it have been determined that the speed of light was the same in any inertial reference frame or at least that something was amiss from classical considerations? Could problems from a classical approach to the properties of light have appeared in thought experiments?

Being a mathdrooler one can make a mathematical construct and fantasize that it is real like the big boys do high up on the mountain tops. Below is a diagram of an observer and what is being observed.



The object being observed is a machine that produces sticks. As the red ball moves forth and back, a stick is produced out of the left of the machine. Each cycle of the red ball produces a stick. The red ball moves at a velocity w with respect to the machine, which is stationary with respect to the observer. The rate at which the stick is produced, and thus its velocity, is related to the velocity of the red ball, but not necessarily equal to it nor necessarily proportional to it. The stick is produced at a constant rate as long as the red ball is away from the right hand wall. The velocity of the stick above is v_1. The length of the stick above is L_1.

The above is a mathematical construct. It exists on the surface of a pad of paper. Many besides mathdroolers read physics books for the masses found in the bookstores. I have had people I know that are interested in these things tell me that the universe is made up of tiny strings

vibrating in 26 dimensions. David Lindley in “The End of Physics” is the only author I have read that points out that the likes of string theory are a mathematical construct.

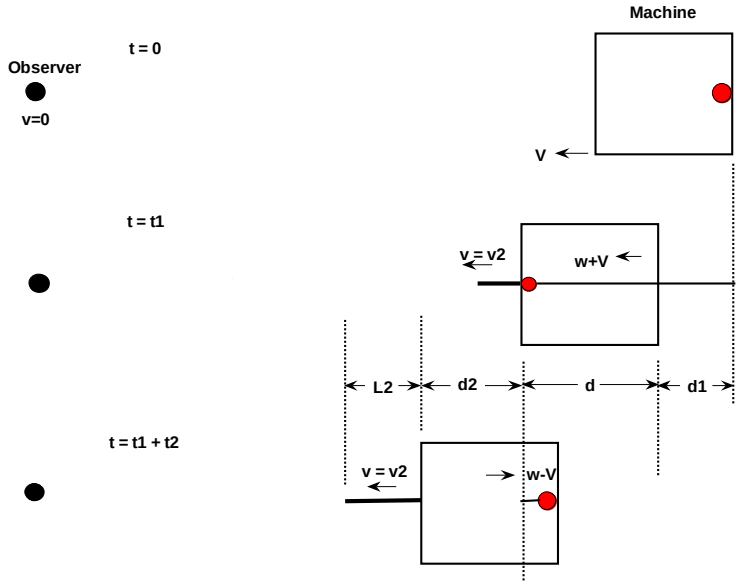
The construct above is not very interesting. A machine could be made to spit out sticks. Liberties can be taken in a construct that cannot be taken with a real machine. As the stick goes by the observer the observer will measure its energy. The energy in the construct will be proportional to the inverse of the length of the stick, i.e., it will be equal to some constant divided by the stick length.

The energy of the stick is $E_1 = \frac{\beta}{L_1}$, for some constant β. The rate at which the stick is made is not known. So, its length and velocity are also unknown. The time it took to make the stick is

$$t = t_1 + t_2 = \frac{d}{w} + \frac{d}{w} = \frac{2d}{w}.$$

For the construct above $L_1 = v_1 t = v_1 \frac{2d}{w}$ and $E_1 = \frac{\beta}{L_1}$.

To make things more interesting consider the diagram below.



Using the relation between velocity, distance and time from classical physics, the following relations are made.

$$t_1 = \frac{d_1}{V} \qquad t_2 = \frac{d_2}{V}$$

and

$$w + V = \frac{d + d_1}{t_1} \qquad w - V = \frac{d - d_2}{t_2}$$

$$w + V = \frac{d}{t_1} + V \qquad w - V = \frac{d}{t_2} + V$$

$$t_1 = \frac{d}{w} \qquad t_2 = \frac{d}{w}$$

This may be the long way around to get to the obvious that $t_1 = t_2 + \frac{d}{w}$, but time is available for clarity. To continue:

$$t = t_1 + t_2 = \frac{2d}{w} \quad and$$

$$d_1 + d_2 = Vt_1 + Vt_2$$

$$= Vt$$

$$= V\frac{2d}{w}$$

The tip of the stick in a time t has moved at a velocity v_2 a distance $d_1 + d_2 + L_2$. For the stick

$$d_1 + d_2 + L_2 = v_2 t$$

$$V\frac{2d}{w} + L_2 = v_2 t$$

$$L_2 = (v_2 - V)\frac{2d}{w}$$

Within the construct a reasonable assumption is that the energy of stick 2, that is the stick from the machine moving toward the observer, is greater than the energy of stick 1. This assumption leads to

$$E_2 > E_1$$

$$\frac{\beta}{L_2} > \frac{\beta}{L_1}$$

$$L_1 > L_2$$

$$v_1\frac{2d}{w} > (v_2 - V)\frac{2d}{w}$$

$$v_2 < v_2 - V$$

There is nothing in the construct that could not be realized in the real world from classical physics except for the energy of the stick being inversely proportional to its length. In the real world of classical physics $v_2 = v_1 + V$, and classical physics (by classical is meant non-relativistic as well as all else meant by it) was all that was used, except for the relation between energy and stick length. This lead to a conflict: if $V = 0$ then $v_1 = v_2$ form the first diagram and $v_1 < v_1$ from the second diagram - a contradiction.

To strictly stay within classical physics the energy of the stick would be $E = \frac{1}{2}mv^2$, where m is the mass of the stick. $E_2 > E_1$ would then lead to $v_2 > v_1$, which is not in conflict with $v_2 = v_1 + V$. Within the construct the stick has no mass with its only physical property being length. In the real world the stick has similarities to light.

Light, electromagnetic radiation, is massless and its energy can be related to the inverse of a length, wavelength. The question is why the speed of light is the same for all observers. That has not been shown. What has been shown is that a massless entity whose energy is inversely proportional to length within the construct yields results that are amiss when looked at using classical considerations. The energy relation yields results that are contrary to the common sense notion of adding velocities.

Perhaps there has been presented a physical explanation as to why the speed of light is the same for all observers in non-accelerating motion. It is understood that the speed of light is a constant in the wave equation for electromagnetic radiation derived from Maxwell's equations, which do not depend on any inertial reference frame. When I took physics years ago I felt that Maxwell's equations were the greatest achievement in physics. I have not changed that opinion. Encountering the equations was the first time in my acquaintance with physics that visualizing what was being studied became difficult. As one goes from Maxwell's equations to the wave equation for electromagnetic radiation the light dims on the physical world leaving the mathematical framework alone to be the guide.

There remain some passing thoughts. Whoever put this universe together thought it out well. Imagine if light had mass. The energy of a photon of light would then be determined by its velocity like any other

particle. If the mass were sufficient, light from stars would arrive at earth at different times depending on individual particle energy, which would be related to velocity and color if there would be color as we know it. The night sky would look like spaghetti. Instead of the stars being point light sources they would streak across the sky. To what extent would that have limited our knowledge of the universe?

The speed of light was only looked at vaguely from the construct using the property of energy. Perhaps a careful look at Maxwell's equations with an attempt to physically understand the manipulation of the equations into the wave equation for electromagnetic radiation would give a physical understanding. Or, perhaps this is just another area of reality that is beyond a common sense understanding.

It is of interest that an electromagnetic wave has essentially a disembodied electric field. Perhaps a photon carries with it some history of the electric particle from which it came. From special relativity, in the reference frame of a photon there is no depth and there is no time. It would seem that within the reference frame of a photon it does not exist.

There is one last curiosity. From the equations above one can obtain a relation between L_2 and L_1.

$$L_1 = v_1 \frac{2d}{w} \qquad and \qquad L_2 = (v_2 - V)\frac{2d}{w}$$

$$\Rightarrow L_2 = (v_2 - V)\frac{L_1}{v_1}$$

$$\Longrightarrow L_2 = \left(\frac{v_2}{v_1} - \frac{V}{v_1}\right) L_1$$

This is the Doppler shift for sticks. If $v_2 = v_1$, then this is the same as the Doppler shift for sound. If one applied relativity considerations to the moving stick machine and made $v_2 = v_1$, then the Doppler shift for sticks is the same as for the Doppler shift for light.

Mathdrooler 12Jun10
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