A study on the causes of the constancy of the speed of light

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This paper studied why the speed of light is always constant regardless of the speed of the light source or the observer. I also studied that the theory of relativity can be described only with the basic properties of time and space without introducing the constancy of the speed of light as a basic principle. This logical process presupposes that the correct length change in the special theory of relativity is length expansion, not length contraction, and I have confirmed that length expansion is consistent with known relativistic experimental results.

I. Introduction

The constancy of the speed of light was accepted as a basic principle of the theory of relativity, and many useful results of the theory of relativity were obtained. It is nevertheless impossible to understand this rationally without forcing it to be accepted. The reason is clear. This is because there is an element of non-relativity within the theory of relativity as we currently understand it. It originates from the classical ether theory, and although it is not a theory studied by Einstein, it remains an important part of the theory of relativity. This is the Lorentz-Fitzgerald length contraction hypothesis.

II. Why the constancy of the speed of light has not been understood so far

The problem of length contraction has been pointed out by many people. Streltsov pointed out the problem of length contraction by taking the concept of radar length[1], and Kwak insisted that the correct relativistic length is not length contraction, but the opposite length expansion.[2] Buenker insisted that length expansion, not length contraction, was found in GPS.[3] And Sato argued that if the length contraction was correct, GPS would not work.[4] In addition, Ashby said that they found the effect of time dilation in GPS, but passed over the effect of length contraction because he couldn't find any length contraction effect in GPS.[5] Given the opinions of these various authors, it is reasonable to suspect that there is a problem with the relativistic length as we know it. In general, time, length, and speed have the following relationship (1). Here, l is the length or distance, v is the speed of the object, and t is the time.

$$l = vt \tag{1}$$

If the light vibrates inside the spaceship when it is at rest, it becomes the following: $l_o = ct_o$. Here, l_o and t_o are the proper length and proper time, and l and t are the length and time of a relatively moving system. And γ is the Lorentz factor, and c is the speed of light.

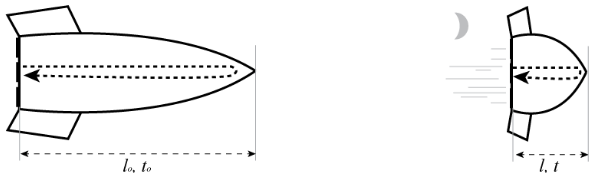

Fig. 1. Length and time of spaceship.

Let the length of the light travel in the spaceship be the unit length and the time it takes to travel is the unit time. If the length contraction theory is correct, the relationship $l = (1/\gamma)l_o$ and $t = \gamma t_o$ holds when the spaceship is moving. Therefore, there is the following relationship inside the moving spaceship.

$$c = \frac{l_o}{t_o} = \frac{l}{t} = \frac{(1/\gamma)l_o}{\gamma t_o} = \frac{1}{\gamma^2}\frac{l_o}{t_o} \neq c \tag{2}$$

If the length contraction theory is correct, the speed of light will inevitably become zero as the speed of the spaceship increases. The time that the light can move increases due to the time dilation. However, if the length of the spaceship decreases due to the length contraction, the speed of the light must be slow. This causes the speed of light to slow down and eventually become zero. Until now, for this reason, we have not been able to rationally understand the constancy of the speed of light. It is impossible for the speed of light to be constant if its length contracts while time is dilated. Anyone can know this through the above formula (2). If we admit that the length contraction theory is correct, the constancy of the speed of light will never be understood and will remain a mystery forever.

III. Theoretical Proof of Length Expansion

It is impossible for the speed of light to be zero in an inertial system. If the speed of light goes to zero, that is a sign that something is wrong. Considering the Planck unit system for simplicity of logic, *ℏ=g=c=1, so c=1*. If so, we can write it like this:

$$l = ct \tag{3}$$

$$l = t \tag{4}$$

In other words, when written in Planck units, the length is time. If time and length are the same, how can one contract and the other expand? It is a contradiction that length contraction and time dilation occur together. Therefore, if the expression $l = t$ holds, the variables on both sides must change together. If both sides are to be the same, one of ‘time dilation-length expansion’ and ‘time contraction-length contraction’ should be selected. Length contraction has never been experimentally proven so far, but time dilation has been proven through many experiments. Therefore, we must choose the ‘time dilation-length expansion’. If the time dilation is correct, then of course length expansion is also correct. This can be proved by a simple formula.

$$t = \gamma t_o \qquad \textit{time dilation} \tag{5}$$

$$ct = \gamma ct_o \qquad \textit{multiply both sides by c} \tag{6}$$

$$l = \gamma l_o \qquad \textit{length expansion} \tag{7}$$

If the time dilation is correct, the length expansion is also correct. It is not difficult to understand why the speed of light is always constant with respect to the light source or the observer, if we discard the idea that the length contraction is correct. First, looking at the mechanism of light propagation, it is helpful to determine which of the length contraction theory and the length expansion theory is the relativistically correct length. Here we will use only the two principles of relativity, no other assumptions are required. I have not yet explained why the speed of light is constant, so I will use the constancy of the speed of light. Let us consider that a system with a spherical mirror emits light at its origin. If the system were not moving, the reflective surface from which the light returned would form a sphere. Since a sphere is a set of points reaching the same distance from a point in 3D, the light reflecting from the surface must form a sphere.

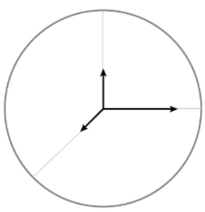

Fig. 2. Light reflective surface of rest system

But if this system is moving, everything is different. All photons depart from the same origin, travel the same distance, and then return to the same origin. Since the system is moving, the point when the photon departs and arrives is no longer in the same position.

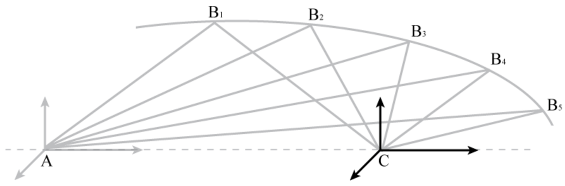

Fig. 3. Starting point A and ending point C

There are two different origins, the starting point (A) and the ending point (C). We are familiar with the geometric figures that explain this. It is either just an ellipse or an ellipsoid. The definition of an ellipse is ‘a closed plane curve generated by a point moving in such a way that the sums of its distances from two fixed points is a constant’. Light travels from the same origin and travels, but returns to the origin at the same time, so it naturally travels the same distance and returns. This description is exactly in line with the definition of an ellipse.

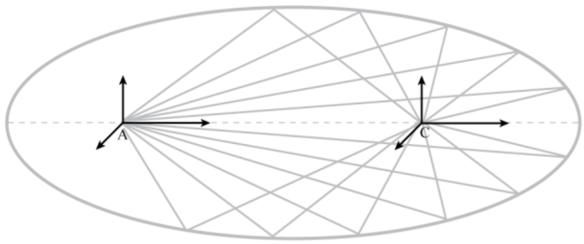

Fig. 4. Ellipse, a figure that appears when light reflecting surfaces are connected

The reflective surface was observed in the form of a sphere when it was stationary, but it was observed as an ellipsoid when it was in motion. Clearly, the sphere has stretched to become an ellipsoid. The principle of relativity supports the idea that the above sphere and ellipse are both physically correct. If only the principle of relativity and the constancy of the speed of light are applied, the length of the path of light in a moving system increases, not contracts. Since the round-trip path of light directly means the length, this means that the length is expanded. Let us call this ‘length expansion’. If this perspective is extended and applied to a general object such as a rocket, the rocket will show the following appearance.

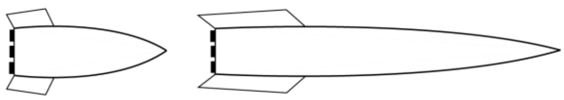

Fig. 5. Applying the propagation principle of light to general objects

Let us simplify the above situation. In the figure below, the left side shows the spherical mirror in the rest system, and the right side shows it in motion.

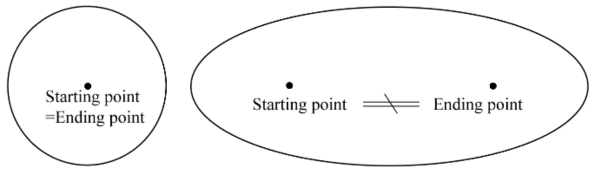

Fig. 6. Light propagation in the rest system and the moving system

If we observe a moving spherical mirror, the light will be emitted at the starting point, and the photons will return to the ending point. The reflective surface formed when the spherical mirror and light collide with each other becomes an ellipsoid with two focal points because the starting and ending points are different. When light is emitted from a stationary system with a spherical mirror, all photons will depart from and arrive at the same point at the same time. This is undoubtedly true. If the principle of relativity is correct, the circle and the ellipse in Figure 6 are exactly equivalent. A circle is an observation of light in a proper state, and an ellipse is an observation of the system in a state of motion. This position should hold equally even if the observers change each other. After all, the length of any object moving at relativistic speed does not contract, but rather expand. In reaching this conclusion, only the principle of relativity and the constancy of the speed of light were used, and no other hypotheses were introduced. Applying purely two principles, a relativistically just length always leads to expansion, not contraction. If length contraction theory is applied, it is impossible to derive the length of an object through the path of light in this way. If the length contraction theory is correct, there is an error in the constancy of the speed of light. Conversely, if the constancy of the speed of light is correct, there is an error in the length contraction theory. There must be an error in one of the two.

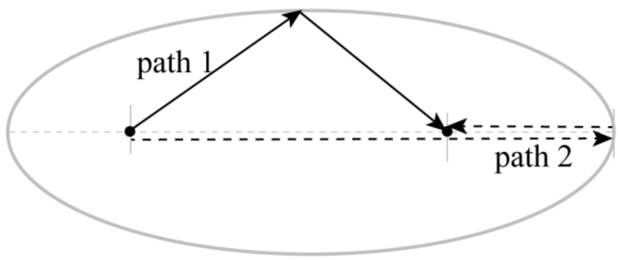

Fig. 7. Different paths through which light propagates

There are many different paths for light to travel back and forth between the two focal points of an ellipse. We will look at path 1 first. Path 1 shows the propagation path of light in space, not the path of light in space-time. However, this path represents the correct time and length. This path can be found in David Kutliroff's paper in 1964.[6] The path of light vibrating in his cylinder (light clock) corresponds to path 1 above. He derived the following equation to easily explain time dilation to high school students. He induced time dilation, but not length contraction.

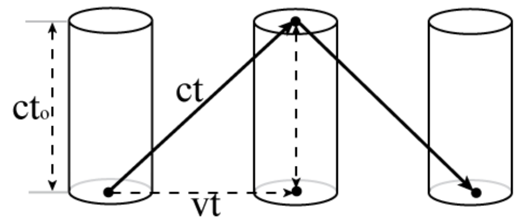

Fig. 8. Light emitted perpendicular to the direction of motion(path 1)

$$c^2t^2 = v^2t^2 + c^2{t_o}^2 \tag{8}$$

$$t = \frac{1}{\sqrt{1-\beta^2}}t_o \tag{9}$$

$$l = \frac{1}{\sqrt{1-\beta^2}}l_o \tag{10}$$

He stopped after deriving time dilation, but we can further derive the next equation, the length expansion equation. In the time dilation equation, the length expansion equation is derived by multiplying only the constant c on both sides. It is not possible to derive the length contraction in path 1 using several different methods. Of course, it is impossible to derive the length contraction from the above equation of Kutliroff. Only the length expansion can be derived. The reason is simple. This is because length contraction did not exist in nature from the beginning. Now examining the two equations, $t = \gamma t_o$ for time and $l = \gamma l_o$ for distance. The two expressions are similar in shape. If so, the speed of light is constant because it travels an increased distance for an increased amount of time. The equation is as follows.

$$c = \frac{l}{t} = \frac{\gamma l_o}{\gamma t_o} = \frac{l_o}{t_o} = c \tag{11}$$

The equation (9) derived by Kutliroff was considered only in space, not in space-time. He was lucky to derive a time dilation, but not so for the other paths. All other paths can represent their exact path only in space-time, not space. The next path we will look at is path 2. This path should be looked at in space-time, not space. It shows the path that light starts and returns parallel to the direction of the spaceship. We can look at the length of this path through the K calculus or through the wavelength of light. Here we will look through the wavelength of light. When light is emitted from the origin of the rest system, the forward and return wavelengths are the same length. However, it is known that the frequency of light in a moving system is as follows.[7] Wavelength is the reciprocal of frequency.

$$Approaching:\ \nu = \nu_o\sqrt{\frac{1+\beta}{1-\beta}} = K\nu_o \tag{12}$$

$$Separating:\ \nu = \nu_o\sqrt{\frac{1-\beta}{1+\beta}} = K^{-1}\,\nu_o \tag{13}$$

$$Transverse:\ \nu = \nu_o\sqrt{1-\beta^2} = \gamma^{-1}\,\nu_o \tag{14}$$

$$\left(K = \sqrt{\frac{1+\beta}{1-\beta}},\qquad \beta = \frac{v}{c}\right)$$

If we assume that the distance from the origin to the reflective surface is one wavelength, one wavelength can be expressed as follows. The figure below corresponds to path 2.

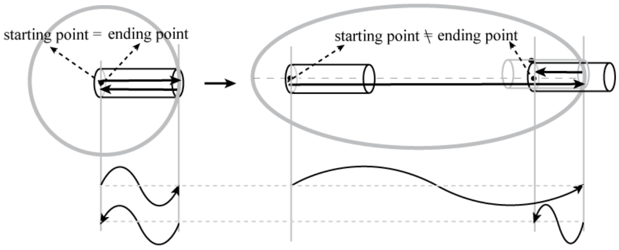

Fig. 9. Light emitted in parallel (path 2)

The path of this light is shown in the figure below when shown in the space-time diagram.

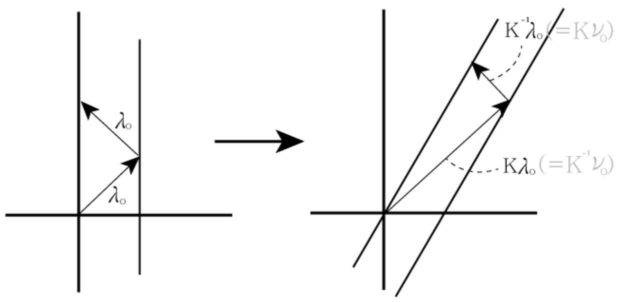

Fig. 10. Light emitted in parallel in the space-time diagram (path 2)

In a rest system, the wavelength is λ_o, the wavelength away from the observer is $K\lambda_o$, and the return wavelength is $K^{-1}\lambda_o$. Then, the average wavelength ($\bar{\lambda}$) of these two wavelengths becomes $\gamma\lambda_o$.

$$\bar{\lambda} = \frac{K\,\lambda_o + K^{-1}\lambda_o}{2} \tag{15}$$

$$= \frac{\sqrt{\frac{1+\beta}{1-\beta}}\,\lambda_o + \sqrt{\frac{1-\beta}{1+\beta}}\,\lambda_o}{2} \tag{16}$$

$$= \frac{1}{\sqrt{1-\beta^2}}\,\lambda_o \tag{17}$$

$$\therefore\ \bar{\lambda} = \gamma\lambda_o \tag{18}$$

Therefore, the length of all wavelengths in the moving system is $\gamma\lambda_o$, regardless of the direction, whether it is a wavelength that moves vertically in front of me or a wavelength that moves in parallel with me. The figure below shows path 1 and path 2 together.

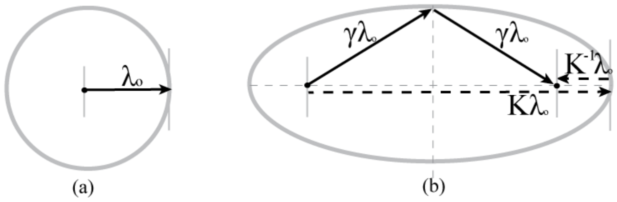

Fig. 11. (a) Wavelength length of a rest system
(b) The length of the wavelength of the moving system

We are not familiar with this, but this is the length expansion phenomenon. Although path 1 and path 2 have been discussed here, the relation $\lambda = \gamma\lambda_o$ holds for all paths propagating at all other angles. This is supported by the principle of relativity.

IV. Experimental proof of length expansion

For any scientific hypothesis to be widely accepted as a valid scientific theory, it must be a phenomenon that exists in nature. No matter how beautiful and logical a theory is, it is not a good theory if it does not actually exist in nature. In that sense, it is necessary to verify which length contraction or length expansion exists in nature. One of the ways to test the relativistic effect in the laboratory is the transverse Doppler effect. This is an observation of the frequency or wavelength of an object moving across in front of the observer. Suppose that an excited hydrogen atom passes in front of the observer at a relativistic speed. If so, the frequency of the hydrogen atom can be described as follows.[8]

$$\textit{Transverse Doppler Effect}:\ \nu = \nu_o\sqrt{1-\beta^2} \tag{19}$$

If the wavelength of the emitted light is shown as a picture, it is as follows.

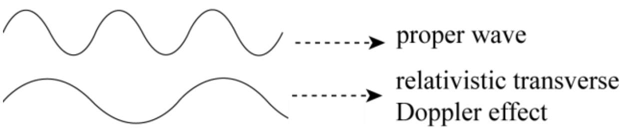

Fig. 12. Comparison of the classical Doppler effect and the relativistic transverse Doppler effect

Although the frequency of light emitted from fast moving hydrogen has decreased, the speed of light emitted is constant, so it is natural that the relationship is $c = \nu\lambda = \nu_o\lambda_o$. Then we can see that Equation (23) holds, and if this is converted to a general length rather than a wavelength, it can be written as Equation (24).

$$c = \lambda \nu \tag{20}$$

$$= \left(\lambda_o \frac{1}{\sqrt{1-\beta^2}}\right)\left(\nu_o\sqrt{1-\beta^2}\right) \tag{21}$$

$$= \lambda_o \nu_o = c \tag{22}$$

$$\therefore\ \lambda = \frac{1}{\sqrt{1-\beta^2}}\lambda_o \tag{23}$$

$$\therefore\ L = \frac{1}{\sqrt{1-\beta^2}}L_o \tag{24}$$

If we accept the transverse Doppler effect as relativistic experimental evidence, it is inevitably admitted that length expansion is also correct. The transverse Doppler effect is generally expressed as Equation (19). This is only the transverse Doppler effect expressed in terms of frequency and can be expressed in terms of wavelength, as shown in (23). If the transverse Doppler effect is not expressed as a frequency, but as a wavelength, it can be confirmed that the length expansion is correct immediately (24). There are several more examples that can experimentally prove the length expansion.

Second, in a particle accelerator, muon particles travel farther than classically expected. According to the experiment of Bailey, high-speed muon particles in the particle accelerator flew about 30 times longer than the classically predicted value.[9] From a non-relativistic interpretation, the flight distance of a muon particle is short, but the actual flight distance is longer. This is not evidence of length contraction, but evidence of length expansion. This is shown in the figure below to make it easier to understand. This experiment has many differences in the way of interpretation from the observation of David, the muon falling from the sky.[10] Unlike the experiment, it is impossible to claim that the observation was made from muon's point of view.

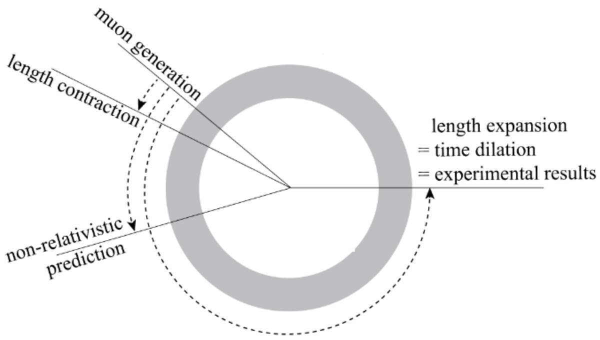

Fig. 13. Long-distance flight of muon in particle accelerator

The third evidence is the special relativistic effect of GPS satellites. GPS satellites are flying at an altitude of 20,000 km above sea level at a speed of 4 km/sec per second. They flew about 10m in a year longer than classically predicted.[4] Since the satellite has flown farther than the classical prediction, this is not evidence of length contraction, but evidence of length expansion. Ashby passed over the effect of length contraction in the process of finding the special relativity effect of GPS.[5] This is natural. Since the length contraction phenomenon does not exist from the beginning, it is impossible to confirm this experimentally. Anyone can easily find the effect of length expansion instead of the length contraction effect. Therefore, the satellite's long-distance flight is additional evidence of length expansion.

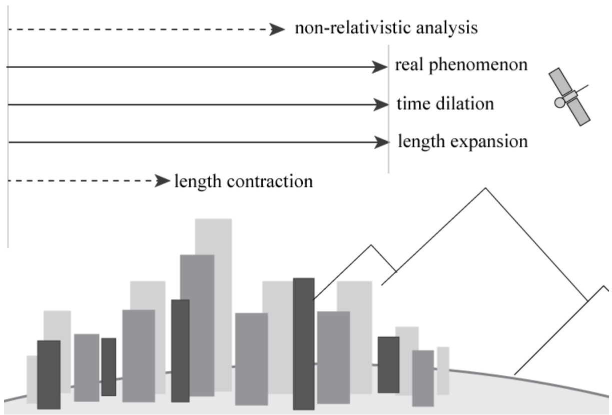

Fig. 14. Long-distance flight of GPS satellites

The fourth evidence is the phenomenon of muon particles reaching sea level. If this phenomenon is interpreted as a time dilation, it is interpreted naturally without any problems. If an observer on Earth observes a muon, the muon's flight time increases, so it can move longer and reach sea level. This is the correct interpretation. However, if this phenomenon is interpreted from the point of view of a muon, various complex problems arise. Those who support length contraction argue that from the muon's point of view, the Earth rushes to the muon at a relativistic speed, and the length of the Earth contracts like a pancake, resulting in the muon reaching sea level.[11] When explaining this phenomenon using time dilation, they explain it from the point of view of the Earth, and when explaining length contraction phenomenon, they explain it from the point of view of muon. Why is it suddenly changing the observer's point of view?

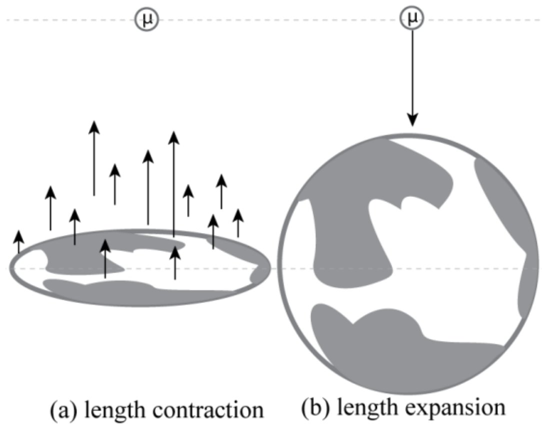

Fig. 15. Two interpretations of the muon paradox

To allow them to change the observer's point of view as they solve this problem, they must resolve the logical contradiction that arises immediately. Suppose a muon was created over the North Pole and entered Earth. At the same time, other muons can also be created from the opposite Antarctic side and enter Earth. So, if two muons at the North and South Poles at the same time fall to sea level, which muon should Earth rush toward? Should the earth be split into two? The Earth cannot ever be divided. The existence of a peaceful, undivided earth is evidence that the contraction is not correct.

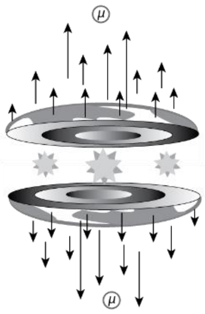

Fig. 16. Contradictions that arise when interpreting from the point of view of a muon

Today we generally have a unified view of the twin paradox. Considering only the special relativity effect, the twins who traveled on a rocket rather than the twins left on Earth experience a relativistic effect of time dilation. Based on these results, let us summarize other experiments in the theory of relativity. A frame to which the relativistic effect is not applied is called a '*lab frame*', and the frame to which the relativistic effect is applied is called a '*rocket frame*'. Then, the twins left on Earth belong to the lab frame, and the twins who traveled on a rocket belong to the rocket frame. Therefore, the system to which the Earth belongs becomes the lab frame, and small objects such as airplanes, satellites, etc. belong to the rocket frame. However, if the muon is observed with the theory of length contraction, the Earth is moving toward the muon, so the Earth corresponds to the rocket frame and the muon corresponds to the lab frame. This is the opposite of most other experiments in the theory of relativity.

Table 1. Lab frame and rocket frame

Experiments	Lab frame	Rocket frame
Hafele-Keating Experiment	Earth	Aircraft
Twin paradox	Earth	Rocket
Muon in particle accelerators	Earth	$\mu - Meson$
The relativistic effect of GPS satellites	Earth	Satellite
Muon paradox (length contraction)	$\mu - Meson$	Earth
Muon paradox (length expansion)	Earth	$\mu - Meson$

As we can see from Table 1, the Earth is the lab frame in all experiments. However, when interpreting the muon paradox from the perspective of length contraction theory, it is the only one that sets the earth as a rocket frame. This results in a series of fatal errors. If the length contraction theory is to be asserted to be correct, long-distance flight phenomena within particle accelerators, long-distance flight phenomena of GPS satellites, and the transverse Doppler effect must also be explained by the length contraction theory. However, to explain these phenomena in terms of length contraction, it is necessary to introduce far more unusual assumptions than the pancake-shaped earth. Conversely, if the length expansion theory is correct, then none of these strange assumptions is necessary, and all interpretations are explained naturally and in common sense.

V. Understanding the constancy of the speed of light

It is not difficult to understand the constancy of the speed of light if we admit that the correct length change in relativity is length expansion, not length contraction. First, it is important to clearly define the definitions of time and length, and second, strictly adhere to the principle of relativity. Then, the constancy of the speed of light is understood naturally. The key is the definition of time and length, and the principle of relativity. Let us define the round-trip time of the bottom and top of the light clock as unit time t_o, and the round-trip distance between the bottom and top as the unit distance l_o.

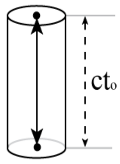

Fig. 17. Vertically oscillating light clock

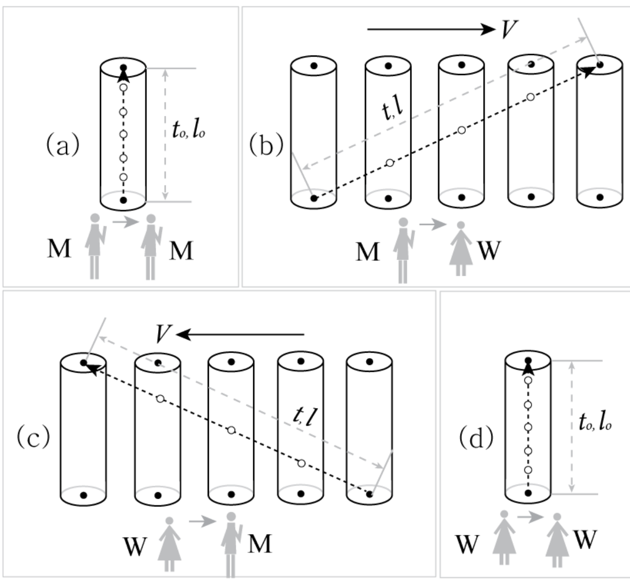

Fig. 18. Light clock vibrating in various directions

Let t, l be the unit time and unit distance of a moving light clock. Here, there is the following relationship between t and t_o, and between l and l_o.

$$t > t_o \tag{25}$$

$$l > l_o \tag{26}$$

It is as follows:

$$t = \gamma t_o \tag{27}$$

$$l = \gamma l_o \tag{28}$$

Light on an oblique path travels a longer distance and for a longer time than light on a proper path. This is because while the light propagates, the top of the light clock moves away from its original position, so the light travels a longer distance to catch up. The important notion is that the position of the observer who perceives that (a) and (b) in Figure 18 is correct and that of the observer who perceives that (c) and (d) are correct are the same. According to the principle of relativity, all inertial systems are equal, so it is impossible to determine whose observation is correct. It should not be forgotten that the length and time of the path are longer when observing the other, and the two observers are equal. Based on this, the following equation holds for the speed of light.

$$c = \frac{l}{t} = \frac{\gamma l_o}{\gamma t_o} = \frac{l_o}{t_o} = c \tag{29}$$

No matter what speed you move, time increases at the same rate as the length increases, so the speed of light is always constant. If we think in Plank unit, we can see that it is true. Therefore, the speed of light is always constant regardless of the speed of the object or the speed of the observer. If we set $c = 1$ in $l = ct$, we immediately see that $l = t$. If we believe that length contracts and time expands, the constancy of the speed of light will forever remain a mystery. And if space-time isotropy is established, this relationship must always be established for all directions. This is supported by the principle of relativity. If this is true, the final appearance of a light clock tilted in several directions would be as follows. where $\alpha,\ \delta,\ \varepsilon \ldots$ indicates different directions.

$$c = \frac{l}{t} = \frac{\alpha l_o}{\alpha t_o} = \frac{\delta l_o}{\delta t_o} = \frac{\varepsilon l_o}{\varepsilon t_o} = \cdots = \frac{l_o}{t_o} = c \tag{30}$$

The laws of physics are the same for all observers, and the time and length they observed are all justified from their point of view. In all these cases, the speed of light must be constant because the length also increases at the same rate as the increase in time. And if the principle of relativity is supported, (a), (b), (c), and (d) are all justified as unit physical quantities. Therefore, it is natural that each other's time and length seem to be larger. If we mark together the reflective surfaces of light propagating at all angles, it will look like the figure below.

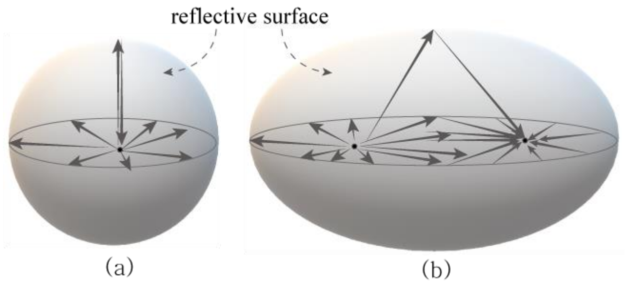

Fig. 19. Light oscillating in multiple directions.
(a) rest system, (b) moving system

Figure 19-(a) shows reflective surface in the rest system, and (b) shows the reflective surface in the moving system. Below, the path of light reciprocating in the direction of motion of the spherical mirror is shown in the space-time diagram.

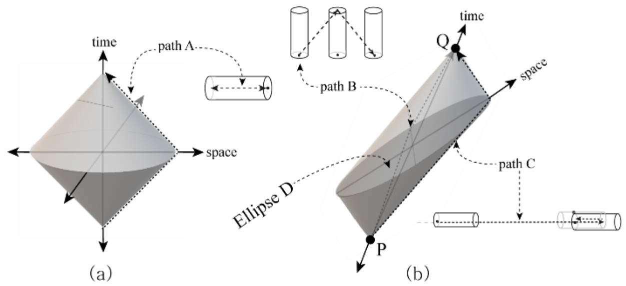

Fig. 20. The path of light in space-time.
(a) path A: A light clock vibrating at rest.
(b) Path B: Vertically vibrating light clock in moving system.
(c) Path C: Horizontally vibrating light clock in moving system.

Figure 20-(a) is a space-time diagram for the rest system and 20-(b) is a space-time diagram for moving system. The path of light induced by Kutliroff corresponds to path B, which is a special case. As can be seen from Figure 20-(b) path B, Figure 8 is the same as Path B. And the ellipse in Figure 4 is the same as the ellipse D. As shown in Figure 20, all photons depart from point P at the same time and arrive at point Q at the same time. Therefore, points P and Q must be the focal points of the ellipse, and the path lengths of all photons must be the same. Due to this, the constancy of the speed of light is understood by common sense.

VI. Conclusion

We have seen the propagation of light in a system moving at relativistic speed and the shape these photons form. As a result, it was found that the length expansion, not the length contraction, as we have known so far is correct. Since light travels for an increased amount of time by the length of the increased path, the speed of light is necessarily constant. Therefore, it was confirmed that the constancy of the speed of light is not a hidden property of light but is caused by the symmetrical properties of time and space. Then, in special relativity, we can reduce all unnecessary things. Excluding the constancy of the speed of light from the essential principle in the theory of relativity, only the principle of relativity can describe everything.

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