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Time dilation, time contraction and the motion direction of photon

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One of the concepts of Special relativity (SR) is time dilation which depends upon the second postulate of this theory that the speed of light c (= 2.99792×10^{8} m s^{-1}) is the same in all inertial frames of reference [1]. This theory states that the time interval ΔT as measured by an observer in a stationary frame (so-called the stationary observer) is longer than the time interval ΔT_0 measured by an observer in a frame moving (so-called the moving observer) with a relative speed v to the first one. (In relativity, subscript 0 usually denotes the rest time and distance intervals). Of course, this initial choice which frame is stationary and which is moving is arbitrary and it could be *vice versa*. SR asserts that ΔT_0 and ΔT are related by the the Lorentz-Einstein factor or the time dilation factor $\gamma = 1/\sqrt{1-v^2/c^2}$ and expressed by the following equation:

$$\Delta T/\Delta T_0 = 1/\sqrt{1-v^2/c^2}$$

The traditionall (thought) light clock experiment is usually used to demonstrate time dilation in numerous introductory textbooks of modern physics and in related teaching and learning materials/media. This experiment is based on the SR (classical) assumption that the motion direction of photon depends on an (inertial) frame of reference. However, there is no experimental piece of evidence supporting this assumption [1]. Employing the same assumption, we have demonstrated that the two light clocks of different constructions and different photon paths show time dilation (the traditional light clock) or time contraction (so-called the "novel" light clock) [2]. For this reason, in this report, we are mainly concerned about the dependence of time dilation and time contraction from the motion direction of photon. For the sake of readers, in the first part of this report, we will "run" the traditional and "novel" light clock experiments based on the SR assumption.

The traditional light clock is made from two plane mirrors M_1 and M_2 facing each other at the distance L_0, as shown in Fig. 1a. The lower mirror M_1 then emits a photon at 90 degrees towards the upper mirror M_2. If the clock is resting the photon for a time interval ΔT_0 reaches M_2 traveling a distance $L_0 = c\Delta T_0$.

Suppose now that the same clock is moving with a relative speed v in the direction of the positive x-axis, Fig. 1b. SR states that for a stationary observer (hereinafter the stationary observer) the photon emitted by M_1 travels a larger distance $L = c\Delta T$. Simultaneously, the clock moves a distance $l = v\Delta T$. An observer moving with the clock (hereinafter the moving observer) records that the same photon travels a distance $L_0 = c\Delta T_0$. According to SR, ΔT and ΔT_0 are related by the relativistic time dilation expression:

$$\Delta T/\Delta T_0 = \sqrt{1-v^2/c^2}$$

with a time dilation factor $\gamma = 1/\sqrt{1-v^2/c^2}$. It follows from this equation that when $v \to 0$, $\Delta T \to \Delta T_0$ and when $v \to c$, $\Delta T \to \infty$.

We next consider the thought experiment using the "novel" light clock which moves with a relative speed v along the positive x-axis. This clock is similar to the traditional light clock except that the two plane parallel mirrors M_1 and M_2 not facing each other and are spaced a distance L_0 apart, as shown in Fig. 1c [see also reference 2]. The stationary and moving observers record that the photon of M_1 travels $L = c\Delta T$ and $L_0 = c\Delta T_0$, respectfully[1]. For the same time, the clock covers a distance $l = v\Delta T$.

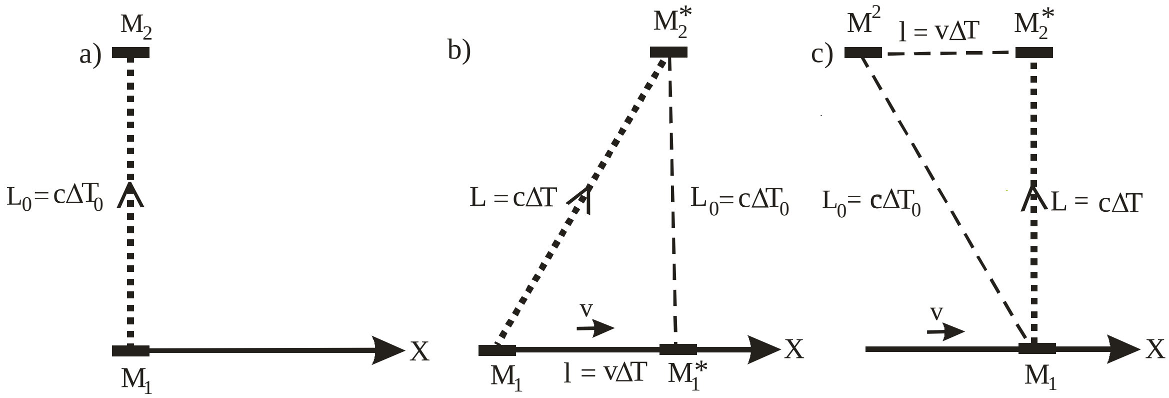

Figure 1: The traditional (a/b) and "novel" (c) light clock experiments. These experiments are based on the (classical) SR assumption. (M_1/M_2* are the subsequent positions of mirrors, and M^2, the former position of M_2). For further details see the text.*

According to Pythagora's theorem:

$$L_0^2 = L^2 + l^2 = c^2\Delta T_0^2 = c^2\Delta T^2 + v^2\Delta T^2.$$

After a little algebra, we obtain the time contraction equation which relates ΔT and ΔT_0:

$$\Delta T/\Delta T_0 = 1/\sqrt{(1 + v^2/c^2)}$$

with a time contraction factor $\gamma_C = 1/\sqrt{(1 + v^2/c^2)}$. It follows from this equation that when $v \to 0$, $\Delta T \to \Delta T_0$ and when $v \to c$, $\Delta T \to \Delta T_0/\sqrt{2}$. (In other words, $\Delta T_0 \geq \Delta T > \Delta T_0/\sqrt{2}$). This puts on ΔT a lower limit $\Delta T_0/\sqrt{2}$ and an upper limit ΔT_0. In contrast, to the traditional light experiment where for ΔT the lower limit is ΔT_0 and the upper limit is infinite.

In our previous note [1], we reported the time contraction factor equals to $\gamma_C = \sqrt{1-v^2/c^2}$. This is, however, the case only if $l = v\Delta T_0$ which contradicts to the relativity of time.

[1] If the clock is at rest, the photon travels a distance L_0.

Thus, the above light clock experiments based on the SR assumption is “thorn” between time dilation or time contraction (with the limit range from $\Delta T < \Delta T_0/\sqrt{2}$ to $\Delta T = \Delta T_0$).

In the second part of this report, we will “perform” the thought experiments but assuming that the motion direction of photon is independent of a frame of reference.

If the traditional light clock is moving with a relative speed v along the positive x-axis, Fig. 2a[2]. The stationary/moving observers record that for ΔT_0 the photon of M_1 reaches the former position of M_2 (labeled as M^2) traveling a distance $L_0 = c\Delta T_0$. For the same time period, the clock covers a distance $l = v\Delta T_0$. So, there is no time dilation or time contraction.

Let us now “run” the thought experiment when the “novel” light clock is moving, Fig. 2b. If the clock is resting the photon of M_1 for a time interval ΔT_0 travels $L_0 = c\Delta T_0$ (to reach M_2). The stationary/moving observers record that the photon of M_1 travels $L_0 = c\Delta T_0$ in order to reach M^2. For the same time period, the clock covers a distance $l = v\Delta T_0$. So again, there is no time dilation or contraction. Thus, if we negate the SR assumption then the light clock experiments show no time dilation or time contraction between two reference frames moving relative to each other.

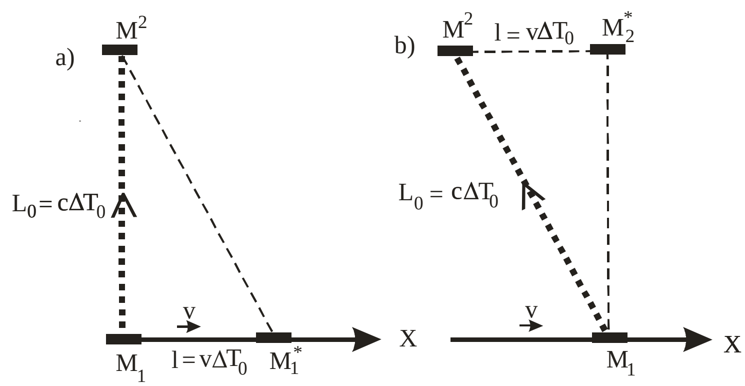

Figure 2: The traditional (a) and “novel”(b) light clock experiments. These experiments are based on the assumption that the motion direction of photon is independent of a frame of reference. (M_1/M_2* are the subsequent positions of mirrors, and* M^2*, the former position of* M_2*). For further details see the text.*

As we noted previously, the traditional and “novel” light clock experiments, based on the SR assumption, display an unsurmountable ambiguity between time dilation or time contraction. On the other hand, the light clock experiments based on the assumption that the motion direction of photon is independent of a frame of reference is not ambiguous at all: there is no time dilation or time contraction.

Finally, as far as we are aware, there is no yet experimental evidence for the SR concept of time dilation. Indeed, the Ives–Stilwell experiment [3, 4] is commonly accepted to have proved the reality of time dilation. Since then many of this type experiments have been performed with increased precision [5]. However, it appears that all these experiments cannot be regarded as a verification of time dilation [6-10].

[2] If the clock is at rest, the photon travels a distance L_0.

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