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Relativistic Light Clock Experiments: Time Dilation or Time Contraction?

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One of the concepts of Special relativity (SR) is time dilation which depends upon the second postulate of SR that the speed of light c (= 3×10^8 m $\sec^{-1}$) is the same in all inertial frames of reference [1]. According to this theory if ΔT_0 is the (proper) time interval of an event that occurs at the same position in an inertial frame, then the (improper) time interval ΔT of the same event has a longer duration as measured by an observer in an inertial frame that is in uniform motion relative to the first frame. Of course, this initial choice of which of frames is stationary and which is moving is arbitrary and it could be vice versa. It appears that time dilation is successfully tested by - the muon experiment [2] and the experiment of synchronizing two atomic clocks [3].

Many physics textbooks demonstrate time dilation using a device known as a light clock. In this note, we will consider a set of thought experiments for time intervals ΔT_0 and ΔT employing the two different light clocks. Of course, you may find some of the following derivations in many elementary physics texts.

The traditional light clock consists of two-plane parallel mirrors M_1 and M_2 facing each other at a distance d apart as in Fig. 1a. The lower mirror M_1 has a light source at the center that emits a photon (or light signal/pulse) at 90 degrees in the direction of mirror M_2. For the sake of simplicity, we will consider in this note only the time interval needed for the photon to travel from mirror M_1 to mirror M_2. For the light clock at rest, this is the (proper) time interval $\Delta T_0 = d/c$.

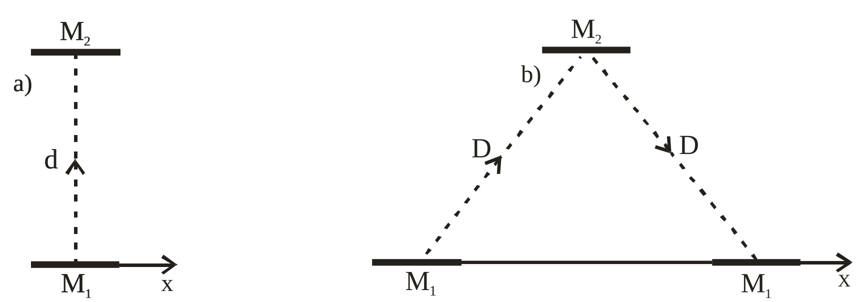

Fig. 1. The traditional light clock: (a) no relative motion and (b) the clock moving at speed υ.

Now allow the same clock to be moving with a relative speed v horizontally in the direction of the positive x-axis, Fig. 1b. The photon will now travel a larger distance D, and thus will take a longer time: the (improper) time interval $\Delta T = D/c$. Elementary SR shows that ΔT_0 and ΔT are related by the following formula: $\Delta T = \Delta T_0/\sqrt{(1 - \upsilon^2/c^2)}$ where $1/\sqrt{(1 - \upsilon^2/c^2)}$ is the Lorentz factor or the time dilation factor. Thus, the stationary observer measures time dilation for the moving classical light clock.

Let us now perform the thought experiments using a somewhat different ("novel") light clock. 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 they are at a distance D away, as shown in Fig. 2a. The proper time interval required for the photon to reach mirror M_2 is now $\Delta T_0 = D/c$.

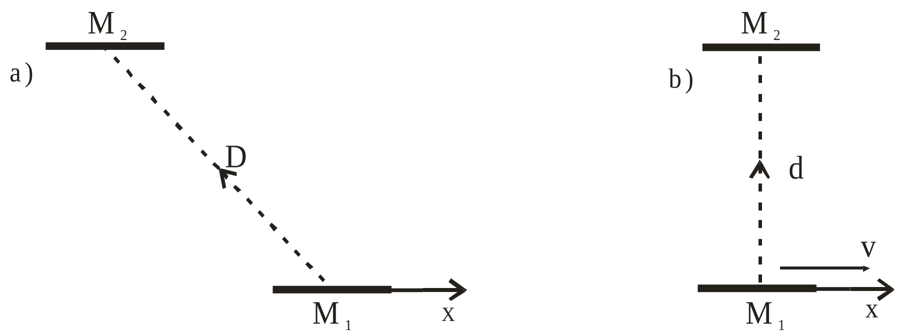

Fig. 2. The "novel" light clock: (a) no relative motion and (b) the clock moving at speed υ.

In the next thought experiment, we assume that the "novel" light clock moves, as the previously classical light clock, in the direction of the positive x-axis with the same speed υ. The stationary observer observes that the photon travels from mirror M_1 to mirror M_2 following the path shown in Fig. 2b. She/he now measures the improper time interval $\Delta T = d/c$. ΔT_0 and ΔT are now related with the following expression: $\Delta T_0 = \Delta T\sqrt{(1 - \upsilon^2/c^2)}$. In other words, the stationary observer measures time contraction with the "novel" light clock.

Thus, the two light clocks give different results. The classical light clock shows time dilation but the "novel" light clock *time contraction*. The question is now which of these two clocks is relativistically right?

References

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[3] J. Hafele. and R. Keating, *Around the world atomic clocks: observed relativistic time gains,* Science 177, 167–168 (1972).