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Traditional Light Clock Experiment: Principle of Energy Conservation and Special Relativity

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The Principle of energy conservation is one of the basic laws of physics. It states that the total energy of an isolated system remains constant or conserved over time.

Time dilation is one important effect of the Special theory of relativity. This effect depends upon the second postulate of this theory that the speed of light c ($\approx 3\times10^8$ m sec^{-1}) is the same in all inertial frames of reference. According to this theory, the time interval T_0 an event measured by an observer in an inertial frame stationary relative to the event is shorter than the time interval T of the same event measured by an observer in an inertial frame moving with a relative speed υ to the same event.

According to the Lorentz-Einstein transformations, T_0 and T are related by the time dilation expression

$$T = T_0/\sqrt{(1 - \upsilon^2/c^2)} \quad \ldots (1)$$

where $1/\sqrt{(1 - \upsilon/c^2)}$ is the time dilation or the Lorentz factor. The effects of time dilation only start to become measurable at speeds close to the speed of light c, i. e. at so-called relativistic speeds.

In a previous communication [1], we performed a light clock experiment dealing with the "colors" of the incidence and reflected lights when the light clock momentarily stops moving (or comes to rest). A similar experiment will be considered in this communication but in its initial stage, Fig. 1.

There are two plane-parallel mirrors M_1 and M_2 facing each other at a distance d apart. The lower mirror M_1 has a light source at the center that emits a monoenergetic light beam at 90 degrees in the direction of mirror M_2, Fig. 1a. For the sake of simplicity, we will only consider the travel of the light beam from mirror M_1 to mirror M_2. For the light clock at rest, the time interval is then $T_0 = d/c$.

Now allow the same light clock to be moving with a certain relative speed υ horizontally in the direction of the positive x-axis, Fig. 1b. The beam will now travel the larger distance D. Thus it will take a longer time interval T = D/c. An observer comoving with the light clock would measure T_0 (= d/c).

As T_0 and T are related by the time dilation eqn. (1), a simple derivation shows that

$$d/D\ (= T_0/T) = \sqrt{(1 - \upsilon^2/c^2)} \quad \ldots (2).$$

As we stated previously, a stationary observer concludes that the number of wavelengths would be identical for the light clock at rest and when it is moving with a constant speed υ [1]. In expression,

$$d = N\lambda_d \text{ and } D = N\lambda_D.$$

Combining eqns. (1) and (2), we get

$$\lambda_d = \lambda_D\sqrt{(1 - \upsilon^2/c^2)}.$$

We know that the frequency equals the speed of light divided by the wavelength (or $\nu = c/\lambda$) and after a bit of algebra, we find

$$\nu = \nu_0\sqrt{[(1 - \upsilon^2/c^2)]}$$

where ν_0 and ν are the frequency of the light beam emitted by the light clock at rest and in motion, respectively. If $\upsilon \to 0$, $\nu \to \nu_0$ and if $\upsilon \to c$, $\nu \to 0$.

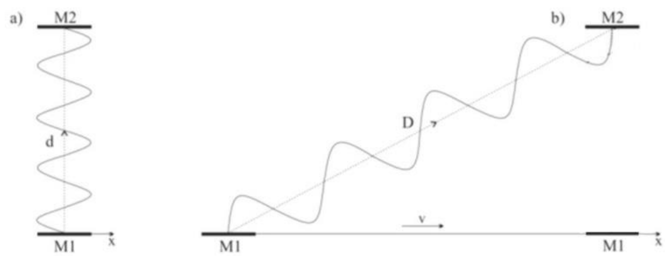

Fig. 1. The light clock is positioned perpendicular to the x-axis. (a): No relative motion. (b): the light clock is moving at speed υ.

Multiplying this equation with Planck's constant h (= 6.63×10^{-34} J sec) and after some rearrangement, we get

$$h\nu = h\nu_0\sqrt{[(1 - \upsilon^2/c^2)]}$$

where $h\nu_0$ is the intrinsic energy of the beam photon before emitted by the light clock at rest and $h\nu$ is its intrinsic energy when this light clock is in motion with a constant speed υ. If $\upsilon \to 0$, $h\nu \to h\nu_0$ and if $\upsilon \to c$, $h\nu \to 0$. So, the energy of the beam photon $h\nu$ decreases as the speed υ decreases and tends to zero if it approaches the speed of light c. Thus, as space for the stationary observer appears (relativistically) to stretch out the beam photon loses its energy. This loss can be mathematically expressed as

$$\Delta E = h\nu_0 - h\nu.$$

Of course, a beam photon cannot lose energy except unless it collides with a particle. Now the question arises how to explain the energy loss of the beam photon emitted by the light clock source?

A simple solution is that it is converted into the kinetic energy of this clock denoted as E_K or

$$\Delta E\ (= h\nu_0 - h\nu) = E_K \quad \ldots (2).$$

This is by the Principle of energy conservation.

The relativistic kinetic energy of the light clock (or in general of a massive particle) is given by

$$E_K = \{[1/[\sqrt{(1- \upsilon^2/c^2)}] - 1\}m_0c^2$$

where m_0 is the rest mass of the light clock. If the speed of the light clock υ tends to zero (or $\upsilon \rightarrow 0$) then E_K (= $h\nu_0 - h\nu$) $\rightarrow 0$. When the speed of the source υ approaches the speed of light c then E_K (= $h\nu_0 - h\nu$) $\rightarrow \infty$, this contradicts the above conclusion for $\upsilon \rightarrow c$ drawn from eqn. (1) based on the Principle of energy conservation. Moreover, the value of $h\nu_0$ (or ν_0) is initially fixed in the above thought experiment there is no way to make $h\nu_0 - h\nu \rightarrow \infty$.

To resolve this contradiction there are two options. The first one is that the Principle of energy conservation is not valid for the classical light clock experiment. Conservation of energy is one of the fundamental laws of physics. It is not violated by any known process.

The second option is that the classical light clock experiment is unrealistic. Indeed, in several previous communications [1- 5], we have expressed some doubts about the validity of this experiment. In the author's opinion of this communication, the second option appears much more preferable.

References

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