INTERNATIONAL ATOMIC TIME AND THE ONE-WAY SPEED OF LIGHT

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Abstract

We show that the accuracy of the international atomic time (TAI) system imposes no conditions on the one-way speed of light. The TAI is given by a network of atomic clocks distributed around the world which communicate with one another using radio synchronization signals. The synchronization signals sent by a transmitting station always arrive at the receiving station 'on time,' at any time of day and in any season, despite the motion of the earth. For certain authors this means that these signals propagate isotropically (with one-way velocity *c*), even on earth. In fact this may not be so; we shall show that the proper working of the TAI network says nothing about the one-way velocity *c*, as it is consistent with another theory, empirically equivalent to special relativity, in which the one-way speed of light has a directional dependence in moving frames.

1. Introduction

There is a whole network of atomic clocks around the world and they are continuously connected via radio by signals of synchronization: they supply the international atomic time (TAI, Temps Atomique Internationale).

In Sexl and Schmidt's opinion [1] the proper functioning of this system demonstrates that the light has the same speed *c* in every direction. They consider two stations with atomic clocks, separated by a distance *d* (measured on the Earth). The first one transmits synchronization signals at regular time intervals to the other one. 12 hours after the first synchronization, due to the Earth rotation, the radio signal goes to the opposite direction of the previous one, and if its velocity were not constant, a phase-difference between the clocks would be detected. This does not happen so, they say, the velocity of light is isotropic also on the Earth which moves into the ether at least at its orbital velocity $v \cong 30$ Km/sec.

The situation, in two generic moments of synchronization, might be the same as shown in Fig.1 (we neglect the Earth curvature in the path of lenght *d*). The synchronization of the atomic clocks, experimentally detected, is an objective fact and must be predicted by observers at rest in every system of reference. We will name S the inertial system, which moves at velocity *v* in accordance to the Earth but, of course, does not rotate.

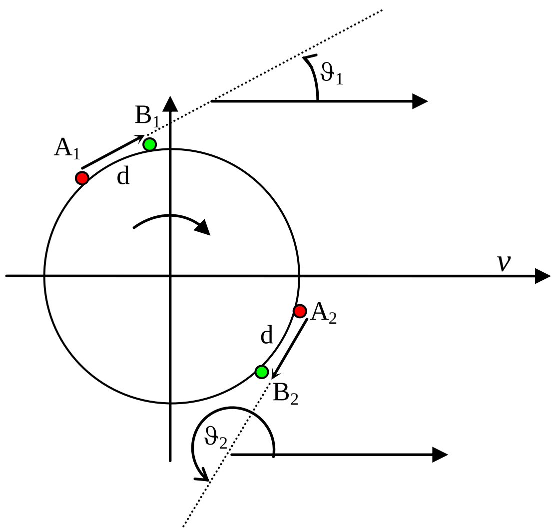

Fig.1: Generic situation during two subsequent moments of synchronization between the stations

In this system we are going to consider the experiment, at first by using the Special Relativity (SR) and the Lorentz transformations, then by the theory proposed by F.Selleri and its "inertial transformations" [2].
In such a theory the concepts of absolute space and time are retained and, consequentially, the one way velocity of light **does not** have the same value in all of inertial systems. Similar conclusions have been obtained by other authors [3]-[6].

2. Standard relativistic approach

1. The light has the same velocity (c) in every direction and for everyone, so also for the two stations, no matter where they are placed.
2. The time which the signal takes will be the same in the two cases of Fig. 1.
3. The movement of the two stations due to rotation, no matter what effect it might have on the clocks, will be the same for both of them, since there are no privileged directions and the relative motions are symmetric.
4. This means that no time difference will be detected by the two clocks.

3. Review of the inertial transformations

Postulating:

(i) Linearity of the transformations among inertial systems in relative motion;
(ii) Homogeneity of space and time;
(iii) Existence of an isotropic inertial system S_0 (ether) in which the one way speed of light is c in every direction;
(iv) Invariance of the speed of light on closed paths in every inertial system;
(v) Time dilation of all the clocks in motion with respect to S_0 by the factor:

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \text{where} \qquad \beta = v/c$$

and v is the clock velocity measured in S_0, one obtains the following general transformations between any system S, in “absolute” motion with velocity v (in the direction of $+x$) and S_0:

$$\begin{cases} x = \gamma(x_0 - vt_0) \\ t = \dfrac{t_0}{\gamma} + e_1(x_0 - vt_0) \end{cases} \tag{1}$$

e_1 is a parameter that remains free. The transformations (1) explain all experimental evidences independently of the chosen value of e_1.

If we presume that light propagates isotropically in one way mode in every inertial system, we will adopt Einstein's synchronization where e_1 will be set as $e_1 = -\dfrac{\beta\gamma}{c}$. In this case (and only in this one), the principle of relativity is valid in its strong form and the (1) become the Lorentz transformations.

There are good reasons to set $e_1 = 0$ and so (1) become the inertial transformations [2]:

$$\begin{cases} x = \gamma(x_0 - vt_0) \\ t = \dfrac{t_0}{\gamma} \end{cases} \tag{2}$$

This choice, without contrasting with any experimental data, gives a different vision of the world, pretty much different from the relativistic one:

An absolute space (ether) and an absolute time exist, those of S_0

The rods in absolute motion, at v velocity, contract by a factor $1/\gamma$ and the clocks in absolute motion decrease their pace by the same factor $1/\gamma$, as in SR

But, differently from SR, these effects are not "of perspective", they are real and absolute: the system in absolute motion measures the *extension* of the rods and the *increase* of the clock pace of the (S_0) system in absolute rest. These variations are of the same extent as the contractions measured by S_0. To prove that it is sufficient to invert the (2).

In fact, the (2) between two S_1 and S_2 systems, both in absolute motion (with v_1 and v_2 velocity) become:

$$\begin{cases} x_2 = \dfrac{\gamma_2}{\gamma_1} x_1 + \gamma_1\gamma_2 (v_1 - v_2) t_1 \\ t_2 = \dfrac{\gamma_1}{\gamma_2} t_1 \end{cases} \qquad \begin{cases} x_1 = \dfrac{\gamma_1}{\gamma_2} x_2 + \gamma_1\gamma_2 (v_2 - v_1) t_2 \\ t_1 = \dfrac{\gamma_2}{\gamma_1} t_2 \end{cases} \tag{3}$$

where $$\gamma_1 = \frac{1}{\sqrt{1 - v_1^2 / c^2}} \quad ; \quad \gamma_2 = \frac{1}{\sqrt{1 - v_2^2 / c^2}} \tag{4}$$

From (3) we obtain that lengths and durations transform by multiplying them by the ratio between the two system contraction factors.

The absolute velocities are composed in a Galilean mode, but the measurements of velocity in absolute motion systems are made false because of the contraction of rods in the motion direction ($1/\gamma$) and of the slowing down of clocks ($1/\gamma$). Therefore, velocities which are parallel to the absolute v of the moving system S will be measured, in S itself, as increased by a factor γ^2 (contracted rods and dilated time), the ones which are perpendicular to v, will be increased by a factor γ (only dilated time).

A velocity, in S, in an arbitrary direction, can be decomposed into three orthogonal components (Fig.2); we transform it to S_0 (absolute velocities) by dividing the v parallel component by γ^2 and the perpendicular ones by γ; we sum it (in a Galilean mode) to the v of the S system and we compose it again using Pythagoras.

If a body p moves at a u_p velocity, with respect to the S system in absolute motion at v velocity, its absolute velocity v_p will be:

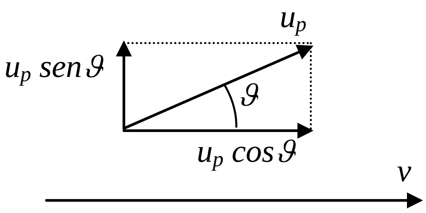

Fig.2: Components of a generic velocity

$$v_p = \sqrt{\left(v + \frac{u_p \cos\vartheta}{\gamma^2}\right)^2 + \left(\frac{u_p \,\mathrm{sen}\,\vartheta}{\gamma}\right)^2} \qquad \text{(where } \vartheta \text{ is the angle between } u_p \text{ and } v) \tag{5}$$

As a consequence of (5), the velocity of light is isotropic in S_0 only: for the system S in absolute motion, replacing u_p and v_p by $c_{(\vartheta)}$ and c respectively, one gets

$$c_{(\vartheta)} = \frac{c}{1 + \beta\cos\vartheta} \tag{6}$$

Of course, from (6) we can obtain a velocity on closed paths equal to c in every inertial frame.

4. Application to the rotating Earth

The two synchronization signals of Fig.1 propagate, in S, respectively, at:

$$c_1 = \frac{c}{1+\beta\cos\vartheta_1} \qquad \text{and} \qquad c_2 = \frac{c}{1+\beta\cos\vartheta_2} \tag{7}$$

while the arrival station moves away at the rotation velocity.
But S (which synchronized its clocks according to the inertial transformations) does not detect a uniform rotation velocity. Let us explain why.
We set in S a segment P-Q with a unitary length, and when the terrestrial station A (at velocity u_A) passes close to P, P itself sends out a light signal (at c_A velocity). In Q we measure the time lag between the arrival of the light signal and the passage, still in Q, of the station A.
This delay will be the difference between the propagation times: $1/u_A - 1/c_A$. This measurement is made with one clock only, so the result cannot depend on the synchronization used and must be the same that would be obtained according to SR. Therefore, this delay does not depend on the position or the direction of the velocities used in the measurements.
So, u_1 and u_2 being the two velocities of Earth on two generic positions 1 and 2, the time differences must be equal:

$$\frac{1}{u_1} - \frac{1}{c_1} = \frac{1}{u_2} - \frac{1}{c_2} \tag{8}$$

c_1 being different from c_2 , u_1 will also be different from u_2, as is immediately clear from (8). Substituting (7) in (8), one easily gets:

$$\frac{c-\beta u_1\cos\vartheta_1}{u_1} = \frac{c-\beta u_2\cos\vartheta_2}{u_2} \tag{9}$$

a result which will soon be useful.

Let us apply what we exposed to the physical context.
According to (5), if u_1 and u_2 are the rotation velocities of the stations (measured in S) in the two cases, the corresponding absolute velocities v_1 and v_2 will be:

$$v_1 = \sqrt{\left(v+\frac{u_1\cos\vartheta_1}{\gamma^2}\right)^2 + \left(\frac{u_1\,\mathrm{sen}\,\vartheta_1}{\gamma}\right)^2} \quad ; \quad v_2 = \sqrt{\left(v+\frac{u_2\cos\vartheta_2}{\gamma^2}\right)^2 + \left(\frac{u_2\,\mathrm{sen}\,\vartheta_2}{\gamma}\right)^2} \tag{10}$$

A short direct calculation of γ_1^{-2} and γ_2^{-2} starting from (4) and (10) gives

$$\begin{cases} \gamma_1^{-2} = \dfrac{1-\beta^2}{c^2}\left[(c-\beta u_1\cos\vartheta_1)^2 - u_1^2\right] \\ \gamma_2^{-2} = \dfrac{1-\beta^2}{c^2}\left[(c-\beta u_2\cos\vartheta_2)^2 - u_2^2\right] \end{cases} \tag{11}$$

whence, taking (9) into account:

$$\gamma_1^{-2} = \frac{u_1^2}{u_2^2}\gamma_2^{-2} \tag{12}$$

Therefore:

$$\gamma_1 u_1 = \gamma_2 u_2 \tag{13}$$

The condition (13) allows us to reason as follows.

The contractions of bodies in motion are due to the absolute velocities and these velocities, in the considered cases of Fig.1, are different: in the first case rotation contributes to an increase of v_1, while in the second case it contributes to a decrease of v_2 (in the whole upper hemisphere of the picture the absolute velocities are larger than in the lower hemisphere).

So the contractions are different and, being also real, they produce a dishomogeneity of the body itself (Fig. 3): the distances among the atoms are smaller in position 1 (and in the whole upper hemisphere) than in position 2 (in the whole lower hemisphere). What has to be kept uniform is not the velocity of rotation but the "flow", the flux of matter, the number of atoms that traverse any given section in the unit of time. The (13) ensures exactly this.

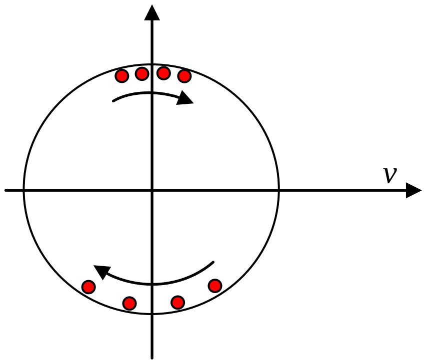

Fig.3: Dishomogeneity of a rotating and translating body

The quantity of matter traversing an arbitrary section (for instance the v perpendicular axis of Fig.3, which passes through the center) in the unit of time has to be constant. In the opposite case, the rotation would have a translation component which would shift, and cumulate in the time, some matter either back or forth, violating, in this way, the conservation of the quantity of motion of the Earth in S (which, by definition, must be zero). This condition is also necessary because an observer on S, who counts the number of atoms (or the number of the unitary rods, placed longitudinally on the Earth circumference) which he sees passing in the unit of time, finds the same value in each point: *when the atoms (rods) are more contracted, they go slower.*

It is important to notice that, while the measurement of the rotation velocity u depends on the used transformations, the isotropy of the flow of atoms (or rods) around the circumference is objective and cannot depend on the used transformations, hence the result must be the same which would be obtained by a "relativistic" observer who, of course, measures an isotropical flow.

5. The time differences

Let us apply, at last, the inertial transformations (3) in S and calculate the times taken by the two synchronization signals to travel the distance d as ratios between distances between the two stations and the velocities of light.

$$t_{c1} = \frac{\gamma}{\gamma_1}\frac{d}{c_1 - u_1} \quad ; \quad t_{c2} = \frac{\gamma}{\gamma_2}\frac{d}{c_2 - u_2}\,. \tag{14}$$

These times will be registered by the stations on the Earth, the former slowed down by γ/γ_1 and the latter by γ/γ_2 . Their difference will be (clocks desynchronization):

$$\Delta t'_c = \frac{\gamma}{\gamma_1} t_{c1} - \frac{\gamma}{\gamma_2} t_{c2} = \frac{\gamma^2}{\gamma_1^2} \frac{d}{c_1 - u_1} - \frac{\gamma^2}{\gamma_2^2} \frac{d}{c_2 - u_2}, \tag{15}$$

station A and the second synchronization signal being in *advance* by such a value.

But there is a second phenomenon which also produces a desynchronization, and to quantify that we will place ourselves again in S.

The paths followed by the stations, due to the rotation of Earth, are not the same: the symmetry is broken by the presence of a privileged direction, that of the absolute *v* of translation with which the rotation velocity composes. The different paths followed by the stations produce different slowing downs on their own clocks, the absolute velocities being different. This point is crucial (Fig. 4)

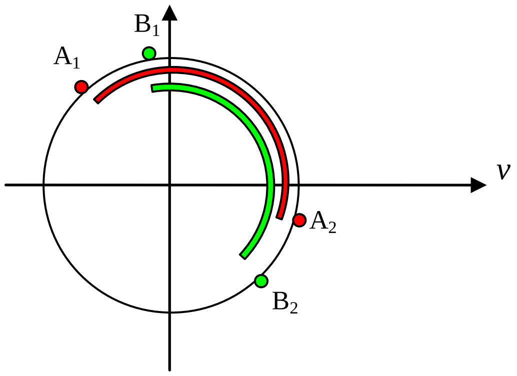

Fig.4: The absolute paths of the two stations are different

The segment B_1-A_2 is common to the two paths and does not introduce any difference.

The segment A_1-B_1 is travelled only by the station A at a faster (absolute) velocity, compared to the segment A_2-B_2 which is travelled only by the station B at a lower (absolute) velocity. The times marked by the two clocks, in these two segments, will be different: the station A, going faster, will show a *delay*.

The observer in S calculates the times taken to cover the two segments, still as ratios between distances and velocities:

$$t_{u1} = \frac{\gamma}{\gamma_1} \frac{d}{u_1} \qquad ; \qquad t_{u2} = \frac{\gamma}{\gamma_2} \frac{d}{u_2} \tag{16}$$

As we did earlier, we calculate the difference between these times, but now being considered in the terrestrial stations:

$$\Delta t'_u = \frac{\gamma}{\gamma_1} t_{u1} - \frac{\gamma}{\gamma_2} t_{u2} = \frac{\gamma^2}{\gamma_1^2} \frac{d}{u_1} - \frac{\gamma^2}{\gamma_2^2} \frac{d}{u_2} \qquad (17).$$

Not only the distance among atoms (length of rods), but also the pace of clocks in a system that rotates and translates relative to the ether, is submitted to cyclic variations due to the composition of the rotation and translation movements.

We now show that the two time delays cancel, so that:

$$\Delta t'_c + \Delta t'_u = 0 \qquad (18).$$

From the definitions (15) and (17) one easily gets

$$\Delta t'_c + \Delta t'_u = \frac{d\gamma^2}{\gamma_1^2} \left[\frac{1}{c_1 - u_1} + \frac{1}{u_1} \right] - \frac{d\gamma^2}{\gamma_2^2} \left[\frac{1}{c_2 - u_2} + \frac{1}{u_2} \right] \tag{19}$$

which is the same as

$$\Delta t'_c + \Delta t'_u = \frac{d\gamma^2}{\gamma_1^2 u_1^2}\left[\frac{u_1^2}{c_1 - u_1} + u_1\right] - \frac{d\gamma^2}{\gamma_2^2 u_2^2}\left[\frac{u_2^2}{c_2 - u_2} + u_2\right] \quad (20)$$

The first (second) terms in parenthesis in (20) is equal to the inverse left hand side (right hand side) of Eq. (8). Therefore these two terms are equal. Also the multiplying factors are equal because of Eq. (13). Thus the right hand side of (20), being the difference of two equal terms, vanishes and Eq. (18) holds.

Therefore the two stations will not detect, in any case, any out of phase condition between the clocks. The different times taken by the two synchronization signals are compensated by the variations of the rates of the two clocks, these being in an absolute motion composed of a uniform and a variable velocity in direction (and modulus).

6. Conclusions

- With Lorentz's transformations *c* is isotropic in every system and the clocks must be synchronous.
- With the inertial transformations we have two out of phase effects on the clocks: the first one because of the *c* anisotropy, the other one because of the variations in the clocks pace, due to their different absolute *v*. The two effects are equal and opposite and the clocks appear to be synchronized again.
- Sexl and Schmidt demonstrate that Galileo's transformations do not function, but Lorenz's transformations are not the only ones which explain these matters. They are also explained by Selleri's theory.
- The two theories are equivalent, and the proper functioning of the world time system does not say anything about the one-way light-speed and cannot establish which is "true".

I would have many reasons to be grateful to Prof. F. Selleri but I will mention only one: he made me understand that no matter how fundamental and tested a theory is, it must not become object of faith.

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