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# THE RATE OF THE PASSAGE OF TIME IN INERTIAL COORDINATE SYSTEMS

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## ABSTRACT

*A comparison of the rate of the passage of time was made based on the results of the Michelson-Morley experiment and the Albert Einstein postulate of the invariance of the speed of light propagation in inertial coordinate systems, stationary (x,y,z,t) and moving (x',y',z',t'). It was found that the time flows at the same speed in a moving and stationary systems.*

## INTRODUCTION

In 1905 a condition has been formulated by Albert Einstein [1] for the simultaneity of events occurring in the inertial systems of reference moving relative to each other in a vacuum with a uniform rectilinear motion at a constant speed "v".

This condition implies that a light ray emitted from the point A, which is the origin of a stationary system of reference (x, y, z, t) takes exactly the same time to reach the point B, which is the origin of a moving system of reference (x', y', z', t') moving in space rectilinearly at a constant speed "v" relative to the stationary system , as a light ray sent at the same time in the opposite direction from the point B to the point A.

This condition derives directly from the experiment conducted by Michelson-Morley in 1887 in a laboratory in Cleveland (USA), which has been repeated many times throughout the year during the Earth's movement around the Sun, and therefore in a situation where the speed of the laboratory in space oscillated between 29,3 km/s (at aphelion) – 30,3km/s (at perihelion)[2].

The Michelson-Morley experiment described in the manual [3] has been repeatedly conducted in other laboratories around the word, yielding the same results, namely that the speed of visible light, i.e. electromagnetic rays in the range from 380 nm (violet) to 780 nm (red), is independent of whether they are emitted from a stationary or moving source.

## DESCRIPTION OF THE VIRTUAL EXPERIENCES

Starting from the axiom [1], which has not been questioned so far, that light emitted by a stationary source moves in a vacuum with the same speed "c" as a light emitted by a moving light source moving uniformly in a straight line with a constant speed "v", we will analyze the consequences of such a statement below.

We consider two Cartesian coordinate systems, one of which A is stationary and the other B is movable and moves in a uniform rectilinear motion relative to the system A with a constant velocity "v".

In each of the coordinate systems (A and B), there is an identical clock counting the passage of time in a given system. The readings from the clock in the stationary system A can be transposed from A to B at the speed "c" along the path AB, and conversely, the reading from B to A can be transposed from B to A along the same path, but in the opposite direction also at the speed "c". The transmission of readings along the same path $\underline{AB(t)}=\underline{BA(t)}$ takes place simultaneously but in the opposite directions.

We carry out a balance of time measured in the A coordinate system and the B coordinate system for two different readings on identical clocks at moments marked No1 and No.2

At moment No.1 the clock A displays time $t_{A1}$ and the clock B displays time $t_{B1}$. To transpose the hour indication $t_{A1}$ from the system A to the hour indication in the system B, we need transposition time $\Delta t_{A1B1}$, which when added to $t_{A1}$ we will receive the time $t_{B1}$, according to the formula:

$$t_{A1} + \Delta t_{A1B1} = t_{B1} \qquad (1)$$

At moment No.1 we have on the clock B displays $t_{B1}$. To transpose the hour indication $t_{B1}$ from the cock B to the hour in the system A, transposition time $\Delta t_{B1A1}$ is needed, which when added to $t_{B1}$ will give the time $t_{A1}$ in A. We write this with the formula:

$$t_{B1} + \Delta t_{B1A1} = t_{A1} \qquad (2)$$

The distance between coordinate systems A and B is a function of time and changes uniformly along a straight line connecting the origins of these systems at a speed "v". However, for any given moment in time, it can be stated that $\underline{AB(t)} = \underline{BA\ (t)}$, i.e. the distance measured from A to B is at any given moment equal to distance measured in the opposite direction from B to A. Based on Michelson-Morley experiment, Albert Einstein formulated the postulate [1] : "*light is always propagated in empty space with a definite velocity "c" which is independent of the state of motion of the emitting body"*

Based on the above condition it can therefore be written that time needed at the moment No.1 to travel from A to B at a speed "c" measured on clock A in coordinate system A will be equal to the time needed to travel from B to A measured too on clock A in coordinate system A, i.e.:

$$\Delta t_{A1B1} = \Delta t_{B1A1} \qquad (3)$$

Balancing the time from the side of system A and from the side of system B, i.e. subtracting the times from the side of system A and from the side of system B, equation (1) minus equation (2) we get:

$$t_{A1} - t_{B1} + \Delta t_{A1B1} - \Delta t_{B1A1} = t_{B1} - t_{A1} \qquad (4)$$

Using the equality (3) and performing arithmetic operations we get:

$$t_{A1} = t_{B1} \qquad (5)$$

At any other arbitrarily chosen moment No.2 the time $t_{A2}$ is displayed on the clock A in system A, while the time $t_{B2}$ is displayed on the clock B in system B.

For moment No2 we perform a time balance in systems A and B similarly to moment No1.

The transposition of the display $t_{A2}$ from the clock A to system B is carried out according to the following formula:

$$t_{A2} + \Delta t_{A2B2} = t_{B2} \tag{6}$$

Whereas to transpose the $t_{B2}$ indication in system B to the hour in system A, the time $\Delta t_{B2A2}$ transposition time is needed, which shows the following formula:

$$t_{B2} + \Delta t_{B2A2} = t_{A2} \tag{7}$$

Similarly to moment No.1, we can write an equation for moment No.2. The time needed to travel from A to B at a speed “c” measured on clock A in the coordinate system A and in the opposite direction from B to A, (where at this moment there is $\underline{A_2B_2} = \underline{B_2A_2}$,) measured too on the clock A in the coordinate system A is equal:

$$\Delta t_{A2B2} = \Delta t_{B2A2} \tag{8}$$

Balancing the time from the side of system A and from the side of system B, i.e. subtracting the times from the side of system A and from the side of system B, equation (6) minus equation (7) we get;

$$t_{A2} - t_{B2} + \Delta t_{A2B2} - \Delta t_{B2A2} = t_{B2} - t_{A2} \tag{9}$$

Using the equality (8) and performing arithmetic operations we get:

$$t_{A2} = t_{B2} \tag{10}$$

Base on the correspondences of the clock readings at moment No1 and moment No2 in systems A and B found by equations (5) and (10), we can determine the appropriate time intervals determined by these readings:

$$t_{A2} - t_{A1} = t_{B2} - t_{B1} \tag{11}$$

The above equation shows that the time interval measured on clock A in system A between moment No.2 and moment No.1 is the same as the time interval between moment No2 and No.1 measured on clock B in system B. Due to the fact that moments No.1 and No.2 were chosen arbitrarily, for any numbers denoting hours on the clock, its means that the equation is satisfied for general numbers denoting hours and satisfying this equation. It should be noted that the considerations were carried out on general numbers and therefore describe arbitrary time intervals.

From the above it follows that time flows at the same speed in both the stationary and moving coordinate systems, so it can be measured both by means of a clock placed in system A or clock placed in system B.

The courses of the light ray sent from system A to B and in the opposite direction can also be considered using the notations consistent with notations used in the work [1]. In this case the condition of simultaneity of events in systems A and B seen from the system A was written as follows :

$$t_B - t_A = t^I_A - t_B \tag{12}$$

where:

$t_A$ – indication on the clock in system A at the moment of sending a light pulse from system A to system B.

$t_B$ – indication on the clock in system B at the moment when a light pulse arrives from A to B and reflects this pulse back towards system A.

$t^I_A$ – indication on the clock in system A at the moment of arrival of the reflected pulse from B to A.

The light pulse sent from A travels the distance $\underline{A_1B_1}$ with a speed “c”, so to reach system A it needs time $\underline{A_1B_1}$ /c – moment No.1 .The return path of light pulse after reflection changes because the systems move with respect to each other at a constant speed “v” and the reflected light pulse has to cover another distance namely $\underline{B_2A_2}$ , which takes time $\underline{B_2A_2}$ /c – moment No.2.

We write it down with the following equation:

$$t_A + \underline{A_1B_1}/c + \underline{B_2A_2}/c = t^I_A \tag{13}$$

Therefore, the time that will expire in system A, measured on clock A, needed for the light pulse to travel from A to B and then return back to system A , can be written by the following equation:

$$t^I_A - t_A = \underline{A_1B_1}/c + \underline{B_2A_2}/c \tag{14}$$

Similarly to equation (12) the simultaneity condition of events in systems A and B seen in system B is written in the form of following equation:

$$t_a - t_b = t^I_b - t_a \tag{15}$$

where:

$t_b$ – indication on the clock in system B at the moment of sending a light pulse from system B to system A.

$t_a$ – indication on the clock in system A at the moment when a light pulse arrives from B to A and reflects this pulse back towards system B

$t^I_b$ – indication on the clock in system B at the moment of arrival of the reflected pulse from A to B.

The light pulse sent from B travels the distance $\underline{B_1A_1}$ (moment No.1) with a speed "c", so to reach system A it needs time $\underline{B_1A_1}$ /c.

The return path of light pulse after reflection changes because the systems move with respect to each other at a constant speed "v" and the reflected light pulse has to cover another distance namely $\underline{A_2B_2}$ (moment No.2) , which takes time $\underline{A_2B_2}$ /c.

The time that clock B will indicate in system B after the pulse previously sent to A returns in B can be written with the following equation:

$$t^I_b = t_b + \underline{B_1A_1}/c + \underline{A_2B_2}/c \qquad (16)$$

This time will be the sum of the reading on the clock B at the moment of sending the pulse towards the system A and the time needed to travel the distance $\underline{B_1A_1}$ (moment No.1) which takes time $\underline{B_1A_1}$/c and time needed to travel distance $\underline{A_2B_2}$ (moment No.2) which takes time $\underline{A_2B_2}$ /c.

Hence, after arithmetic transformation of (16), it is possible to determine the time period measured on clock B in system B from the moment of sending the light pulse towards system A until it returns after being reflected in system A.

$$t^I_b - t_b = \underline{B_1A_1}/c + \underline{A_2B_2}/c \qquad (17)$$

It should be noted that $\underline{A_1B_1} = \underline{B_1A_1}$ (moment No.1) denotes the mutual distance between coordinate systems A and B at the moment when the light pulses reach the turning point at the moment of reflection, one sent from A to B the other sent from B to A

$$\text{Because of } \underline{A_1B_1}=\underline{B_1A_1} \quad \text{it results} \quad \underline{A_1B_1}/c = \underline{B_1A_1}/c \qquad (18)$$

$\underline{A_2B_2} = \underline{B_2A_2}$ denote the mutual distance between coordinate systems A and B at the moment when these impulses reach, after reflection, each of them to its own system from which it was emitted (moment No.2)

$$\text{Because of } \underline{B_2A_2} = \underline{A_2B_2} \quad \text{it results} \quad \underline{B_2A_2}/c=\underline{A_2B_2}/c \qquad (19)$$

Here, we introduce the designation $\alpha = A_1B_1 = B_1A_1$ representing the distance between the origins of coordinate systems A and B at the moment described above as moment No.1 and the designation $\beta = A_2B_2 = B_2A_2$ representing the distance between the origins of coordinate systems A and B at the moment described as moment No.2. and we enter the introduced symbols into formulas (14) and (17) we get:

for (14) $$t^I_A - t_A = \alpha/c + \beta/c \qquad (20)$$

for (17) $$t^I_b - t_b = \alpha/c + \beta/c \qquad (21)$$

The following identity follows from comparing the (20) and (21):

$$t^I_A - t_A = t^I_b - t_b \qquad (22)$$

and the equation means that the clock A in a system A showed the same time interval as a clock B in a system B. counting from the moment of sending the light pulse to the moment of its return in a given coordinate system.

This effect was to be expected because each impulse had to travel the same distance and moved at the same speed "c".

The fact that the distance between coordinate systems A and B changes is of no importance here, because when the same moment is established for initiating the emission of light pulses in both systems, the paths $\underline{ABA}$ and $\underline{BAB}$ change uniformly in an identical way for each of the pulses. Identical speed on a road of the same length means that travel times for such roads are identical.

For this reason since clock A in a system A measured the same time period to cover the distance $\underline{ABA}$ as a clock B in system B measured the same time period to cover the same distance only in the opposite direction $\underline{BAB}$, this means that clocks in both coordinate systems A and B measure the time equally and time flows in system A with the same speed as time in system B.

Instead of light pulse, any electromagnetic wave of any frequency can be used to transpose the signal, because, as is now commonly known, all electromagnetic waves, regardless of frequency, travel at the same speed "c" in a vacuum.

## SUMMARY

The above considerations are based solely on the postulate quoted from Albert Einstein, which indicated the independence of the speed of light propagation "c" from the speed "v" of the body emitting this wave in a vacuum-filled space.

It should be noted that the Doppler effect has no influence on the speed of light propagation in this case and does not occur in these calculations. The rate of the passage of time in the stationary and moving inertial systems is thus the same, as presented in the paper [4].

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