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# A Time Machine in an Anisotropic Spacetime

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**Abstract**

**Problem statement.** According to the special theory of relativity, all physical processes are slower than stationary processes should be as measured in the laboratory frame of reference. The effect of time dilation, along with gravitational deceleration, is taken into account in global satellite navigation systems, such as GPS. Controlling the clock rate should also be possible if we assume the existence of certain topological features of the universal space-time continuum. The results of experiments to measure the detection time of a neutrino burst by detectors of neutrinos and gravitational waves may be explained assuming that the space of the terrestrial observer has anisotropic properties.

**Purpose.** To consider the possibility of controlling the rate of physical processes in an anisotropic space.

**Results.** It is shown that in a space-time continuum with dipole anisotropy, or when a spacecraft moves at a relativistic speed with respect to the cosmic microwave background, not only dilation may be experienced but also acceleration of clock rate in cyclically moving clocks or acceleration of physical processes. Efficient operation of the machine may be assured by moving at a constant speed along a closed trajectory, for example, an elliptical one.

**Practical significance.** During long space flights, when the crew and on-board equipment are in a time-dilated state, it should be possible to accelerate the operation rates for the equipment which moves cyclically along the spacecraft velocity vector with respect to the CMB radiation.

***Keywords***

*Cosmic microwave background, invariance, differentials of transformations, inertial frames of reference, accelerated motion, time dilation*

***For citation***

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A brief version in Russian is given at the end of the article

## Introduction

The main principles of spatiotemporal description of physical processes are generalizing the Lorentz group, employing equation invariants, and investigating mathematical admissibility for possible transformations [1]. Nevertheless, we may assume that certain physical experiments could involve manifestations of non-invariant properties of transformations [2], without violating general interval invariance.

Suppose it is necessary to determine the total differential of a function of several variables, which requires finding all partial derivatives of the original transformation. If a variable is kept constant, then the partial derivative will be zero, so when switching to another inertial frame of reference (IFR), we will obtain a new form for transformations which should preserve shape invariance of the differential.

A physical experiment involves the measurement of an inexact differential when, for example, we measure the time intervals of synchronized clocks at rest with respect to different moving IFRs. In this case, we can compare these intervals by means of transforming the partial differentials of the general transformations, where the partial derivatives of the coordinates are zero. Experiments of this type include comparing the lifetime of mesons moving in an air shower and mesons produced in a laboratory IFR. Such experiments feature comparison of instantaneous clock readings (for example, duration of the ensemble-averaged elementary decay for a particle) in different IFRs.

The physical origin of the difference between transformations for total transformations in which some variables are reset to zero and transformations of partial differentials may be explained in the following way.

In the first case, the partial derivatives preceding the differentials of the variables depend on the rotation in 4-dimensional space; they are physically interdependent for the case of two arbitrary moving IFRs corresponding to two rotations in the original spacetime. At the same time, of course, any new 4-space will be built on independent variables, considering mathematical dependence.

In the second case, since we only carry out single-scale renormalization, variable confounding does not occur and partial differentials of physical variables in different IFRs are strictly independent.

In other words, if in the first case the time dilation of the moving clock can be partially compensated by its displacement, in the second case this cannot happen in principle. Moreover, in both cases, the expressions for total differentials must be represented as invariants.

Consider the experiment to measure the detection time of the SN1987A neutrino burst by detectors of neutrinos and gravitational waves, in which an abnormally long delay in the signal detection time by widely spaced detectors was measured [3], [4]. The flare was detected by gravitational antennas in Maryland and Rome, as well as a neutrino detector at Mont Blanc, all of which are synchronised to universal time. Over 2 hours, the readings of the detectors correlate with the signal delay of 1.1 s as recorded by the neutrino detector. The probability of a random coincidence concerning the readings is $10^{-5}$.

The measured delay in the detection time for a signal propagating at the speed of light in a vacuum in any IFR cannot be explained by a time delay resulting from signal propagation between detectors and means that the measurement procedure used and the corresponding coordinate transformations should be analyzed.

We should point out that it is possible for the source of the signal recorded by the detectors at Mont Blanc to be not the SN1987A flare, but another physical source. Therefore, in our paper, calculating the delay in recording a supernova flare via ground-based detectors is regarded as an example of considering a measurement procedure that requires taking into account non-invariant transformation properties.

The foundation of the measurement procedure used in this experiment is comparing instantaneous eigenparameter values in physical processes (proper time of spatially separated clocks) at different points in time; it is based on a procedure for synchronizing remote clocks. This means that we need to derive transformations that can be applied in the case of a procedure for comparing instantaneous eigenparameter values in different moving IFRs at different time points.

Our analysis shows that the desired transformations are additional to the main group on which they are built; they may be obtained by keeping the temporal and spatial coordinates physically independent when switching to an arbitrary IFR. Such transformations are precisely consistent with the results of transforming the group currently used with respect to the original IFR; they agree with known experiments and can be used to expand the Lorentz group.

The physical interpretation of variations in the transformation form becomes clear if we assume that the transformation form undergoes simplification and takes a more classical, simpler form when describing processes in an IFR at rest in the physical space of fundamental interactions, i.e. in the family of preferred IFRs. Previously, it was believed that considering these IFRs is meaningless, as a preferred IFR is impossible to determine. However, after the discovery of the CMB radiation, an IFR relative to which the CMB radiation displays minimum potential energy is usually treated as a preferred IFR.

The CMBR anisotropy has a dipole component, which may be interpreted as a result of the observer moving with respect to the background of the cosmic thermal radiation. Another possible interpretation of the anisotropy observed in cosmic radiation properties may be a global anisotropy of spacetime. A consequence of both interpretations is the local clock rate changing.

We know what the physical mechanism for changing the rate of a process in motion is. It has been known since the foundations of the Special Theory of Relativity were developed and implies time dilation as measured by a moving clock. Traveling at a high velocity allows the astronaut returning to Earth to arrive into its future. Time dilation of moving clocks was experimentally verified in experiments [5]. The second method of controlling time is based on the assumption that there exist certain topological features known as “wormholes” connecting different spacetime regions [6, 7]. However, in order for the “wormhole” not to collapse before an astronaut can pass through it, negative energy density is required to exist, which is unlikely for macroscopic time and justifies being skeptical of such constructions [8].

Let us assume that a space-time continuum featuring dipole anisotropy is equivalent to the space of an observer moving at a constant velocity in an isotropic physical space (PS) of the propagation of fundamental interactions.

It is of interest to consider the following questions: how the clock rate depends on the motion velocity relative to the direction and magnitude of anisotropy, as well as whether it is possible to accelerate the rate of physical processes in cyclical motion. It should be noted that we will introduce a metric tensor of a special kind in order to consider these problems; using a metric tensor with other anisotropic properties will change the expected magnitude of the effect of time contraction or dilation.

Following the method described in [9], we obtain a metric with a dipole anisotropy equivalent to translational motion in a flat space. Let us assume that the variables $\vec{r}$, $t$ correspond to the IFR at rest in the PS, while $\vec{r}_i$ and $t_i$ correspond to IFRs in arbitrary motion.

According to the Moeller method, it is possible to write inverse transforms for time

$$t = \gamma_i t_i + \gamma_i \frac{\left(\vec{r}_i, \vec{V}_i\right)}{c^2}, \tag{1}$$

where $\alpha_i = \gamma_i - 1$, $\gamma_i^{-2} = 1 - \beta_i^2$, $\beta_i = V_i / c$, $i = 1,2$.

Here $\vec{r}_i$ sets the position of the clock $T_i$ in the $i$-th IFR. The vector $\vec{V}_i$ is the velocity of the moving IFR numbered $i$, measured in the original IFR, so the dot product $\left(\vec{r}_i, \vec{V}_i\right) > 0$ if the $i$-th IFR is moving in the direction $\vec{r}_i$. The values $t$ and $t_i$, $r_i$ are provided by the synchronization procedure, therefore (1) links the observed values in proper coordinate systems.

Let us compare proper readings of the clocks $T_1$ and $T_2$, both at rest in two moving IFRs. Considering the spatial coordinates $\vec{r}_i$ constant, for partial time differentials it is possible to write for $i$=1, 2

$$\gamma_1 dt_1 = \gamma_2 dt_2 . \tag{2}$$

Note that, since the synchronization procedure is not violated, the expressions for the proper time intervals will correspond to the values observed.

Using the velocity transformation expression

$$\vec{\beta}_2 = a\vec{\beta}_0 + b\vec{\beta}_1, \tag{3}$$

$$a = \frac{\sqrt{1-\beta_1^2}}{1+\left(\vec{\beta}_1, \vec{\beta}_0\right)}, \quad b = \frac{\left(\vec{\beta}_1, \vec{\beta}_0\right)\left(1-\sqrt{1-\beta_1^2}\right)+1}{1+\left(\vec{\beta}_1, \vec{\beta}_0\right)},$$

(2) leads to

$$dt_1 = \frac{1+\left(\vec{\beta}_0, \vec{\beta}_1\right)}{\sqrt{1-\beta_0^2}} dt_2 . \tag{4}$$

Here $\vec{\beta}_0$ is the relative velocity of the 2nd IFR with respect to the 1st.

This expression has a form different from the form $dt = \gamma_i dt_i$ that follows from (1). To find the transformations of the time coordinate, we state the desired transformations in the form

$$dt_1 = \gamma_0 \left(1 + \left(\vec{\beta}_0, \vec{\beta}_1\right)\right) dt_2 + \tilde{\lambda} \frac{\gamma_0}{c} \left(d\vec{r}_2, \vec{\beta}_0\right), \tag{5}$$

where $\tilde{\lambda}$ is a coefficient compensating for the time coordinate contribution to this transformation.

In order for the result of the transformations to match the result of the transformations of the invariant form, the following condition should be met:

$$\left(1+\left(\vec{\beta}_0,\vec{\beta}_1\right)\right)dt_2+\tilde{\lambda}\frac{1}{c}\left(d\vec{r}_2,\vec{\beta}_0\right)=dt_2+\frac{1}{c}\left(d\vec{r}_2,\vec{\beta}_0\right). \tag{6}$$

Solving for $\tilde{\lambda}$, we obtain

$$\tilde{\lambda}=1-\frac{\left(\vec{\beta}_0,\vec{\beta}_1\right)cdt_2}{\left(d\vec{r}_2,\vec{\beta}_0\right)}. \tag{7}$$

Taking into account that $cdt_2=\left|d\vec{r}_2\right|$ and $\frac{d\vec{r}_2}{\left|d\vec{r}_2\right|}=d\vec{r}_2^{\,n}$, we substitute (7) in (5).

$$dt_1=\gamma_0\left(1+\left(\vec{\beta}_0,\vec{\beta}_1\right)\right)dt_2+\frac{\gamma_0}{c}\left(1+\frac{\left(\vec{\beta}_0,\vec{\beta}_1\right)}{\left(d\vec{r}_2^{\,n},\vec{\beta}_0\right)}\right)\left(d\vec{r}_2,\vec{\beta}_0\right), \tag{8}$$

In a similar fashion, it is possible to derive transformations for radius vectors [10].
After the transformations, we obtain

$$dt_1=\gamma_0\left(1+\left(\vec{\beta}_0,\vec{\beta}_1\right)\right)dt_2+\frac{\gamma_0}{c}\frac{1+\beta_1}{\beta_1}\left(\vec{\beta}_0,\vec{\beta}_1\right)dr_2, \tag{9}$$

It can be seen that when $T_1$ and $T_2$ move along $OX$ then $\left(\vec{\beta}_0,\vec{\beta}_1\right)=\beta_0\beta_1$, and the coordinate transformation tensor will have the form

$$g_\mu^\nu=\begin{vmatrix}\gamma_0\left(1+\beta_1\beta_0\right) & 0 & 0 & \gamma_0V_0\left(1-\beta_1\right)\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ \gamma_0\frac{V_0}{c^2}\left(1-\beta_1\right) & 0 & 0 & \gamma_0\left(1+\beta_1\beta_0\right)\end{vmatrix}. \tag{10}$$

Using (10) and the expression for the interval squared

$$dS_1^2=dx_1^2+dy_1^2+dz_1^2-c^2dt_1^2,$$

it is possible to discover that even in the particular case of motion along $OX$ this expression is not form-invariant

$$dS_1^2=\alpha_0dx_2^2+dy_2^2+dz_2^2-c^2\alpha_0dt_2^2,$$

where $\alpha_0=\gamma_0\left[\left(1+\beta_1\beta_0\right)^2-\beta_0^2\left(1-\beta_1\right)^2\right]$.

In the case of $\beta_1=0$ the expression for the interval switches to the standard form. However, when switching to any other IFR pair, only $\beta_1$ and $\beta_0$ will change, while the form of the expression for $dS_1^2$ will not. This definition of invariance may be named “special interval invariance”.

In the case of uniformly accelerated rectilinear motion of the clock, in the absence of gravitational fields, only the diagonal components of the metric tensor are non-zero, and the expression for the time interval measured by the clock $T_2$ has the form

$$t_2=\int_0^{t_1}\frac{dt_1}{g_1^1}=\int_0^{t_1}\frac{dt_1}{\gamma_0\left(1+\vec{\beta}_1\vec{\beta}_0\right)}. \tag{11}$$

Let a clock $T_1$ be at rest in the IFR with the coordinate basis $X_1Y_1Z_1$, while another clock $T_0$ undergoes a cyclic motion relative to the first clock along the length $OX_1$ (Fig. 1).

The length of an extended contour, the transverse dimensions of which can be neglected, is equal to $2l$. We consider $l$ to be sufficiently large, so that the reversal time is negligible for a first-order estimation. The clock rates $T_0$ in the directions $-OX_1$ and $OX_1$ equal $V_{01}$ and $V_{02}$ respectively. The time interval of the moving clock $T_0$ as measured by the clock $T_1$ is equal to $\Delta t_1$ and $\Delta t_2$. Then the period is equal to

$$T_1 = \Delta t_1 + \Delta t_2 = \frac{l}{c}\frac{\beta_{01}+\beta_{02}}{\beta_{01}\beta_{02}}. \quad (12)$$

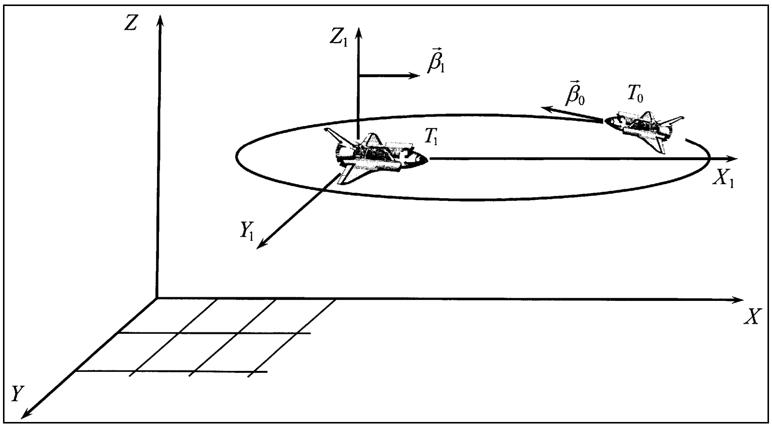


**Fig. 1.** The clock $T_0$ undergoes a cyclic motion around the clock $T_1$ at a velocity $\vec{V}_0$

**Рис. 1.** Часы $T_0$ подвергаются циклическому движению вокруг $T_1$ со скоростью $\vec{V}_0$

The time intervals measured by $T_1$ and $T_0$, when $\beta_1$ and $\beta_0$ are constant over time, are linked by the function

$$\Delta t_{1i} = \frac{1+\beta_1\beta_0\cos\alpha_i}{\sqrt{1-\beta_0^2}}\Delta t_{0i},\ i=1,2 \quad (13)$$

In the case of $i=1$, the clock $T_0$ moves in the direction $-OX_1$, therefore $\alpha_1 = \pi$; in the case of $i=2$, it moves in the opposite direction, and $\alpha_2 = 0$. Compare the difference between the readings of the clock $T_0$, which cyclically changes its motion direction along two sections of its trajectory, and the clock $T_1$.

Over a single period, the difference in clock readings will be equal to

$$\delta t = \Delta t_{01} - \Delta t_{11} + \Delta t_{02} - \Delta t_{12}. \quad (14)$$

Substituting (13) into (14):

$$\delta t = \Delta t_{01}\left(1-\frac{1-\beta_1\beta_{01}}{\sqrt{1-\beta_{01}^2}}\right) + \Delta t_{02}\left(1-\frac{1+\beta_1\beta_{02}}{\sqrt{1-\beta_{02}^2}}\right). \quad (15)$$

Consider that $\Delta t_{11} = \frac{l}{\beta_{01}c}$, $\Delta t_{12} = \frac{l}{\beta_{02}c}$, then (13) yields

$$\Delta t_{01} = \frac{1}{\beta_{01}c}\frac{\sqrt{1-\beta_{01}^2}}{1-\beta_1\beta_{01}},\ \Delta t_{02} = \frac{1}{\beta_{02}c}\frac{\sqrt{1-\beta_{02}^2}}{1+\beta_1\beta_{02}}. \quad (16)$$

Then (15) leads to

$$\delta t = \frac{l}{c}\left\{\frac{1}{\beta_{01}}\left(\frac{\sqrt{1-\beta_{01}^2}}{1-\beta_1\beta_{01}}-1\right)+\frac{1}{\beta_{02}}\left(\frac{\sqrt{1-\beta_{02}^2}}{1+\beta_1\beta_{02}}-1\right)\right\}. \quad (17)$$

To maximize the clock rate $T_0$, the ratio $\frac{\delta t}{T_1}$ is to reach its maximum over the period $T_1$. Dividing (17) by (12), we obtain

$$\frac{\delta t}{T_1} = \frac{\beta_{01}(1-\beta_1\beta_{01})\sqrt{1-\beta_{02}^2}+\beta_{02}(1+\beta_1\beta_{02})\sqrt{1-\beta_{01}^2}}{(\beta_{01}+\beta_{02})(1-\beta_1\beta_{01})(1+\beta_1\beta_{02})} - 1. \quad (18)$$

Fig. 2 shows the function $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ for $\beta_1 = 0{,}9$. Considering the form of (17) and Fig. 2, it follows that the value $\delta t$ may be positive and negative. Since $T_1 > 0$ always,there exists a range of values where $\delta t > 0$ defines the region where $\frac{\delta t}{T_1}(\beta_{01},\beta_{02}) > 0$. Let us find this region on the plane $\beta_{01},\beta_{02}$, by setting $\frac{\delta t}{T_1}(\beta_{01},\beta_{02}) = 0$, then (18) can be reduced to the form

$$\beta_{02}^3 + a_1\beta_{02}^2 + a_2\beta_{02} + a_3 = 0\,, \tag{19}$$

where

$$a_1 = 2\frac{\alpha-\beta_1}{\alpha\beta_1},\ a_2 = \frac{1+\alpha^2-4\alpha\beta_1+\beta_1^2}{\alpha^2\beta_1^2},\ a_3 = 2\frac{\beta_1-\alpha}{\alpha^2\beta_1^2},\ \alpha = \frac{1}{\beta_{01}}\left(\frac{\sqrt{1-\beta_{01}^2}}{1-\beta_1\beta_{01}}-1\right).$$

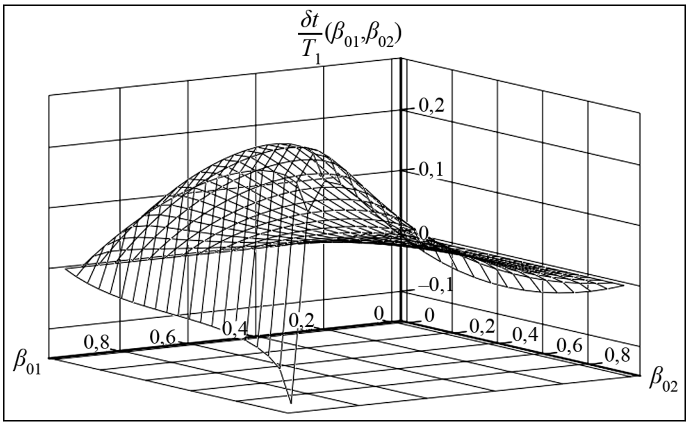


**Fig. 2.** The maximum of the function $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ lies in the region of $\beta_{01},\beta_{02}$ being close to $\beta_1$

**Рис. 2.** Максимум функции $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ лежит в районе, где $\beta_{01},\beta_{02}$ имеют близкие значения $\beta_1$

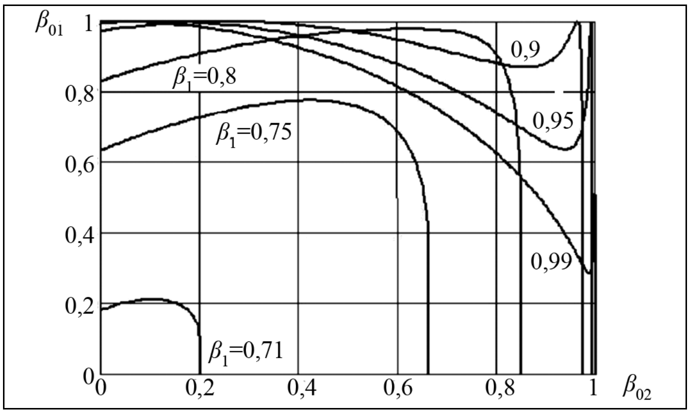


**Fig. 3.** Function $\beta_{01}(\beta_{02})$ in the case of $\frac{\delta t}{T_1} = 0$ for different values of $\beta_1$

**Рис. 3.** Функция $\beta_{01}(\beta_{02})$ в случае $\frac{\delta t}{T_1} = 0$ для различных значений $\beta_1$

Equation (19) has a real solution, which is presented in Fig. 3 for different $\beta_1$. It follows from Fig. 3 that for $\beta_1 = 0{,}71$ the major part of the function lies in the negative region.

We proceed to determine the minimum value of $\beta_1$ for which $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ can be greater than or equal to zero. Note that for small $\beta_1$ the functions $\delta t$ and $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ are symmetric with respect to $\beta_{01},\beta_{02}$, meaning that $\beta_{01} = \beta_{02} = \beta_0$ may be set, then it follows from (18) that

$$\frac{\delta t}{T_1} = \frac{\sqrt{1-\beta_0^2}}{1-\beta_1^2\beta_0^2} - 1\,. \tag{20}$$

The function $\frac{\delta t}{T_1}(\beta_0)$ will be positive from the moment $\frac{\delta t}{T_1}(\beta_0) = 0$, yielding

$$\beta_0 = \pm\frac{\sqrt{2\beta_1^2-1}}{\beta_1^2}\,. \tag{21}$$

Therefore, we derive the minimum value of $\beta_1$ at which $\frac{\delta t}{T_1}(\beta_0) = 0$ equals $\beta_1 = \sqrt{2}/2$.

It follows from Fig. 2 that the maximum of the function $\frac{\delta t}{T_1}(\beta_{01},\beta_{02})$ lies in the region where $\beta_{01},\beta_{02}$ are close to $\beta_1$. An important conclusion follows: efficient operation of the machine is possible when moving at a constant speed along a closed trajectory, for example, an elliptical one. In this case, same as if we were to describe circumferential motion in a rotating frame of reference, the presence of normal acceleration components does not affect the result.

The function $\frac{\delta t}{T_1}(\beta_{02})$ for $\beta_{01} = 0{,}9$ and $\beta_1 = 0...1$ is shown in Fig. 4.

To find the maximum of the function $\frac{\delta t}{T_1}(\beta_{01}, \beta_{02})$, it is necessary to solve the system of equations derived by differentiating (7) twice with respect to $\beta_{01}$ and $\beta_{02}$

$$\begin{cases} (\beta_{01}+\beta_{02})\left(1-2\beta_1\beta_{01}-\gamma_{01}\gamma_{02}\beta_{01}\beta_{02}(1+\beta_1\beta_{02})\right)+ \\ +\left(1-\beta_1(2\beta_{01}+\beta_{02})\right)\left(\beta_{01}+\dfrac{\gamma_{02}\beta_{02}(1+\beta_1\beta_{02})}{\gamma_{01}(1-\beta_1\beta_{01})}\right)=0, \\ (\beta_{01}+\beta_{02})\left(1+2\beta_1\beta_{02}-\gamma_{01}\gamma_{02}\beta_{01}\beta_{02}(1-\beta_1\beta_{01})\right)- \\ -\left(1+\beta_1(\beta_{01}+2\beta_{02})\right)\left(\beta_{02}+\dfrac{\gamma_{01}\beta_{01}(1-\beta_1\beta_{01})}{\gamma_{02}(1+\beta_1\beta_{02})}\right)=0. \end{cases} \tag{22}$$

where $\gamma_{0i} = \dfrac{1}{\sqrt{1-\beta_{0i}^2}}$.

Numerical solutions for (22) and (18) show that a high degree of accuracy is possible when stating

$$\beta_{01} = \beta_{02} = \sqrt{2-\frac{1}{\beta_1^2}}. \tag{23}$$

It follows from Fig. 4 that for $\beta_{01} = 0{,}9$ and $\beta_1 = 0{,}9$ the maximum of the function is observed at $\beta_{02} = 0{,}9$. This means that we may assume that the maximum is observed at $\beta_{01} \simeq \beta_{02} \simeq \beta_1$ at least in the region where $\beta$ is large.

Comparing (23) with (21), we can conclude that when $\beta_1$ are large, the maximum is close to the boundary $\frac{\delta t}{T_1}$=0. The maximum values of $\frac{\delta t}{T_1}$ may be derived from (20)

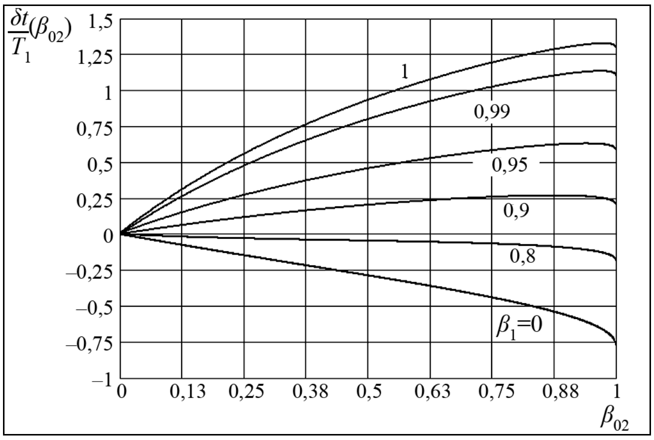


**Fig. 4.** Function $\frac{\delta t}{T_1}(\beta_{02})$ at $\beta_{01} = 0{,}9$ for different $\beta_1 = 0...1$

**Рис. 4.** Функция $\frac{\delta t}{T_1}(\beta_{02})$ в $\beta_{01} = 0{,}9$ для разных $\beta_1 = 0...1$

$$\frac{\delta t}{T_1}(\beta_1) = \frac{1}{2\beta_1\sqrt{1-\beta_1^2}} - 1. \tag{24}$$

The maximum values of $\frac{\delta t}{T_1}$ as a function of $\beta_1$ are shown in Fig. 5. The curve shows unlimited growth of $\frac{\delta t}{T_1}$ when $\beta_1$ increases. In the case of $\beta_1 = 0{,}99$ the function $\frac{\delta t}{T_1}(\beta_1)$ reaches $2{,}58$. This means that the clock $T_0$ will measure $2{,}58$ times more time than the clock $T_1$. For $\beta_1 = 0{,}9$, $\frac{\delta t}{T_1} = 0{,}275$ corresponds to the maximum of the function.

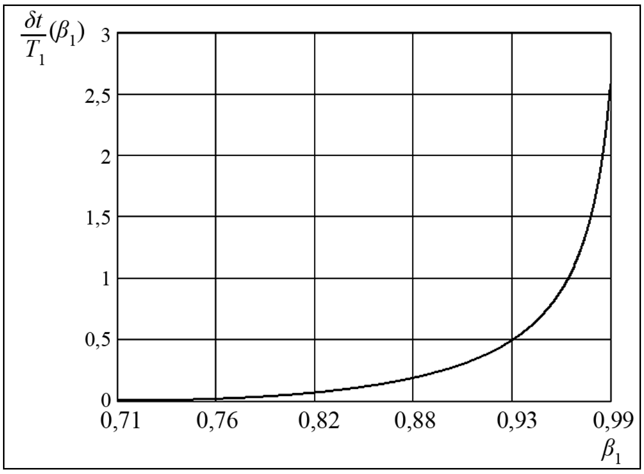


**Fig. 5.** Maximum relative values of the difference between the readings of the clock $\frac{\delta t}{T_1}$ as a function of the anisotropy parameter $\beta_1$. At $\beta_1 = 0{,}9$ the function $\frac{\delta t}{T_1}(\beta_{01}, \beta_{02})$ reaches its maximum of $\frac{\delta t}{T_1} = 0{,}275$

**Рис. 5.** Максимальные относительные значения разницы между показаниями часов $\frac{\delta t}{T_1}$ как функция параметра анизотропии $\beta_1$. При $\beta_1 = 0{,}9$ функция $\frac{\delta t}{T_1}(\beta_{01}, \beta_{02})$ достигает своего максимума в $\frac{\delta t}{T_1} = 0{,}275$

Let the clock $T_0$ undergo a cyclic motion along a closed trajectory. If we set $\beta_{01} = \beta_{02} = \beta_0$ and consider the angle $\alpha$ as a continuous function $t_0$, i.e. $\alpha$ is measured in the frame of reference of a moving clock $T_0$, then (13) yields

$$t_1 = \frac{1}{\sqrt{1-\beta_0^2}}\left(t_0 - \frac{1}{c}\int_{(l_0)} \vec{\beta}_1 d\vec{l}\right), \tag{25}$$

where an element of the trajectory length in the frame of reference $T_0$ equals $d\vec{l}_0 = \vec{V}_0 dt_0$, while the integral is taken along the trajectory $l_0$ in the frame of reference of the moving clock $T_0$.

When moving along an elliptical orbit at a constant velocity $V_0$ in the frame of reference $T_0$ for $\alpha(l_0)$ we have

$$\cos\alpha(l_0) = \pm\frac{a}{\sqrt{a^2 + b^2 \mathrm{ctg}^2\left(\frac{\omega_0 l_0}{V_0}\right)}}, \tag{26}$$

Then integrating (25) yields

$$t_1 = \frac{1}{\sqrt{1-\beta_0^2}}\left(t_0 - \frac{\beta_1\beta_0}{\varepsilon\omega_0}\mathrm{arctg}\frac{a\varepsilon}{\sqrt{b^2 + a^2\mathrm{tg}^2(\omega_0 t_0)}}\right),$$
$$a^2 > b^2. \tag{27}$$

It appears to be of more interest to estimate the difference between the clock readings in the IFR of the observer associated with the clock $T_1$. To calculate $t_0$ according to the known $t_1$, we write

$$t_0 = \int_0^{t_1} \frac{\sqrt{1-\beta_0^2}}{1-\beta_1\beta_0\cos\alpha(t_1)} dt_1. \tag{28}$$

When moving along an elliptical orbit, we have for $\alpha(t_1)$

$$\cos\alpha(t_1) = \pm\frac{a\,\mathrm{tg}(\omega_0 t_1)}{b\sqrt{1 + \frac{a^2}{b^2}\mathrm{tg}^2(\omega_0 t_1)}}, \tag{29}$$

where $a, b$ are the semi-axes of the orbit. Then (28) takes the form

$$t_0 = \sqrt{1-\beta_0^2}\int_0^{t_1} \frac{\sqrt{1-\varepsilon^2 + \mathrm{tg}^2(\omega_0 t_1)}}{\sqrt{1-\varepsilon^2 + \mathrm{tg}^2(\omega_0 t_1)} - \beta_1\beta_0 \mathrm{tg}\omega_0 t_1} dt_1. \tag{30}$$

Here $\varepsilon^2 = 1 - b^2/a^2$ is eccentricity.

Integrating (30), provided $\gamma^2 > 0$ while using the substitution $\cos(\omega_0 t_1) = -\mathrm{ch}(t)$, yields the expression

$$t_0 = \frac{\sqrt{1-\beta_0^2}}{1-\beta_1^2\beta_0^2}\left\{\varepsilon^2 t_1 - \frac{\beta_1^2\beta_0^2}{\omega_0\gamma}\operatorname{arctg}\left(\gamma \operatorname{tg}(\omega_0 t_1)\right) - \frac{\varepsilon^2\beta_1\beta_0}{\omega_0}\left[\operatorname{arsh}\left(\varepsilon\cos(\omega_0 t_1)\right) - \operatorname{arsh}(\varepsilon) - \lambda I(t_1)\right]\right\} \tag{31}$$

where $\lambda = \dfrac{\beta_1\beta_0}{\sqrt{\gamma^2\varepsilon^2 - 2\beta_1^2\beta_0^2}}$, $\gamma^2 = \dfrac{1-\beta_1^2\beta_0^2}{1-\varepsilon^2}$,

$$I(t_1) = \begin{cases} \operatorname{arctg}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2\cos^2(\omega_0 t_1)-1}}{\varepsilon\cos(\omega_0 t_1)}\right) - \operatorname{arctg}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2-1}}{\varepsilon}\right), & \dfrac{\gamma^2-1}{\beta_1^2\beta_0^2} > 1 \\ \operatorname{arth}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2\cos^2(\omega_0 t_1)-1}}{\varepsilon\cos(\omega_0 t_1)}\right) - \operatorname{arth}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2-1}}{\varepsilon}\right), & 0 < \dfrac{\gamma^2-1}{\beta_1^2\beta_0^2} < 1 \\ \operatorname{arcctg}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2\cos^2(\omega_0 t_1)-1}}{\varepsilon\cos(\omega_0 t_1)}\right) - \operatorname{arcctg}\left(\dfrac{1}{\lambda}\dfrac{\sqrt{\varepsilon^2-1}}{\varepsilon}\right), & \dfrac{\gamma^2-1}{\beta_1^2\beta_0^2} < 0 \end{cases}$$

The solution is presented in Fig. 6 in the form $\delta t(t_1) = t_0(t_1) - t_1$ for the following parameters: $a/b = 10$, $\omega_0 = 3\times10^8$ rad/s, $\beta_1 = 0{,}9$, $\beta_0 = 0{,}9$.

It follows from Fig. 6. that at the first stage of the clock $T_0$ moving in the direction $-OX_1$ it is ahead of the clock $T_1$ by $\delta t \simeq 1{,}2\times10^{-8}$ s. At the second stage of moving along $OX_1$ the clock $T_0$ lags behind by $\delta t \simeq 0{,}9\times10^{-8}$ s. Over a single period $T_1 = \dfrac{2\pi}{\omega_0} = 2{,}09\times10^{-8}$ s, the clock $T_0$ leaves the clock $T_1$ behind by $\delta t(T_1) = 3\times10^{-9}$ s.

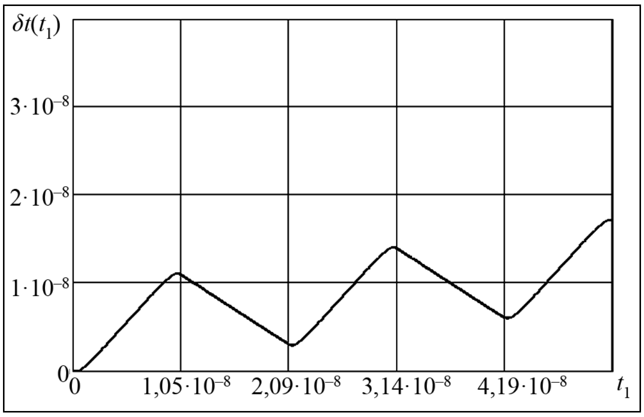


**Fig. 6.** The difference in clock rates $T_0$ and $T_1$ as a function of $t_1$

**Рис. 6.** Разница в тактовой частоте $T_0$ и $T_1$ как функция $t_1$

Since the solution (31) includes the frequency $\omega_0$ only as the product $\omega_0 t_1$, as the frequency $\omega_0$ decreases, the period $T_1$ will increase, and, as a result, for a fixed ratio of $\dfrac{\delta t}{T_1}(\beta_1 = 0{,}9) = 0{,}3$, for example (see Fig. 5), the value $\delta t$ will increase in proportion to the period $T_1$. In other words, if the period $T_1$ increases twofold, then $\delta t$ for a set $\beta_1$ will increase twofold as well.

As an example, consider the motion along an elliptical orbit with a semi-major axis equal to the radius of the Oort cloud ($10^4 - 10^5$ AU). To ensure $\beta_0 = 0{,}9$, it is necessary that the period of revolution $T_0$ around the earth-bound clock $T_1$ should be equal to $T_1 = 3{,}5\times10^7 ... 10^8$ s, which corresponds to an interval of 1 to 10 earth years approximately. Then the clock $T_0$ will be ahead of the earth-bound clock $T_1$ by 0,16...1,6 years.

Therefore, the example considered indicates that the rate of a fast-moving clock may be accelerated in an anisotropic space with dipole anisotropy.

Let us now dwell on the effect the orbit ellipticity may have on the difference between clock rates $\delta t$. The numerical solution (31) made it possible to derive the clock rate difference as a function of the ratio of the semi-axes $\delta t(a/b) = t_0(a/b) - T_1$ over a single orbital period $T_1$ for $\omega_0 = 3\times10^8$ rad/s, $\beta_1 = \beta_0 = 0{,}9$ (Fig. 7).

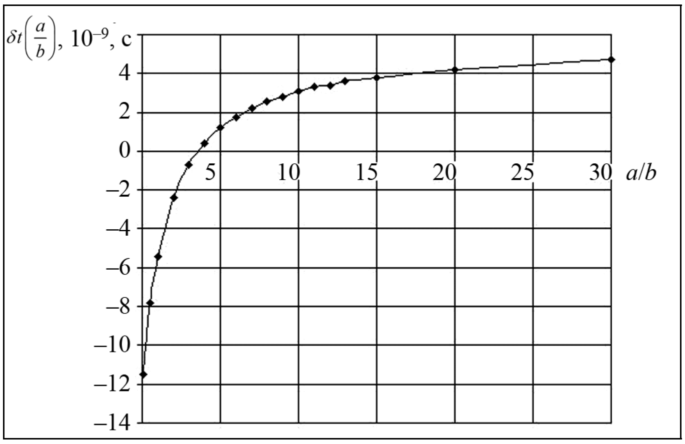


**Fig. 7.** $\delta t\left(\frac{a}{b}\right)$ over a single period as a function of the semi-axis ratio $a/b$ at $\beta_1 = 0{,}9$

**Рис. 7.** $\delta t\left(\frac{a}{b}\right)$ за один период как функция отношения полуосей $a/b$ при $\beta_1 = 0{,}9$

It follows from Fig. 7 that the clock $T_0$ for $\beta_1 = 0{,}9$ and $a/b = 10$ is ahead by $\delta t(10) \cong 3\times10^{-9}$ c.

At the selected frequency $\omega_0$, the period equals $T_1 = 2{,}09\times10^{-8}$ s. Then the ratio $\frac{\delta t}{T_1}(\beta_1) = \frac{3\times10^{-9}}{2{,}09\times10^{-8}} \cong 0{,}144$, which is two times less than the value $\frac{\delta t}{T_1}(\beta_1 = 0{,}9) \simeq 0{,}29$ in Fig. 5. However, as follows from Fig. 7, as $a/b$ grows, the value $\frac{\delta t}{T_1}(\beta_1) \to 0{,}29$, indicating the limiting process.

The example of a clock moving in an anisotropic space that we considered above indicates that accelerating the rate of a moving clock is fundamentally possible. The approximation considered in the paper is based on the assumption of a dipole anisotropy of physical space, so the time contraction effect and the calculations performed depend fully on the anisotropy parameter $\vec{\beta}_1$. As follows from our results, the minimum value of the anisotropy parameter to make clock rate acceleration possible would be $\sqrt{2}/2$.

Despite the fact that this value is high, it must be recognized that for $\vec{\beta}_1$ there is only one limitation $-1 < \beta_1 < 1$ and no other fundamental limitations exist. We can ensure that the anisotropic transformations used for spacetime coordinates comply with conventional Lorentz or Moeller transformations by requiring the total differential (6) to be invariant.

The main conclusion is that the results of a measurement procedure based on measuring partial differentials of transformations depend on the velocity of the laboratory IFR relative to the propagation space of fundamental interactions.

For small $\vec{\beta}_1$, clock rate acceleration becomes impossible, but the presence of a weak dipole anisotropy will lead to corrections to the rate difference for moving clocks at any non-zero value of the anisotropy parameter.

This novel effect may be discovered in experiments to measure variations in the lifetime of fast-moving elementary particles [11]. Clock rate being a function of the vector field $\vec{\beta}_1$ may be important for long space flights.

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Научная статья

# Машина времени в анизотропном пространстве-времени

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**Аннотация**

**Постановка проблемы**. Согласно специальной теории относительности все физические процессы проходят медленнее, чем следовало бы для неподвижных процессов по отсчетам времени лабораторной системы отсчета. Эффект замедления времени, наряду с гравитационным замедлением учитывается в глобальных спутниковых системах навигации, например, в GPS. Управление скоростью хода времени также возможно, если предположить существование топологических особенностей пространственно-временного континуума Вселенной. Результаты экспериментов по измерению времени регистрации нейтринного всплеска нейтринными и гравитационно-волновыми детекторами могут быть объяснены в предположении, что пространство земного наблюдателя обладает анизотропными свойствами.
**Цель.** Рассмотреть возможность управления скоростью протекания физических процессов в анизотропном пространстве.
**Результаты.** Показано, что в пространственно-временном континууме с дипольной анизотропией, или при релятивистской скорости космического летательного аппарата относительно реликтового излучения, наряду с замедлением, возможен ускоренный ход циклически движущихся часов или ускорение физических процессов. Эффективная работа машины возможна при движении с постоянной скоростью по замкнутой траектории, например, эллиптической.
**Практическая значимость.** При длительных космических перелетах, когда экипаж и бортовое оборудование находятся в замедленном состоянии, возможен ускоренный режим работы оборудования, циклически движущегося вдоль вектора скорости летательного аппарата относительно реликтового излучения.

***Ключевые слова***

*Реликтовое излучение, инвариантность, дифференциалы преобразований, инерциальные системы отсчета, ускоренное движение, замедление времени.*

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