Physical Time and Time Clock

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Abstract

Time is a fundamental quantity in physics and its definition has generated many problems starting from Newton's philosophical absolute time. Einstein searched for giving an operative definition of time through the use of unreal ideal clocks and of rays of light. In this paper we will search for giving a physical definition of time pointing out the necessity of avoiding in physics mistakes connected whether with Newton's exclusively philosophical definition, taken out of the scientific context, or with Einstein's operative definition through unreal clocks. We will prove nevertheless also the use of real clocks raises generally problems because of their real working and of the inadequacy of measuring instruments.

1. Introduction

Time is the most controversial concept in physics. In the pagan world time was considered circular and cyclic as a consequence of the fact that time was defined through the observation of cyclic phenomena: the alternation of day and night, the apparent circular and cyclic movement of the Sun round the Earth, etc.. . In the Middle Ages the philosopher Saint Augustine introduced a linear and progressive concept of time as distinct from the pagan concept. Saint Augustine was the author too of the famous statement:

"I know what time is if no one asks me about, but I don't know to say what it is if someone asks me about".

This difference between cyclic time and linear time is proposed again today via analogue clocks with lands that are cyclic and digital clocks that are linear.
In the 17th century Newton introduced the concept of absolute time:

"Absolute time, true and mathematical, isn't connected with sensible things. It flows always similarly. Relative time, apparent and common, is the sensible measure, obtained by the movement and it is usually used instead of the true time".

This concept of absolute time, together with the concept of absolute space, allowed to define in classical physics the absolute reference frame that afterwards was identified with the ether. The idea of ether was introduced in the Greek ancient world and it was considered by Aristotele the fifth element of the universe, together with the other four elements: air, water, earth, fire.

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Besides ether in classical physics was a material medium that was necessary for the propagation of electromagnetic waves and of light.
Classical physicists were sure about the existence of this absolute reference frame and of the ether and when A. Michelson proposed an experiment in order to prove the real existence of the ether they were certain about the positive outcome of the experiment. Maxwell in person supported the experiment with a famous letter to Michelson who performed the experiment at first alone (1881) and after together with E. Morley (1887). In both cases the result was negative and it produced great confusion in the world of physicists. In the meantime Maxwell died (1879) and hence he didn't know the outcome of the experiment and we cannot know his viewpoint on the outcome of the experiment. Anyway that experiment signalled the end of the absolute time, of the absolute reference frame and of ether. Also the most strenuous supporters of the absolute reference frame were obliged to change the classical concept of ether and their efforts came to the definition of new transformations of space-time (Lorentz's Transformations) unlike Galilean-Newtonian classical transformations. It is known in classical physics time of two different inertial reference frames was defined by the relation t'=t that nevertheless for Galileo didn't have the same meaning as Newton's absolute time, but that relation meant only time of the two considered reference frames was equal. In postclassical physics instead the time transformation in the order of Lorentz's Transformations is

$$t' = \gamma\left(t - \frac{ux}{c^2}\right) \qquad (1)$$

in which u is the velocity of the second reference frame S' with respect to the first reference frame S, supposed at rest, and γ is the Lorentz factor

$$\gamma = \frac{1}{\sqrt{1-(u/c)^2}} \qquad (2)$$

The same transformations were demonstrated by A. Einstein in Special Relativity starting from the "postulate of constancy of the velocity of light" rather than from a modified concept of ether and he reached practically the same conclusions. The Lorentz transformation of time introduced the concept of relativistic time whether in postclassical physics or in modern physics[1]. Afterwards there were numerous attempts to bring modifications to the Lorentz transformations but they were without positive outcome because also Lorentz's modified transformations had the same contradictions of original transformations.

2. Operative time

Einstein replaced the Newtonian absolute time with an operative definition of time[2]:

"Time is the physical quantity measured by a clock".

Einstein considered ideal clocks and his main worry was the theoretical synchronization of those ideal clocks. The procedure of synchronization that Einstein used is very controversial and it is based on thought physical experiments that make use of rays of light.
In actuality it is known that every place of the Earth is characterized at present by a conventional time and consequently every real clock has to be synchronized with the conventional time of the place where the clock is placed. Consequently no further synchronization of real clocks is necessary. Einstein's definition of synchronization is conditioned by the use of rays of light and hence Einstein's physics is conditioned by the velocity of light like all physical theories that make use of Lorentz's Transformations, in the original or modified form.
In the Theory of Reference Frames[3] [TR] we subscribed to the same operating definition of time, but in TR the time transformation is different from the (1) and it is given by:

$$dt' = \frac{m'}{m} dt \qquad (3)$$

in which m and t are mass and time in the reference frame S[O,x,y,z,t], supposed at rest, and m' and t' are mass and time in the moving reference frame S'[O',x',y',z',t']. In TR the concept of time is connected with the concept of mass and if mass of the considered physical entity is constant with respect to the velocity (m'=m), as it happens for ordinary bodies and for energy entities that don't have mass, then the time transformation in TR becomes

$t' = t$ **(inertial time)**[3][4] (4)

The time transformation (4) is the same as in classical physics in Galileo's meaning and not in the meaning of Newton's absolute time. We have demonstrated[3] the (4) is valid in mechanics, in optics and in electromagnetism. In particle physics instead elementary particles have a different physical behaviour with respect to ordinary bodies: in fact electrodynamic mass of elementary particles changes with the particle velocity and hence in particle physics inertial time, given by (4), isn't valid and it is replaced with the (3).
A critical analysis of the operative definition of time through ideal clocks **(clock time)**, used by Einstein, proves this definition is insufficient and inappropriate.
In fact real clocks, all clocks with any physical nature, are physical systems that work as per defined laws of physics and the Principle of Relativity guarantees laws of physics and the working of physical systems are the same only with respect to inertial reference frames. We remind inertial reference frames are reference frames that have a constant difference of velocity each other, hence the inertial time, given by the (4) and measured by clocks, is valid only with respect to inertial reference frames. Besides we know the physical behaviour of elementary particles with respect to inertial reference frames is different from ordinary bodies and for elementary particles time is given by (3). In that case for elementary particle time flows otherwise because mass changes with the velocity. It explains why "the operative definition of time through clocks is inappropriate". In fact in the event of ordinary bodies the inertial operative time, measured by clocks, is valid only for

inertial reference frames where real clocks work similarly. For elementary particles instead because of the change of mass with the velocity also for inertial reference frames, as per the (3), the time with respect to a moving observer is different from the intrinsic resting time of particle.

3. Relativistic time

With respect to a reference frame, that is able to define a limited part of the Universe, the operative time is defined by the "local time" of the reference frame that is given by the measurement of time through a synchronized clock with the local time. Naturally the operative local time is characterized by prospective errors of measurement like for measures of any physical quantity. The question concerns instead the behaviour of the operative time with respect to different reference frames. It is manifest that the relation existing between reference frames becomes important. The operative time is the local time of the preferred reference frame where the physical phenomenon happens. With respect to other reference frames we have to consider in general a "relativistic time" given by the relation between the local time of the preferred reference frame and the time of other references frames.

Considering the figure 1, in the Theory of Reference Frames (TR) transformations of space-time for reference frames, also non-inertial, with any linear velocity **u** with respect to the resting reference frame, in the passage from S to S' are given[3][4][5] by

$$
\begin{aligned}
x' &= x - \int_o^t u_x dt \\
y' &= y - \int_o^t u_y dt \\
z' &= z - \int_o^t u_z dt \\
dt' &= \frac{m'}{m}\, dt
\end{aligned}
\qquad (5)
$$

in which (u_x,u_y,u_z) are scalar components of the vector velocity **u**, x,y,z are the space coordinates and t is the time coordinate in S, x',y',z' are the space coordinates and t' is the time coordinate in S'. Besides m and m' are mass of the physical entity respectively in S and in S'. The transformations equations (5) can be written in the brief shape

$$\mathbf{P'}[x',y',z',t'] = \mathbf{P}[x,y,z,t] - \int_0^t \mathbf{u}\, dt \qquad (6)$$

$$dt' = \frac{m'}{m} dt$$

in which **P'** is the point with respect to the moving reference frame S'[O',x',y',z',t'] and **P** is the same point considered with respect to S[O,x,y,z,t].

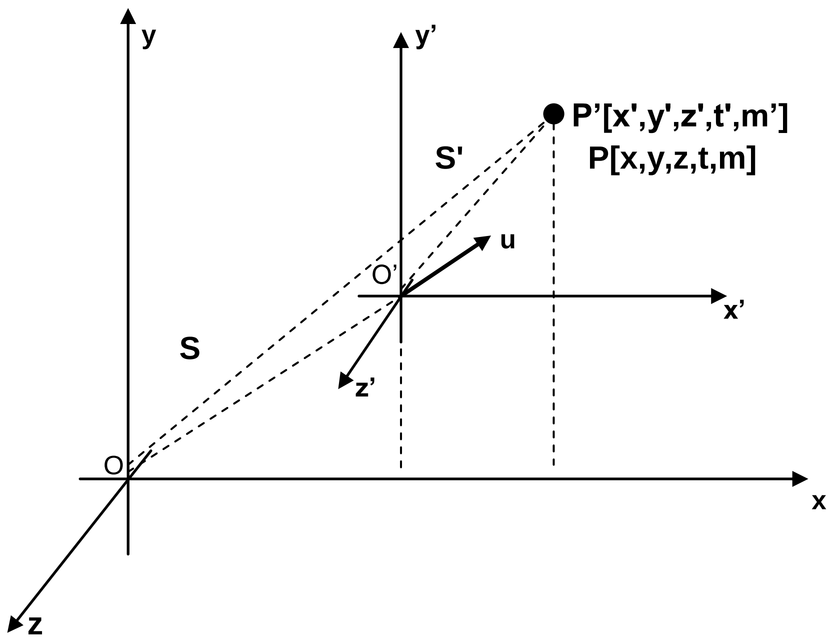

Fig.1 The reference frame S' moves with linear vector velocity **u** with respect to the resting reference frame S. The point **P'** is referred to S' while P is the same point that is referred to S.

We observe in TR in every situation the relation that connects times of the two reference frames is

$$dt' = \frac{m'}{m} dt \qquad (7)$$

The (7) establishes there is a relation and a connection between masses and times of the two reference frames that regard exclusively objects that have a mass that changes with the velocity. In fact if mass doesn't change (i.e. m'=m) we have t'=t.
Hence in the Theory of Reference Frames, unlike the Special Relativity in which all masses at micro and macroscale have the same physical nature, the relation that connects masses of the physical entity, that is represented by the point **(P, P')** in the two reference frames, depends on the physical nature of mass[3]. Let us distinguish the following cases:

a. **ordinary bodies of mechanics**.

In that case the relation of masses in the two reference frames S and S' is

$$m' = m \tag{8}$$

and consequently from the (7)

$$t' = t \tag{9}$$

For ordinary bodies of mechanics time of body with respect to the two reference frames is the same. This common time is valid for all reference frames, inertial and non-inertial.

b. elementary particles of electrodynamics.

Unlike Special Relativity in which mass of all physical entities increases with the velocity, in the Theory of Reference Frames mass of ordinary bodies is constant with the velocity while mass of elementary particles decreases (instead of increasing) with the velocity, in concordance with the relation

$$m = m'\left(1 - \frac{u^2}{2c^2}\right) \tag{10}$$

where m' is the resting mass in S' and m is the moving mass with respect to S**.**
From the (7) we deduce for electrodynamic particles

$$dt = \left(1 - \frac{u^2}{2c^2}\right) dt' \tag{11}$$

If u is constant, and consequently the two reference frames are inertial, we have

$$t = \left(1 - \frac{u^2}{2c^2}\right) t' \tag{12}$$

In this situation in which the physical entity is an electrodynamic particle, time of the particle in the two reference frames is different. In particolar if $t'=\tau'$ is the average life of the particle at rest in S', the relativistic average life τ of the particle that moves with velocity u with respect to the reference frame at rest S is

$$\tau = \left(1 - \frac{u^2}{2c^2}\right) \tau' \tag{13}$$

Because the measurement of the relativistic average life τ of a particle happens with respect to the resting reference frame S of the Laboratory, from the (13) we deduce the intrinsic average life τ' of the particle in S' is

$$\tau' = \frac{\tau}{\left(1 - \frac{u^2}{2c^2}\right)} \tag{14}$$

It needs to specify the real average life of particle is the relativistic average life that is measured while it is very difficult to measure the intrinsic average life. It is due to the fact that the intrinsic average life doesn't have a precise physical meaning.
It needs also to specify every elementary particle, that has mass, belongs to the leptonic subfamily or to baryonic subfamily. Hence in the first case electron is the mather particle while in the second case proton is the mather particle. In the stable state ($u<u_c=\sqrt{2}\,c$), in which u_c is the critical velocity, particle is always electron or proton. In the unstable state ($u>u_c$) particle type depends on the velocity and consequently on mass that is negative, as per (10).

c. light and electromagnetism

Classical electromagnetism is characterized by the propagation of e.m.waves (from ultra long waves to microwaves) and it is known real mass of an e.m. wave is zero. Similarly light is composed of a photon beam and the singe photon, like all quanta of energy, is an e.m. nanowave. It follows that also light, photons and in general energy quanta have zero real mass. Hence because light, electromagnetic waves and energy quanta have zero mass, it cannot change with the velocity and consequently

$$t' = t \qquad (15)$$

i.e. time of light, of electromgnetic waves and of all quanta of energy is the same with respect to the reference frames S and S'.
In conclusion for mechanics, optics and electromagnetism the relativistic time doesn't exists while it exists only for elementary particles that have an electrodynamic mass.

4. Physical time

In the Universe all physical systems change their state and it isn't possible to observe systems that are into an eternal stationary state. If the Universe could be into an eternal stationary state thus time not would be necessary. Consequently the concept of time is associated with changes that happen into the universe so that a value t_1 of the variable t is associated with the state ST_1 of the Universe and the value t_2 is associated with the state ST_2. Naturally if $t_2>t_1$ it means the state ST_2 is subsequent to state ST_1. This definition of time represents the "**universal time"**:

"The universal time is the physical quantity that allows to identify the succession of states of the Universe".

It is manifest that the human observer is unable to observe changes of the whole universe and hence the definition of "universal time" has only a theoretical meaning. It is manifest too the real observation is necessarily limited to a finite part of the universe and of the space. This definition of time and of space regarding a finite part of the universe

represents the "**physical time"** and the "**physical space**" . We can consider this finite part of the universe like a **"reference frame"** characterized by the following paradigm **S[O,x,y,z,t]** where x,y,z are the coordinates of the thredimensional physical space, t is the time coordinate of this physical space and O is the origin of S in which generally the observer is placed and the physical event happens.
Synchronized clocks at rest into the reference frame S[O,x,y,z,t] measure the same physical time of S, excluding broken-downs or lacks of clocks.
Besides as per the Principle of Relativity all clocks, with any physical working, that move with constant velocity with respect to the reference frame S, supposed at rest, work similarly and consequently they measure the same physical time.
The principle of Relativity instead doesn't guarantees the same physical behaviour of clocks that move with non-constant velocity in S. In fact the Principle of Relativity claims laws of physics are the same for reference frames that are into an inertial state and move with a constant difference of velocity. Consequently it is possible that accelerated clocks that move with non-constant differences of velocity measure different times.
It doesn't mean the physical time of the reference frame flows differently but only clocks measure a different operative local time because of a different working od the same clocks that aren't inertial each other.
Similarly clocks that are at rest into a gravitational field at different altitude aren't into an inertial state and consequently they can have different physical workings and they can give different measurements of the same time.
These considerations prove a definition of time raises many problems above all with regard to its measure because real clocks don't have the same physical behaviour because of different physical situations in which they work.
Synchronized clocks with the conventional time of the place, excluding broken-downs and lacks, measure the same time with regard to the same physical event if they are into an inertial state: i.e. they are at rest or move with constant velocity.
If clocks are into a gravitational field, it is normal that they measure a different time with regard to the same physical event if they are at different altitude, because they are in different gravitational physical conditions.
Hence synchronized clocks in non-inertial conditions can measure different times even if the local time flows similarly inside the same reference frame.
In conclusion we may claim there isn't only one definition of physical time: the **physical time** coincides with the universal time when we consider the whole universe like reference frame, it coincides with the operative local time when we consider a privileged local reference frame, and it coincides with the relativistic time when we consider a moving reference frame with respect to the privileged reference frame where the physical process happens.

5. Muon paradox

Cosmic muons are unstable particles that are produced in great strength in collision processes of cosmic rays with high layers of Earth's atmosphere.

They reach Earth's surface travelling a distance of about d=13.5Km that is equal to atmosphere's height. The measured average life of muons with respect to the reference frame of Earth's laboratory is about τ=2.2μs.
In the order of Special Relativity nothing, and consequently also muons, can travel with greater velocity than the velocity of light that is about $c=3\times10^8$m/s. Doing calculations and supposing that muons travel just with the maximum velocity c, then the maximum distance travelled by muons during the average life, before decaying, is

$$d = c\tau = 3\times10^8\times2.2\times10^{-6} = 6.6\times10^2 = 660\text{m} \qquad (16)$$

that is much smaller than the effective distance travelled by unstable muons before decaying.
Supporters of Special Relativity explain this paradox assuming in the calculation it needs to consider the time dilation of the average life of muon. In fact introducing a Lorentz's factor $\gamma=20$ the dilated average life is $\tau'=\gamma\tau=44\mu$s and like this the travelled distance by muons is

$$d = c\tau' = 13.2\text{Km} \qquad (17)$$

that is practically the height of the atmosphere. This explanation has many weak points:

a. Muons are unstable leptonic particles that decay into a smallest time and no experiment has measured the real velocity of a muon that, in the case of γ=20, in the order of SR would be u=0.9988c. This value is theoretical but it doesn't have been measured.
b. The hypothesis that the velocity of unstable muon cannot exceed the physical velocity of light is only a theoretical consequence of Special Relativity and of Lorentz's Transformations.
c. The inapt knowledge of the real physical behaviour of unstable particles doesn't exclude the possibility of alternative explanations for the apparent paradox of cosmic muons.

In fact an alternative explanation is given by the Theory of Reference Frames [3][6] (TR), in which the physical velocity of unstable particles, and in particular of muon, is greater than the velocity of light. As per the variation of mass with the velocity, given in TR by the relation

$$m' = m\left(1 - \frac{u^2}{2c^2}\right) \qquad (18)$$

where m is mass of resting electron, it is possible to observe, assuming the velocity of muon u=20c, muon mass is just equal to known mass m'=-206m in which the sign minus " - " indicates muon is an unstable particle. At this velocity the distance travelled by muon before decaying is equal to

$$d' = 20c\tau = 13.2\text{ Km} \qquad (19)$$

that is practically the height of Earth's atmosphere.

In Laboratories instead, without any scientific proof, the muon velocity is assumed equal to u=0.9988c and this value of velocity doesn't derive from an effective measurement of velocity but from a calculation based on Lorentz's factor γ=20.
Hence the apparent paradox of cosmic muons is in actuality a consequence of a theory (SR) that is able to explain this paradox only introducing a series of contradictions defined by preceding points (**a,b,c**).
In TR muon is an unstable particle that derives from the acceleration of electron that moves with the velocity u=20c>c and, as per the (18), it has just an electrodynamic mass m'=-206m.
In TR mass, time and velocity of elementary particles are strictly related whether for electron subfamily or for proton subfamily[10] . From the (18), for u=0 the elementary particle is the resting stable electron and this particle remains a stable electron to the critical velocity ($u=u_c$) with positive values of mass and average life. At the critical velocity electron is at the limit of the stability with zero electrodynamic mass. At the velocity u=20c electron becomes an unstable muon with electrodynamic mass m'=-206m and a measured real average life equal to τ=-2.2μs.
The (13) allows to calculate the intrinsic average life τ' of muon starting from the real average life τ measured in laboratory. Assuming u=20c and τ=-2.2μs, from calculation we obtain

$$\tau' = \frac{\tau}{\left(1 - \frac{u^2}{2c^2}\right)} \qquad (20)$$

$$\tau' = 11 \text{ ns} \qquad (21)$$

The (21) represents in TR the intrinsic average life τ' of muon.

6. The gravitational clock

We have pointed out previously the operative definition of time through ideal clocks has no physical meaning while the definition through real clocks can generate errors:

a. As per the Principle of Relativity, clocks are physical systems that work similarly in all inertial reference frames and hence they measure the same time in these reference frames.
b. In the event of non-inertial reference frames the Principle of Relativity isn't valid, hence clocks can work otherwise and consequently thay can give different measures of the same time.

Among non-inertial reference frames there are gravitational fields in which the value of gravitational force isn't constant but it depends on the distance r of the point in which the clock is placed with respect to the symmetry centre of the field generated by the central mass M. In concordance with the known Newtonian law, the gravitational force is

$$F = \frac{GMm}{r^2} \qquad (22)$$

Two equal physical systems, for instance clocks, for the **General Principle of Inertia** [3][4][8][9] are into an inertial state, inside a gravitational field, if they are motionless at the same altitude or they move along the same equipotential surface with velocities that can be also different but anyway constant. In that case as per the Principle of Relativity and the TR Transformations of space-time they measure the same time, neglecting prospective misworkings.

If instead two clocks are at different altitudes r_1 and r_2 (fig.2), the two clocks, whether in the resting state or in the motion state, are subject to different gravitational forces:

$$F_1 = \frac{GMm}{r_1^2} \qquad (23)$$

and

$$F_2 = \frac{GMm}{r_2^2} \qquad (24)$$

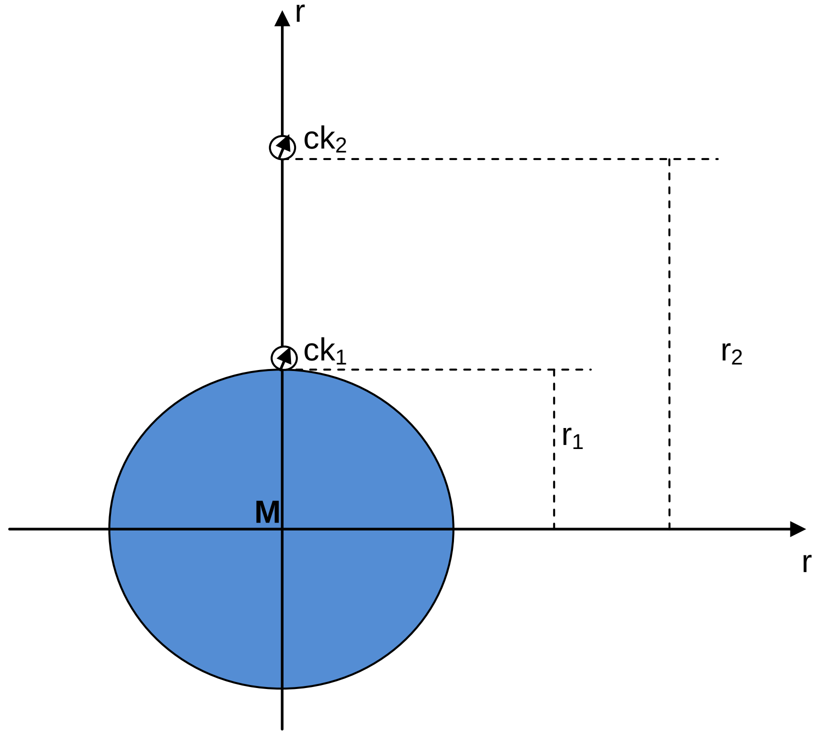

Fig.2 The two clocks ck_1 and ck_2 are at different altitude into the gravitational field generated by mass M.

It is manifest that the two clocks aren't into an inertial state and therefore in spite of time flows similarly at the two altitudes, the two clocks can measure different times because the two equal clocks aren't into an inertial state and they are subject to different physical conditions of working.

This conclusion explains exactly because two equal clocks, working in different physical conditions, like in the event of different altitudes, can measure different times in spite of time flows similarly at the two altitudes.
This result besides explains also because in determinate physical conditions, in which the Principle of Relativity isn't valid, there is a dichotomy between the physical time and its measure making use of clocks whose working is based on defined laws of physics.
A criterion for defining this difference of the operative time with respect to the physical time derives from the behaviour of a physical system inside a gravitational field.
The velocity of any physical system with mass m, that is placed at the distance r from the barycentre M that generates the gravitational field, supposing that at ad infinitum the velocity is zero, is given by [11]

$$v(r) = \sqrt{\frac{2GM}{r}} \qquad (25)$$

From the (25)

$$dt = \sqrt{\frac{r}{2GM}}\, dr \qquad (26)$$

Assuming that "t" is the physical time for r=0 in the barycentre of mass M and "t_g" is the gravitational operative time for every value of r, we have

$$t_g = t + \sqrt{\frac{r^3}{4.5GM}} \qquad (27)$$

In our phisico-mathematical model the (27) represents the variation of the gravitational operative time t_g with respect to the physical time t at every distance r from Earth's barycentre.

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