# 1. PHYSICAL MODELS OF TIME

## 1.1. Physical Models

For short, in this study we use the term "physics" in a broad sense – as a natural science that includes the allied spheres (e.g. astrophysics) associated with a quantitative and observational study of time and space.

In physics, like in engineering, developing a theory which allows us to *quantitatively* describe definite class of phenomena presumes (1) offering a hypothesis(es) defining the basic assumptions relative to these phenomena, (2) construction of mathematical model grounded on these hypotheses which allows us to numerically describe this class of phenomena (or rather – their properties), and (3) verification of the validity of the proposed model. We may consider other classifications of the theories, but as these principal stages are always present and most crucial for the purpose of this study, consider them in more detail.

(1) Conceptual model (CM). For the selected class of phenomena we must firstly define the quantities which are to be considered. Those of them which have the numerical estimates obtained by measurements (or other way) call the *source data*, the remaining ones – the *parameters* of the model. Further on, we must put forward the hypothesis (es) that relates these quantities, mathematically or verbally.

These hypotheses, the accuracy of the source data and the diapasons of admissible variations of these quantities define a domain of applicability of the model that is constructed.

As far as apart from mathematical relations these hypotheses and relations may contain verbal descriptions, it is said that in aggregate they form a *conceptual model* for the considered class of phenomena.

(2) Mathematical model (MM). The proposed hypothesis is formulated in this or that system of mathematical relations; in aggregate, together with the constraints imposed on the considered quantities, they form a mathematical model for the given conceptual model for the considered class of phenomena.

The goal of development of MM – is to obtain a mathematical description (or properties) of the system of the considered phenomena (further referred to as system) in terms of the specified quantities which allows us, through the use of the dependences between the parameters which are accepted in the MM, to foresee the behavior of the system as a response to the source data values. In this sense a physical theory presents a "physical" interpretation of the parameters assigned to the phenomena comprising the considered system, as well as the system behavior, but definitely in compliance with the properties of the considered MM.

At the same time, the choice of mathematical objects to be used in the model is generally not restricted by anything (except the CM) and therefore – is not unique. In other words, different mathematical theories (differential or algebraic equations, random processes, etc.) can be used for this purpose – the choice depend more on the originator of the theory than on the CM itself; in particular, for the same set of source data or CM several theories could be proposed, thus giving various MMs, which is a typical situation for the modern physics. For this reason, at this stage of developing a theory a principle of minimal complexity is used (Occam's razor): the mathematical description must be as simple as possible provided it describes the specified relations and hypotheses with the required precision.

The MM must be internally consistent. But it is also highly desirable for it to be stated correctly (viz. not to present an ill-stated problem); this means, that for any admissible source data the solution (viz. the response of the system) does (i) exist, (ii) unique, and (iii) stable, whereas a problem is called an ill-stated, if at least one of these three conditions takes place. For instance, if for some source data a ***solution***:

- (i) ***does not exist***, the ***model*** could be ***incomplete*** or ***composed incorrectly***;
- (ii) ***is not unique***, the model permits ***appearing*** of ***bifurcation points*** after which the evolution of the system would go in different ways (as in some models of expansion of the Universe);
- (iii) ***is not stable***, a ***small variation*** of ***source data*** can ***result*** in ***great variation*** of the ***solution***.

However, if a problem is ill-stated, this does not necessarily mean that the model is "false" or incorrect, but this definitely presumes a possibility of unpredicted behavior of the system. In general, this situation is explained by the existence of some unknown dependencies or factor(s) of influence.

(3) Verification of the MM (VM). A set of experiments (and/or observations) is carried out with the aim to check that the actual results coincide with those predicted by the theory (viz. by the MM) for the same source data. If the verification is successful, it is believed that the theory describes the considered system of phenomena adequately. In reality, the CM and MM are "tuned" for years (as in the case with ΛCDM model of the expanding universe) until this correspondence is achieved; at that, both the CM and/or MM may be restructured, and their parameter readjusted (relative to their values, diapasons, relations, etc.).

But actually this means only that the theory is correctly approximates the response, that is the behavior of the system within the frame of the accepted CM and MM. This does not reject an "authenticity" of some other MM which describes the response with the same accuracy, but with the use of some other principles – the situation that takes place, for instance, in modern *Quantum mechanics* and *Cosmology*. In such cases with the aim to resolve the problem it is required to find principally new source data (or "facts") and principles (viz. concepts). The former – is the sphere of experimental physics; first of all, it requires new instruments for observing the micro-world (e.g. Large Hadron Collider) and far Cosmos (e.g. Space telescope).

But the latter aspect of the problem is absolutely different, since until the "correct" theory is found we have no criterion for estimating the validity of the theories. From this point of view there is no guarantee of "absolute" validity of this or that theory since each of them does not "explain" but just approximates the relations between the selected parameters (or predicts the behavior of the system), more or less exactly. As well, neither the CM, nor the MM can describe any phenomena identically, but may just approximate them; namely because they are *models* which allow for some things while neglecting others (being either known, or unknown to us).

This situation explains why the universal concepts such as Time and Space are not defined in physics; instead, it uses their operational definitions which, in essence, present mathematical models.

The above presented theory forming formalism (CM→MM→VM) does not present a revelation, but in a compact way reflects the methodology of system approach to analysis of the surrounding world. This methodology became necessary with an intense evolution of sciences and technologies, as well as with a rapid progress of computers. However, even at the dawn of evolution of the modern science Sir Isaac Newton, when analyzing his law of universal gravitation, paid attention to unreasonableness of searching of the cause of phenomena in the formulas which describe them:

> "At the outset of his "Principia," Sir Isaac Newton took the greatest care to impress upon his school that he did not use the word "attraction" with regard to the mutual action of bodies in a physical sense. To him it was, he said, a purely mathematical conception involving no consideration of real and primary physical causes". [SD1-490]

This formalism was not very important in XIX century, when the theories were based on several algebraic formulas. But now, with a cardinal growth of complicacy of phenomena the number of competing and internally consistent theories is also increasing as an avalanche, whereas the perspective for verifying them remains quite dim. Moreover, the complicacy of mathematical models of these theories in most cases prevent from obtaining the exact solutions; instead, the physicist are forced to restrict themselves with approximations. This is apart from the loss of obviousness of these theories.

Even greater problem in study of Time and Space presents a gap between the models of Cosmology and Quantum mechanics which cannot come to an agreement one with the other. Figuratively speaking, the former does not follow from the latter, and vice versa. The pendency of this problem is one of the causes that does not give grounds for setting a physical theory rested on the existing physical concepts that could provide us with a model supporting the hypotheses of the Big Bang and its principal origin – singularity.

For these reasons the evolution of physics is stipulated by two main factors: development of more accurate instruments and offering new paradigms. Amusingly, but a series of such revolutionary paradigms pertaining to Time and Space were announced (in a verbal form) in The Secret Doctrine (SD) [2] in the second half of the XIX century, and a number of them were even realized in the physical theories. It is the author's opinion that follows from comparative analysis of the Physical and Theosophical concepts, that there are still much more paradigms presented in this Doctrine which can be integrated in the modern physical theories dealing with Space and Time. In order to show this, we must firstly overview the latter.

## 1.2. The main types of physical models that define the physical time and its properties

Physical time. From the very beginning we must place the emphasis on the fact that there is great difference between the conceptual and practical ***aspects of*** time. The former is associated with a primary, or absolute, understanding of this phenomenon that still remains unclear both in physics and in philosophy, whereas the latter reflects our intuitive understanding of time and treats it as a parameter of one or another process which allows us to sequence events, to measure their durations and intervals between them, and thus to quantify the motions of objects; in the latter sense the time is also considered in two aspects.

For theoretical purposes the time is considered as a parameter $\tau$ of a considered physical theory; in this case its properties are defined by the chosen mathematical model, that constitutes the basis of this theory, with reference to some coordinate system comprising an axis which is called "time axis" $t$. Intuitively we presume that, if chosen correctly, the quantities $t$ and $\tau$ are to be identical for any situation, and this was also supposed in the classical physics. But we know now, that it is not so; for example, the properties of $\tau$ in a moving object differ from those of $t$ in the resting system.

Alongside, for the purpose of *time measuring*, both for practical and scientific purposes, one or another operational definition is accepted which also specifies not a concept of time, but a ***time count system*** based on a mathematical model pertaining to the chosen physical theory. With rare exception (the cosmological time) this definition is based on a periodic process: by bringing its states into correlation with some scale we obtain what is called "time"; a device that physically realizes this correlation is called a *clock.*

In essence, in both these cases the time, as parameter, is defined in the same way – with the use of one or another mathematical model describing the associated physical process; for this reason, and with the aim to distinguish it from other models we may call it the physical time. However, one must remember that it does not specify the *primary* concept of time.

The limit of clock improvement and lack of absolute time. Usefulness of physical time is defined by intuitively supposed possibility to correlate the sequence and duration of events, that is the states of an arbitrary process, with a clock, that is with the scale or states of the chosen process. For this, from a practical point of view, it is required that some clock (as only a clock indicates the physical time) being accepted to present an etalon clock could be replicated; this means that the basic process defining the etalon could be reproduced where and when it is required and so that different clock copies show the same time.

Until the end of the XIX century it was supposed that this approach to synchronous time counting was possible and required only the secondary clocks to retain the same origin and base process as the etalon. Before the mechanical clocks the most exact etalon was the Earth itself: its rotation was considered as the most stable periodic process and throughout the Earth was used as the base process for the sun-dials. But such clocks were unsuitable for exact measurements (e.g. in astronomy) since the length of day depended on the season (due to the difference between the true and mean solar days). Besides, they did not retain the origin during a motion because a sun-dial always shows, but the local time.

The invention of portable and quite exact mechanical clock had solved an important practical problem: it became possible to measure the longitude by comparing the indications of the mechanical clock and sun-dial that showed the original and local times, respectively. But these clocks were not quite exact due to instability of base process (mechanical oscillation) and required a systematic correlation against the etalon. And even the invention of quartz clock being several orders more exact than the mechanical one had not solved the problem: it was still necessary to correlate the clocks with the etalon.

Meanwhile, the theoretical search of "absolute" etalon became vain after the Lorentz transformations and Michelson-Morley experiment integrated in the special relativity (SR) had shown an ***inconsistency*** of the ***suggestion as to an existence of absolute time scale*** (time dilation, relativity of simultaneity, etc.). It turned out, that the rate of time flow depends on the reference frame, whereas there is no preferred inertial reference frame. Moreover, the general relativity (GR) predicted that the time flow rate should depend on the gravity. But the accuracy of conventional time measurements was still lower than the threshold of this effect, until few decades later the atomic clock was invented and direct measurements had confirmed the predicted gravitational time dilation that was observed even for different latitudes and altitudes.

As a result, the theoretical grounding of relativity of simultaneity and the extremely high precision of atomic clock not only have put the end to a search of "absolute time scale", but engendered a practical problem in developing a world-wide time count system since even the same clock would tick at different rates if placed at different points on the Earth (or satellites). In the upshot, the GPS system averages the values of time from different atomic clocks and allows for the time required for propagation radio signals.

In other words, it follows from the SR that space and time are not independent and we must consider a unified (or indivisible) ***four-dimensional space-time***, or ***space-time manifold***, three spatial coordinates of which are algebraically interconnected with the time coordinate. But the latter is just a parameter of the point associated with the origin and does not present time or space-time properties of other points: for obtaining the time coordinate for other point we must apply the *Lorentz transformation*. Only at low velocities which we observe in life the time coordinates in moving and original frames are practically indistinguishable, as the non-simultaneous events in these frames are observed as simultaneous: just at low velocities the world is quite exactly described by absolute time, Euclidean geometry and classical mechanics.

So, ***at small velocities*** (compared to the speed of light) the ***special relativity is mathematically approximated by Newtonian mechanics***.

The general relativity also admits applicability of the special relativity, but in a special way. As far as the properties of space-time in GR are defined differentially (i.e. by a system of differential equations), the concepts of special relativity are applicable in the GR, but also differentially – for small areas. Within a domain of finite size the special relativity is accurate only when the absolute value of the gravitational potential is much less than $c^2$; so, the ***general relativity becomes special relativity at the limit of weak field***.

The basic distinction of space-time of GR, as against to that of SR, is its curvature which is expressed by a ***curvature tensor***; in SR this tensor is identically equal to zero and, hence, the space-time of SR is flat (in the sense of curvature!). In other words, the curvature of space-time (as a 4-dimension manifold) is uniquely defined by its metric (metric tensor). The difference between the GR and alternating gravitation theories is defined, in most cases, by the correlation between the matter and metric properties of space-time.

Mass and Energy. Mass in special relativity incorporates the general understandings from the concept of mass energy equivalence; it depends on the velocity and, thus, does not present an invariant. For this reason the term *mass* in special relativity usually refers to the rest mass of the object, which is the Newtonian mass as measured by an observer moving along with the object. Meanwhile, it has been increasingly recognized that relativistic mass is a troublesome and dubious concept.

On the contrary, the energy $E$ and momentum $p$ from the invariant which retains its value in any frame of reference; it is called the *relativistic energy-momentum equation* $E^2 - (pc)^2 = (mc^2)^2$ where m is the rest mass. For an object at rest, the momentum $p$ is zero, and we obtain the famous formula

$$E = mc^2$$

which means that the rest mass is only proportional to the total energy in the rest frame of the object. For these reasons the mass is not generally considered in the SR which deals with the energy and momentum.

Therefore, in the relativistic effects it is not so a mass, but the energy which ***acquires special importance.***

The Expansion of the Universe is a phenomenon that further broadens our understanding of space and time, although the description of this expansion and – especially – its starting point are based on a series of diverse and frequently arguable hypotheses and models.

This expansion presents an observed fact: the Universe is uniformly expanding everywhere. In brief, it is described by the metric expansion of space which is the averaged increase of metric (i.e. measured) distance between distant objects in the universe with time. This means that the space itself expands in time so that the distances between the separate objects are increasing but remain proportional at any moment. However, in some models it is stated that over time, the universe is expanding in space. The words "space" and "universe", sometimes used interchangeably, have distinct meanings in this context. Here "space" is a mathematical concept and "universe" refers to all the matter and energy that exist.

Example 1.1. An expanding "raisin bread model" (a loaf of raisin bread expanding in the oven). The loaf (space) expands as a whole, but the raisins (gravitationally bound objects) do not expand; they merely grow farther away from each other. As the bread doubles in width (depth and length), the distances between raisins also double.
In this example the "space" is associated with an unchangeable coordinate system in which we measure the distances, and the bread – with the Universe. We will follow this convention in the below consideration, unless otherwise specified.

The basic means for measurement of the expansion of the universe is based on processing the redshifts from the remote objects.

Redshift. In physics, redshift happens when light seen coming from an object is proportionally shifted to appear more red. Here, the term "redder" refers to what happens when visible light is shifted toward the red end of the visible spectrum. More generally, where an observer detects electromagnetic radiation outside the visible spectrum, "redder" amounts to a technical shorthand for "increase in electromagnetic wavelength" – which also implies lower frequency and photon energy in accord with the wave and quantum theories of light.
Redshifts are attributable to three different physical effects. The first discovered was the Doppler effect, familiar in the changes in the apparent pitches of sirens and frequency of the sound waves emitted by speeding vehicles; an observed redshift due to the Doppler effect occurs whenever a light source moves away from an observer. Cosmological redshift is seen due to the ***expansion of the universe***, and sufficiently distant light sources (generally more than a few million light years away) show redshift corresponding to the rate of increase of their distance from Earth. Finally, gravitational redshifts are a relativistic effect observed in electromagnetic radiation moving out of gravitational fields.

How the Universe expands. The relativity is insufficient for describing the expansion of the Universe.

Integrally (viz. for large areas of space), the ***expansion of the Universe*** is ***approximately described*** by the Hubble's law which says that the recessional velocity of a remote object is proportional to its distance from the observer.
Differentially (viz. locally in space-time), it is ***approximately described*** by the ΛCDM model.

Lambda-CDM model (ΛCDM) is an abbreviation for Lambda-Cold Dark Matter. It is frequently referred to as the standard model of Big Bang cosmology, since it attempts to explain the existence and structure of the cosmic microwave background, the large scale structure of galaxy clusters and the distribution of light elements and also the *accelerating* expansion of the universe observed in the light from distant galaxies and supernovae. It is the simplest model that is in general agreement with observed phenomena.

However, as far as this model is based on the partial differential equations, for obtaining the properties of a definite area of space and time interval it is required to integrate these equations over the space and time starting with some known state of the universe; for this state the current spatial and matter-distribution status of the observable Universe is taken which is estimated on the ground of WMAP and some other data. Such a calculation (viz. extrapolation in the past) yields a ***scale factor change*** of approximately ***1292*** for a period of about ***13.7 billion years***. In other words, this means the Observable Universe has expanded to approximately 1300 times the size it was when the CMBR photons were released, that is in about 13.7 billion years. That state was ***preceded by*** an ***immensely quick*** (within seconds) expansion (called "***inflation***") of the Universe from a state of "singularity" of *unknown* physical nature after the hypothetical ***Big Bang*** had occurred.
In this sense the Big Bang and singularity (and seemingly inflation) ***present*** the hypotheses because these concepts ***arise*** from a degenerate solution to the ***problem of backward extrapolation*** and ***absolutely*** devoid ***of any*** physical sense.

## The initial conditions problem

* The Big Bang hypotheses is seemingly required, first of all, for explaining the appearing of the ***degenerate solution*** (viz. singular initial conditions). It proposes to think that within a second the universe had “come into existence” from an unknown physical state of singularity and expanded from a “void” to a size comparable to the known Universe. All ideas concerning the very early stages are speculative, and only plausible models are proposed for the stage of cosmic inflation during which the newly born Universe in $10^{-32}$ second not only had ***expanded*** by ***dozens or hundreds of orders***, but even obtained the currently ***observed large-scale structure***. In this, the Big Bang hypothesis is as scientific as the Creation by the Old Testament, since it has no physical theories explaining how the “Universe” had unwrapped in a second from “nothing” into a Universe being only 1000 smaller that ours.

* On the contrary, some physicists have tried to avoid the initial conditions problem by proposing models for an eternally inflating universe with no origin. These models propose that whilst the universe, on the largest scales, expands exponentially it was, is and always will be, spatially infinite and has existed, and will exist, forever.

Cosmological time and age of the Universe. Nevertheless, the Big Bang hypothesis is still used for the origin of the cosmological time that coincides with the age of the Universe:

> The age of the *observable* universe is the ***time elapsed*** between the ***start*** of the ***Big Bang*** and the present day. Current theory and observations suggest that the universe is 13.75 billion years old. The ***timeline of the Big Bang*** describes the events (starting with this origin) with the use of the cosmological time parameter of comoving coordinates.

Therefore, the ΛCDM model more or less correctly ***describes*** the expansion of the ***observable universe***, but just from ***right after the*** inflationary epoch to present, that is the evolution of the observable universe from a very uniform, hot, dense primordial state to its present state over a span of about 13.73 billion years of ***cosmological time.***

However, it does not deal neither with initial evolution of the Universe, nor with that ***how and when*** the Universe had come to that size. So, it actually assumes ***quite low rate of expansion*** of the Universe.

## Resume

Although the ***singularity*** and ***Big Bang*** remain inexplicable ideas, the expansion of the ***universe*** presents the actual process which is quite correctly described by the ΛCDM model, but just from ***right after the inflationary epoch*** to present, that is ***quite slow of expansion*** of the ***observable universe*** from a very uniform, hot, dense primordial state to its present state over a span of about ***13.73 billion years*** of ***cosmological time***. In other words, it does not deal neither with initial evolution of the Universe, nor with that ***how and when*** the Universe had come to that size.

This model ***predicts*** the existence of ***new forms of matter*** – the dark matter and dark energy – which exert influence on the evolution of the conventional (viz. baryonic) matter; and this and some other prediction are ***supported*** by the ***observations***.

The ***closeness*** of the ***age of the Universe***, as defined by the Big Bang, to the Hubble time , apart from other correlations, may probably explain why using the former age in some theories is effectual.

***In contrast***, theories of the origin of the primordial state remain very speculative. If one extrapolates the Lambda-CDM model backward from the earliest well-understood state, it quickly reaches a ***Big Bang singularity*** which ***is not considered to have any physical significance***, but it is convenient to quote times measured “since the Big Bang”, even though they do not correspond to a physically measurable time. So, although the universe might have a longer history, cosmologists presently use “age of the universe” to mean the duration of the Lambda-CDM expansion, or equivalently the elapsed time since the Big Bang.

## 1.3. Time count systems

Exact time measurements were always important, especially – in navigation and astronomy. Meanwhile, as far as they are still based on *operational definitions*, in order to increase the accuracy of time count at each historical epoch for the base periods in the *time count systems* the most stable periods were searched among those that could be easily reproduced. For this reason, the TCSs are still in use which are based on astronomical phenomena and oscillating processes with small periods. At that, the time scale is selected to be most convenient for practical purposes relative to the numerical interval and precision of measurements.

Astronomical processes are based on Earth's rotation and revolution (around the Sun). By their essence, they are convenient for everyday purposes (e.g. for civil time count), as well as for navigation and astronomy – for obtaining the geographical coordinates, Earth's orientation and Celestial coordinates of Space objects for large terms. However, a substantial ***shortcomings*** of these processes result from ***slowing down of Earth's rotation*** and ***nonuniform motion of the Earth*** along its orbit. In order to escape from this irregularities various types of "uniform" TCSs were defined for both civil application and astronomical purposes [Supplement 1]. As a rule, in these TCSs the basic period is associated with the time unit (e.g. 1 year, 1 day) which is further divided into lesser units (months, hours, etc.).

However, in this approach it is impossible to define a time unit quite exactly due to the permanent variations in the base processes. For this reason the most exact TCSs are defined on the basis of other physical processes and are correlated with the astronomically-based TCSs. At that, the basic idea lies in use of the most stable, but short-period process. In this case, even if the process itself is heterogeneous, the great number of reiterations of the same stable process allows us to measure time with a greater accuracy. This requires us to consider the most stable oscillating processes with least period.

Small period stable processes were firstly using the mechanical oscillations; in XX$^{th}$ century a much more stable quartz clock was invented with several orders lesser base period. But the real revolution in time count has come with the invention of the ***atomic clock***: with them we come to the ***world of relativity*** since the TCS based on the atomic clock is sensitive to variations in Latitude, altitude (due to ***gravitational time dilation***) and other factors (***velocity***), whereas the duration of time signal transmission becomes greater than the error in time count. As a result, the International unit of time – the SI second – was defined as the specified number of caesium 133 atom oscillations at definite conditions. The second thus defined is consistent with the ephemeris second, which was based on astronomical measurements.

The actual state of affairs. As the result, the most exact TCS, the International Atomic Time (TAI), cannot be used for practical purposes directly – due to irregularities in Earth motion and relativistic effects: one must insert the corrections (predictable and unpredictable caused by abrupt variations in Earth rotation) for it to correspond the actual position of Earth. For solving this complicated problem *several* TCSs are used [Supplement 1]; in each of them, provided for the specific application sphere, the "time" flows in its own way, and those, which are proposed for astronomical observations, take into account the relativistic effects. However, it is still impossible to specify a single TCS for Earth on the whole to be as exact as TAI. For this reason two approaches are used, but each presumes desensitization (loss of accuracy):

* GPS time. Three relativistic effects which influence the flow of the satellites' clocks are the time dilation, gravitational frequency shift, and eccentricity effects. However, these are not "errors" since these clocks tick correctly in their frames; nevertheless, as far as the GPS must present a "single" time, the indications of these clocks must be coordinated, that is corrected. As well, as the time flows with different rates at various latitudes and altitudes, the "GPS" time must be corrected for those places as well. So, the GPS time presents some abstract value which may be recalculated for the exact time on Earth's location but with taking into account of actual Earth's motion (e.g. variation in the rate of Earth rotation).
* on the contrary, a TCS for civil purposes (UTC, UT1, etc.) presumes a synchronism of time all over the Earth; this excludes considering the relativistic effects and requires desensitization of TAI.

Resume. Now, several TCSs are used that are based on various base processes. The most part of them are mutually non-synchronous and may differ in accuracy by orders. However, ***it is not considered advisable to adopt*** a ***single TCS*** – neither for scientific, nor for civil applications, since ***in each application*** that ***base processes*** is ***more adequate*** which ***better reflects*** the ***expected primary property of Time***.

## 1.4. An example of uniform and nonuniform Time Count Systems

Consider a TCS **H** that is based on periodic ball revolutions. It presents a gutter that is rolled in a circle of radius *R*, along which a ball can move without friction, and allocated horizontally. Some point *A* on the gutter is chosen to present the origin. The ball is pushed on at a velocity *v*. Then, the ***time*** *t* specified by the position of the ball is defined by its angle $\alpha$ (in radians) from point *A* (Fig.1.1.a). If, as it is accepted with the oscillating processes, the unity of time corresponds to a full rotation of the ball, the correspondence between the time *t* and angle $\alpha$ is as follows

$$t = \frac{\alpha}{2\pi} u \, , \tag{1.1}$$

where $u \equiv 1$ is the coefficient with the dimension of time which is required for the balance of units of dimension. As well, we may consider a full rotation of the ball as a process with an arbitrary ***base period*** *T* (that could be measured with the use of system **H**). In this case the time is expressed in another unit

$$t' = \frac{\alpha}{2\pi} T \, . \tag{1.2}$$

But transfer to time $t'$ is associated just with the use of the ***scale factor***, since the values *t* and $t'$ linearly dependent: $t' = T \cdot t$. In particular, this means that *for any position of the ball* (viz. angle $\alpha$) the increments of time in both scales conform to the equation $\Delta t' = T \cdot \Delta t$ .

In general case, call a function

$$t = f(\alpha) \tag{1.3}$$

that ***maps the angle*** $\alpha$ ***into a segment*** [*0*, *T*] the time function. It defines a proper time *t* for the system **H** in a sense that it does not depend on any other factor.

So, time function (1.1) specifies time on the segment [*0*, *1*], and (1.2) – on the segment [*0*, *T*].

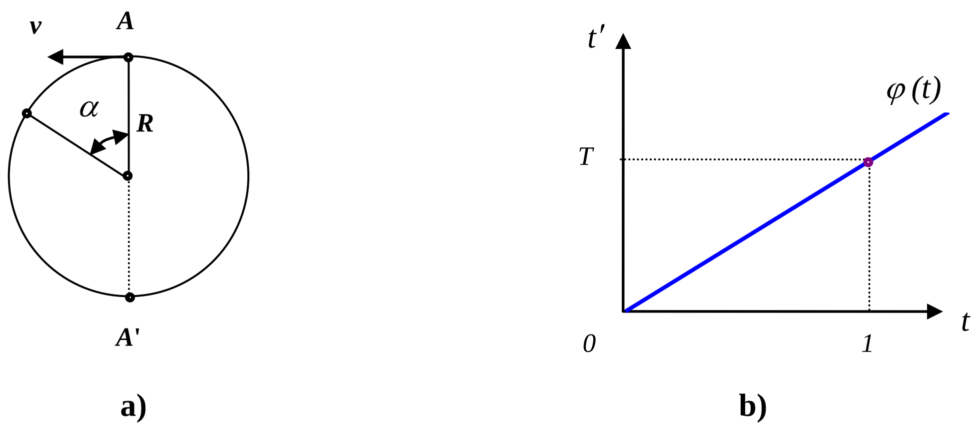



Fig. 1.1. Linear dependence (or uniformity) between the etalon time *t* and time $t' = T \cdot t$

This function may be linear, as in (1.2), and non-linear, but***, in itself, it does not define whether or not the time*** *t* ***is uniform*** because in general case ***we must know the dynamics of motion***, that is the duration ***of transfer from a state to a state***. For instance, that the time *t* in the system **H** is uniform is a sequent of Newtonian mechanics; in some other theory it may not be uniform. This means that the property of ***uniformity*** (or homogeneity) in an ***absolute sense*** (viz. in itself) is ***dubious*** because it makes no sense to discuss whether or not a segment [0, 1] is uniform. ***However***, the ***uniformity*** becomes ***well defined*** if specified ***relative to some*** "***reference***" (or etalon) ***time***:

Let $\tau$ and $t$ present proper times for some TCSs; then, the relation $\tau = \varphi(t)$ specifying the dependence between these values call the **reference time function**.

Thus, for an arbitrary time function $\tau = f(\alpha)$ and time $t$ of (1.1) it takes the form $\tau = f(\alpha) = f(2\pi \cdot t / u)$.

Then, the uniformity of time may be defined as follows.

***The time*** $\tau$ ***is uniform with respect to time*** $t$, if for any intervals $[t_1, t_1']$, $[t_2, t_2']$ of equal length $(\Delta t)_1 = (\Delta t)_2, (\Delta t)_i = t_i' - t_i$, the respective intervals $[\tau_1, \tau_1']$, $[\tau_2, \tau_2']$, $\tau_i = \varphi(t_i)$, are also equal.

The ***time*** $\tau$ ***is uniform relative to time*** $t$, ***if, and only if, the reference time function*** $\tau = \varphi(t)$ ***is linear***. In fact, the uniformity of time $\tau$ relative to $t$ denotes that they differ, but just by a scale factor or origin.

In this sense all the TCSs being uniform to time $t$ are mutually equivalent and thus present a class of equivalence of uniform Time count systems: they remain uniform relative to any TCS from this class having been chosen to present the reference time. So, if we have chosen some TCS to present the reference time, we have a mathematically defined procedure for testing other TCS for uniformity with it.

For example, let the reference system **H** (1.1) define the unit of time and a time count system **H*** being physically identical to the system **H** have a period *T*. Then, the time (1.2) specified by the system **H*** is uniform relative to time *t* of (1.1) by definition and the reference time function takes the form

$$t' = f(\alpha) = \frac{\alpha}{2\pi} T = \frac{2\pi t}{u} \times \frac{1}{2\pi} T = \frac{T}{u} \cdot t, \qquad (1.4)$$

that is the reference time function $t' = \varphi(t) = \frac{T}{u} \cdot t$ presents a straight line (Fig.1.1.b).

Now, consider one more TCS **S** that is identical to the system **H** except that it is slanted at some angle to the horizon; for its origin the highest point B is taken (Fig.1.2.a). The time $\tau$ in this system is still defined by the angle $\alpha$, as in the relation (1.2):

$$\tau = \frac{\alpha}{2\pi} T^* \qquad (1.5)$$

where **T*** is the period of the ball in system **S**. Compare the TCS **S** with a system of type **H*** with the same observational (in time *t*) period *T* =*T**.

**VISUALLY**, if a ball in the system **S** is pushed along the gutter synchronously with passing of the first ball through the point *A* of the *horizontal* gutter **H***, either of them will return to their origins at the same moment (the ball in system ***S*** moves slowly in the vicinity of point *B* and faster – at point $B'$), although all the remaining points, except of *(A, B)* and ($A'$, $B'$), the balls pass non-synchronously – but ***in time*** *t* (that is if we ***count time for both systems*** in the units of system **H***), since the angular positions of the balls in these two systems for the same time *t* differ. In this sense the ***time*** $\tau$ ***, as it is perceived by the position of the ball in the system S, seems to be* nonlinear *and thus –* nonuniform *relative to the* time t**.

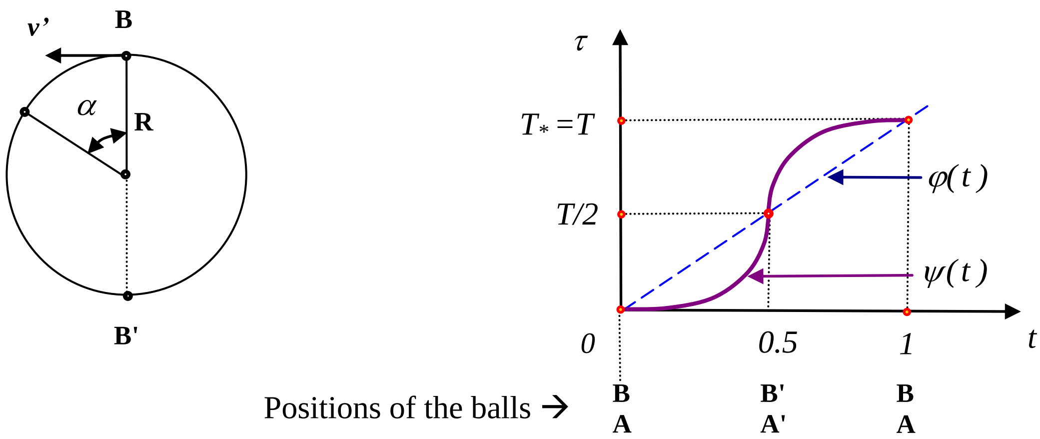
**FORMALLY**, if we consider their motion ***in the proper time*** of these systems, as it is ***defined by the angle*** with respect to (1.2) and (1.5), ***they move*** synchronously – because each point with an angle $\alpha$ they pass at the same proper time $t'$ and $\tau$, respectively:

$$t' = \frac{\alpha}{2\pi} T = \frac{\alpha}{2\pi} T^* = \tau .$$

So, ***when it is defined just by the positions*** of the ball the ***time*** $\tau$ becomes uniform relative to ***time*** $t'$.

This "contradiction" shows that spatial coordinate is insufficient for describing the time as a measure of motion; we must somehow define the "rate" with which the balls change their states (viz. angles); for this ***we must presume*** that there ***exists a measurable property***, which is commonly called "duration" which defines this "rate". But although it is measurable, ***this does not mean the existence of some unique measure of duration for all systems***.

So, for comparative analysis of motions we must adopt some TCS for the etalon (in a sense of reference TCS). Let the system **H** be taken for the reference system; then, the time $t'$ is given by (1.4). Within the ***Newtonian mechanics*** we may find the law of motion of the ball in the system **S**, that is the function $\alpha(t)$ which specifies the position of the ball in the system **S** (note that $\alpha(t)$ is a nonlinear function of *t*).




**a)** **b)**

Fig. 1.2. Non-linear dependence (or nonuniformity) between the time $\tau$ and time *t*

With respect to (1.5) this gives the following ***time reference function*** for time $\tau$

$$\tau = \frac{\alpha(t)}{2\pi}T* = \frac{T*}{2\pi}\alpha(t) = \psi(t). \tag{1.6}$$

This situation is illustrated in Fig. 1.2.b where the function $\tau = \psi(t)$ (purple line) shows how time $\tau$ depends on time *t*; for comparison, the reference time function for time $t'$ (with the same period $T = T*$, and thus time unit) is presented by the dashed line (it is similar to that of Fig. 1.1.b). These two lines cross at the points corresponding to the angles 0° (points A and B), 180° ( $A'$ and $B'$), 360° (A and B), etc., where the time $t'$ coincides with time $\tau$ and equal to $0, T/2, T$, etc.

So, the ***time reference function*** $\tau = \psi(t)$ shows how the ***proper time*** $\tau$ in the ***system*** **S** ***depends on*** the ***proper time*** $t$ in the ***system*** **S**, but just for the case of ***Newtonian mechanics***, since in the case of ***relativistic motion*** the ***function*** $\alpha(t')$ would take ***another form***.

> Comment. If two processes are mutually nonlinear, but have the same physically observed periods, each of them could nevertheless be used for defining the same unit of time. Indeed, if ***just the base period is used for defining a unit of time,*** and the fractions of this period are not considered, it does not matter – whether the process is linear or nonlinear (it is very important when we develop an etalon for which we may have no more precise clock); it is only important for this process to be stable – that is to retain the duration of its base period. Namely ***this situation takes place with the*** SI second.
> However, the ***situation changes drastically***, if the ***submultiple units of a period*** are to be ***considered***.
> Even if the periods of the mutually nonlinear systems **H*** and **S** are the same, the time $\tau$ flows faster around the point $B'$ (approximately at the angles from 90° to 270°) since the same increments $\Delta\alpha$ of angle are corresponded by the same increments $\Delta t$ of time *t*, but various increments $\Delta\tau$ of time $\tau$ .

This is not an abstract example – namely ***this situation takes place with the*** Apparent solar time and Mean solar time within a period of tropical year (in reality the situation is complicated by slowing down of Earth rotation and other effects). As the Earth revolves around the Sun along an ellipse, the Sun moves along the Ecliptic unevenly: the angle it passes daily is greater in Winter (up to 61 arc min) and lesser in Summer ( 58 arc min). As a result, the ***Apparent solar day*** (the time interval between two sequential Solar culminations) varies during a year; this is an analog of the system **S**. An analog of the system **H*** is given by the ***Mean solar time*** which presents a TCS being uniform by definition.

The former reflects a real physical process (culmination of the Sun) and, for this reason, is important in astronomy and other applications, but inconvenient in every day use (for keeping it, we must correct all the clocks on everyday basis). On the contrary, the latter is convenient for everyday use, but only indirectly reflects the physical processes and, therefore, is adjusted both to these processes and the etalon (TAI).

## Resume

Any separate proper time as defined by some TCS on the ground of a continuous base process is always uniform in itself as a segment could be "uniform". This means that there exists no TCS that could define some "absolute" "uniform" time, and ***it is*** impossible ***to theoretically establish a*** uniformity ***of a*** TCS in itself. In this sense the uniformity of time may only be considered as a comparative characteristic.

If the ***proper time*** $\tau$ and ***proper time*** $t$ are defined by some TCSs with the use of the same base process with the states $\{s\}$, and their time functions $\tau(s)$ and $t(s)$ may be correlated through these states, a reference time function may be obtained which sets the ***correspondence*** $\tau = f(t)$ between these TCSs. If this ***reference time function*** is ***linear***, the time $\tau$ is ***uniform*** relative to time $t$, ***and vice versa***. Thus, in the considered example the time $\tau$ in TCS **S** is a nonlinear function of time $t$ in TCS **H.** Hence, any two TCSs defined on the states of the same base process are either *mutually* uniform, or *mutually* nonuniform.

Therefore, the ***uniformity*** of a time (relative to a fixed TCS) that is defined by some TCS ***is specified*** not so ***by the chosen base process*** $P$, but rather by the way how the states of this process are mapped to a numerical segment (time scale) $X$, viz. ***by the time function*** $f(p_i) \rightarrow X$ that metrizes the states of that process.

Meanwhile, the scale factor ***does not present a defining value*** since it cannot neither make a TCS uniform, nor devoid it of this property. For this reason the scale factor is chosen so as to be convenient for practical use in reflecting the properties of the base period – either as a unit of time (1.1), viz. the segment $[0, 1]$, or as a specified number of time units $T$ within the base period as in (1.2).

However, if ***different base processes*** are used, some extra considerations should be used for obtaining a correspondence between their states; as far as this requires comparing their models, the property of ***uniformity becomes model-dependent***.

Last, not least is the stability of the ***base process*** since it presents the ***primal interest*** from the viewpoint of precision of the TCSs: the greater the ***stability*** and the lesser the ***duration*** of the ***base process*** – the greater the accuracy the ***TCS*** provides for the most part of physical observations; for this reason the International Atomic Time is used for defining the ***SI second***. However, for astronomical applications the stable periods with much greater duration are more appropriate.

## 1.5. Classification of Time Count Systems relative to the base periods

So, taking into account the application goal of time count makes it important to consider in Time Count Systems the physical processes the base periods of which differ in ***periodicity***, ***stability*** and ***duration***. These features engender the following natural classification of processes, the type of which names the scale of the respective TCS. As far as all these processes in their nature are considered continuous, the scales are also treated as continuous.

### Periodic Time Scale

A time scale is periodic if it is defined by a process with a more or less stable period of finite length.

By their structure we may distinguish between the following types of periodic scales:

* frequency scale: the unit of time is defined by a specified number of base periods.
  An example is the ***SI second*** based on definite number of quantum oscillations, as well as its exact multiples: minute (60s), hour (3600s), day (86400s), Julian year, Julian century, etc.
* phase scale: the unit of time is defined by the process states within a period.
  An example is the ***Apparent solar time*** based on the apparent motion of the observed Sun.
* coordinated scale: the unit of time is defined as in the frequency scale, but with a corrections that take into account the disturbances in the base process (e.g. the irregularities in Earth motion). An example is the ***Coordinated Universal Time*** based on TAI with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation.

### Cyclic Time Scale

This scale is similar to the periodic one (including both frequency and phase structures), but allows for the durations of the cycles of the basic process to have pronounced variations. This is knowingly a non-uniform (or heterogeneous) scale relative to a civil time since in this time the states of the base process are distributed in cycles unevenly. Nevertheless, for some applications this scale is more appropriate than the “uniform” civil time because the latter does not reflect the peculiarities of the motion (viz. change in-states) that present the main interest in the studied phenomenon.

An example is the ***Mean solar time***: conceptually, it is the hour angle of the fictitious mean Sun, assuming the Earth rotates at a constant rate. However, the length of a mean solar day increases at a rate of approximately 1.4 milliseconds each century. Hence, if high accuracy is required the ***UTC, UT*** and the similar TCSs are to be considered as cyclic, otherwise – as periodic.

Meanwhile, the benefits of this type of scale are much more illustrative in the 11-year Solar cycles, the duration of which varies from 7 to 17 years. It is established that each of four phases of every cycle defines a period during which definite natural and/or social processes culminate [20, 21]. For this reason for economy, emergent services, agriculture and other applications it is very important to know the “time of the cycle”. The same situation takes place in geochronology where the durations of the ages are known but with a low accuracy [16].

### Evolutional Time Scale

Moreover, there are very important time count systems which are not based on periodic or cyclic processes. Thus, in physical cosmology the ***cosmological time*** is used for describing the evolution of the expanding Universe (See Part 4). At present, the origin of this time is set up to the moment of the hypothetical Big Bang, but nobody knows for sure neither the origin of this process, nor the result of the expansion.

Although the accuracy of this TCS based on solving of complicated differential equations is incommensurably lower than that which characterizes the conventional time scales that are based on the observable processes (years, etc.), the cosmological time is more appropriate in cosmology since it presents a natural time axis for cosmological models the accuracy of which corresponds to that of this time count system.

As well, this kind of TCS is pertinent for describing the ***time in subjective perception***; in a combination with the cyclic TCS it is appropriate for ***describing the evolution of Earth and humanity*** (See Part 3).

## Conclusions

1. The Mathematical Models (***operational definitions*** – in particular) constitute the required ***basis for the physical theories*** which provide us with a numerical description of the physical world.

However, these models, in themselves, may not reflect neither the causes of the considered phenomena, nor our intuitive understanding of their essence; moreover, they may describe these phenomena in defiance of our understanding of the "reality", that is formed in the scope of Newtonian mechanics due to our experience to deal with the low velocities (relative to the speed of light) and intermediate distances (between the micro and macro worlds).

In this sense a physical reasoning reflects the mathematical properties of the underlying model which describes the behavior of the considered system, but not its causes. Hence, on the way of modeling we describe the behavior of the physical systems more and more exactly, but mathematically: this does not guarantee that we are approaching to the essence of the problem. Therefore, as far as the physical theories based on mathematical models in the most cases are just approximating the physical phenomena, one must take care for not equating these phenomena with their models. From this point of view, physics is also not entitled to reject a phenomenon if the latter does not fit one of its theories; this conclusion may seem a truism, but we frequently come across this situation when the science qualifies some artefacts.

2. Time ***is not defined*** in physics as a ***primary*** or ***universal concept***, ***but*** is considered to be measurable: it is a ***numerical parameter the properties of which are defined by the accepted mathematical model***.

Time, ***as a parameter of mathematical models*** that make the basis of the modern physical theories, has the following important properties

* ***There exists*** no primary time scale. In other words, time has no absolute (or universal) solemnity, since a flow of time depends on the choice of model and reference frame. The Newtonian absolute time scale is applicable just for small velocities, restricted areas and low accuracy of measurements.

* Time ***has a feature of*** continuous value since in reality we do not observe discrete processes, aside from the approximating models. Therefore, there are no grounds to consider time as discrete value, with the exception of discrete models being accepted for simplification of simulation.

* ***Neither the*** states ***of the base*** process, ***nor a*** time scale ***specify the*** properties of time in themselves: ***these properties*** are dominantly defined by the functional mapping (viz. ***time function***) of the states of the base process considered in the operational definition ***onto*** the numerical axis.

  In general, the scale is the same (to within a factor) – a segment of numerical axis that presents the unit of time which is further divided into lesser intervals and/or expressed in greater units with the use of decimal or sexadecimal scale of notation.

* ***In a separate TCS the*** time ***is always*** uniform ***as a segment could be uniform.*** In essence, the uniformity presents a comparative property which, through a reference time function, ***reflects*** the ***homogeneity*** of a TCS relative to the reference TCS that is chosen to present the uniform time.

* ***The*** Time ***is not only inseparably*** linked ***with the*** Space (in common, they are called Space-time) ***but generally has a local meaning***: the properties of time are defined not only by the frame of reference, but by the spatial location as well. Due to this reason even the most exact time count system – the TAI – cannot be used as an etalon for all points on the Earth, even for all floors of a skyscraper since in all these points the time flows at different rates.

* For any point of space a parametric axis called arrow of time (***or time axis***) may be defined; with respect to this axis the concepts of Past and Future are specified: the former relates to the events that have taken place, the latter – to the events that may take place, but within the ***Light cone*** of this location.

* Time travel. ***In the physical world*** a travel to the future is possible, but it is unknown how to return to the past (or present) or whether it is possible at all. For different spatial locations the simultaneity and precedence of events are generally ***undefined***.

Thus, if the events A and B take place in different locations of the space, the order of their precedence may depend on the choice of the reference frame: in one frame they could be simultaneous, whereas in other ones A may precede B, or vice versa.

Due to the negative profits (friction, etc.), in the most part of physical models the arrow of time is directed in the future. But if at least one process is irreversible, the system, as the whole, becomes irreversible; therefore, it is natural to suggest that in the physical world (in the observable Universe) the arrow of time is directed to the future and a travel to the past is impossible.

Meanwhile, a possibility of travel in the past is discussed in view of ***hypothetical*** wormhole engendered by topological distortion of space-time that may cause great variation of space curvature in a compact region. However, the ***present studies*** show that out of the bounds of huge space objects (black holes, etc.) the observed space-time is almost flat (in the sense of spatial curvature); this leaves ***little hope*** that a ***wormhole could be found*** in an observable vicinity of the Earth.

3. Time, ***as a numerical*** measure, is introduced ***in physics*** by an ***operational definition*** which relates the states of the selected process to the values of the chosen scale in compliance with the accepted mathematical model of the process. This correspondence presents a ***Time Count System*** (TCS).

That is why the properties of time may differ from a theory to theory. Thus, within the last century the physical concept of time has undergone more changes than during the preceding millennia, but it still retains its operational nature. However, although a continual complicating of the underlying mathematical models has led to great progress in description of numerical properties of time, it has taken the “physical meaning” further away from general comprehension – to a sphere of much more complicated mathematical abstraction. Besides, this complication of theories has not solved the problem of time counting; instead, it has led to creation and widespread use of several more TCSs the most part of which are not synchronous due to the use of secular, relativistic and other types of corrections.

4. In physics the time is related to the ***phenomena*** which manifest themselves but just in the ***physical world***, that is in the ***space-time being accessible for physical measurements***. In this sense the concept of time which deals with the physical theories and objects of physical world is further collectively referred to as a physical time.

Meanwhile, far from all phenomena of the outward things can be described in terms of existing physical models. This means that the applicability of physical time for description of non-physical phenomena is restricted by definition, and application of physical concepts of time to “non-physical” phenomena may cause a confusion and unjust accusations since the latter simply do not belong to the scope of physics.

5. Among these “non-physical” phenomena there are such which are already accepted as the facts (e.g. a series of extrasensory experiment results), but are not yet explained physically, but much more of them (various effects associated with consciousness, materialization and dematerialization, future telling, etc.) are simply ignored by the “science” even if they are acknowledged by independent witnesses as the facts.

But if the physical time describes even the physical processes with the use of different models and does not provide means for describing these phenomena, why other concepts of time based on other models for the respective forms of motion cannot exist? They not only have the right to existence, but are to be accepted by modern science if the respective time count systems are based on the same principle, that is on metrization of the process states by means of ***correlating*** its internal states ***with some*** scale.

Therefore, if the ideas implemented in physical TCSs would also be used in other applications, this could benefit to creation of unitary approach to the concept of time and, on this base, – to better understanding of the phenomenon of Time. Meanwhile, the attributive to the models of these “non-physical” phenomena may reflect the peculiarities of the respective applications.