HUNGARIAN STUDIES YEARBOOK
2019 (I)

sciendo DOI: 10.2478/HSY-2019-0002

# The Space-time of Physics: a Kinetic Space

Zoltán NÉDA
Babeș-Bolyai University, Department of Physics, Cluj-Napoca; e-mail: zneda@phys.ubbcluj.ro

**ABSTRACT:**
In his article "The Space-time of Physics: a Kinetic Space" Zoltán Néda reveals why is there a lot of confusion concerning the space-time of modern physics. These concepts are used routinely, but if we dig in deeply, finally we have to recognize that usually our knowledge is rather superficial and limited. The logic on which space and time is constructed in physics is an interesting and enlightening story, in which light plays an import role. The space-time of physics is tailored on light, it is built by using the propagation properties of light rays. In such view, it is a kinetic space. The author presents the logic of this construction in a concise and non-technical manner, so that readers without any mathematical background can also enjoy it.

**Keywords:** foundation of physics, time, geometry of space, light, measurement, postulates.

My argumentation proceeds along the following questions: 1) The problematic concepts of space and time, 2) The absence of clear postulates, 3) Light as our basic tool, 4) The problem of Aether, 5) Geometry in the physical space, 6) Time as abstraction and causality, 7) Cutting the Gordian knot of a paradox, 8) Strange consequences, and 9) The aftermath.

1) I assume that space and time are probably the most fundamental concepts in Physics. But do we really understand them properly? Fiction and science-fiction writers let their imagination flow freely while using these concepts, borrowing stunning results from physics (see, e.g., Rucker, *Master of Space and Time*). Laymen without any background in physics is no longer surprised by concepts like contraction of space and dilation of time. Time-travel, the discrete nature of time and space, the four or even higher dimensional space-time entities, wormholes, curved spaces are no more strange thoughts for mankind. Unfortunately, however we are all ignorant in going deeply and understand in a rigorous manner our basic concepts we operate with. There is an inflation of science popularizing books about relativity theory, cosmology and elementary particles using the notion of physical space and time (see, e.g., Hawking, *A Brief History of Time*; Mermin, *Space and Time*;

Dainton, *Time and space*). In most of these works, authors with a solid background in physics are juggling freely with these basic concepts, forgetting to define them properly and building thus a solid base for our fundamental thoughts. The media and non-specialist writers reiterate the logic and thoughts of science popularizing books emphasizing the sensational, and forgetting again to ask the most obvious question one should raise: how the space and time of physics is built so that it can have so stunning properties?

As always, there are of course noticeable exceptions and some works are intended to fill in exactly this gap. We mention in this sense the more philosophical books written by Reichenbach (*The philosophy of Space and Time*) and Maudlin (*Philosophy of Physics*). These books are instructive texts in such aspects, the only problem with them is that one has to go through more than 200 pages to only grasp the essence of the problem. Can we achieve this missing and essential knowledge needed for understanding basic physics in a few pages? This is the challenge we face in the present work.

2) My inquiry in this rather philosophical problem is motivated by the absence of clear postulates**.** Physics, similarly with biology, chemistry and geology is basically an experimental science (Rogers, *Physics for the Inquiring Mind*). Its fundamental methods are based on ingeniously designed experiments leading to repeatable results. In order to formulate rigorous scientific laws, quantification of the results and measurements are necessary. For explaining the observed laws logical deduction and mathematics is used. From simple and basic assumptions, we aim to describe the large number of observed phenomena.

We might have missed it during our physics studies, but it is important to realize that both the measurement process and theoretical description is based on postulates and axioms. Similarly, with mathematics, axioms are accepted rules for our logical thinking and deductions. Physics uses the logic of mathematics therefore the axioms are the same. Postulates in physics are accepted facts that are rigorously not provable and do not contradict each other or our experimental observations.

In order to be able to make measurements and quantify the results we first have to postulate the units and a basic measuring apparatus. Theoretical description of the observed phenomena is also based on postulates. The postulates of physics are not always obvious however, and even physicist disagree on what has been or what should be postulated (see for example different treatise on Quantum Mechanics). For a mathematician, the postulates are crystal clear, and therefore the methods of mathematics seem to be more rigorous than the one used in physics. It is indeed a fundamental difference in the manner mathematics and physics deals with the postulates. The postulates of physics are usually based on experimental findings, while the postulates of mathematics are "invented". The main reason for this is that mathematicians study virtual worlds built by their own imagination (constructed on their freely chosen but consistent postulate system, [Whitehead and Russel, *Prin-*

*cipia Mathematica*]), while the object of study for physics is the existing Universe.

Euclidean geometry for example is based on five postulates, and all geometrical constructions and theorems in the Euclidean geometry are logically derived from these (Byrne, *The Elements*). Changing the postulates to another consistent system will lead to another virtual world. This was for example the geometries built by Bolyai, Lobachevsky and Gauss, all motivated by the parallels postulate in the Euclidean geometry (Wolfe, *Introduction to Non-Euclidean Geometry*).

The logic in physics is rather fluid, whoever studied it in more depth has an experience with this. The aim of physics is to understand the real world around us, by accepting a minimal number of unproved assumptions. Inside the same field of physics new experimental findings can contradict existing postulates and therefore change them. During its history, the object of study for physics also increased dramatically. New discoveries coming at an exponentially increasing rate, exploring the micro- and macro-cosmos uncovered completely new aspects of the Universe, and their logical understanding needed more and more postulates, both on the experimental and theoretical side. Physics managed well in describing these new phenomena, but as a side-effect, together with the increased amount of knowledge the number of postulates on which our theories is built increased as well.

Instead of reducing the number of postulates we have increased it without keeping a rigorous record on them and rely nowadays more and more on intuition. We never announce clearly what the axioms of our logic are and what are the postulates on which our theories are build. Physics develops far too quick for allowing much rigorous thinking. Postulates are always there in the background, sometime we are just not aware of them. This is definitely not a big problem until everything goes well, and we do not arrive to logical contradictions in our thinking or discoveries. Many time however the untracked postulate system tricks us. This was the case with relativity theory and it is probably the case today with quantum mechanics, particle physics and cosmology. Simple and logical things might look complicated, basic consequences of the accepted postulates seems unbelievable and paradoxes might arise due to conflicting postulates.

In the followings, I will elaborate more on this idea by considering as example Einstein's relativity theory, and constructing rigorously the space-time of modern physics. By doing so I hope to accomplish a double task. First, I will build for laymen the much-debated space-time of physics, offering a solid base for understanding concepts of modern physics. Secondly, I will illustrate how our postulate system for kinematics had to be adjusted in order to keep up in a consistent manner with the increasing knowledge about the nature of light. I will show that the construction of the physical space-time is possible only as a kinetic space, where the basic entity on which we rely are lights rays. I will argue why this is our best option at the present, and what are the consequences resulting from this logically consistent construction.

3) Light is our basic tool as the primary source for information about the World (Bova, *The Story of Light*). Light rays propagate on straight line in vacuum. We know nowadays that it is an electromagnetic wave, where the wavelength is in a relatively narrow interval. Different colors are electromagnetic waves with different wavelength. An electromagnetic wave is the mutual propagation of variable electric and magnetic fields. According to our knowledge about electricity and magnetism, variable electric field generates variable magnetic field and vice-versa. This mutual induction process is the one that allows the propagation of electric and magnetic fields and consequently the existence of electromagnetic waves. The physics of electric and magnetic field is described in a compact manner by the famous Maxwell equations.

There are however surprises with electromagnetic waves when it comes to its propagation speed. Measuring the propagation speed of light was not a simple task for physics. Light propagates very fast and for a long time the question for physics was whether it is finite, or it just propagates from one point in space to another instantaneously. Galileo Galilei was the first one who attempted to measure its speed of propagation by a simple experiment. He sent his apprentice to a hill top a few kilometers away from his observation point. Both of them had a covered lamp and instructed the apprentice to uncover his lamp when it becomes visible the light from the lamp uncovered by Galilei. In this manner with a simple pendulum, Galilei wanted to measure the time it takes for the light to propagate to his apprentice, and back. Of course, due to its very large value (c=300 000 km/s) the experiment was doomed to be unsuccessful and Galilei concluded that his experiment cannot prove that light travels with finite or infinite speed. The first one who succeeded to prove scientifically that light travels with a finite speed was the Danish astronomer: Olaf Roemer in the year 1676 ("*Démonstration touchant le mouvement de la lumière*"). Roemer studied the motion of Jupiter moons and made detailed observation of the eclipse times for the closest moon of Jupiter: Io. He recorded carefully for a long time-period the observed time-moments when Io enters or reappears from the shadow of Jupiter. His carefully collected data suggested discrepancies between the expected eclipse times: a strange shift of the order of minutes oscillating in correlation with the distance between Jupiter and Earth. He attributed these changes to the time needed for light to propagate from Jupiter to Earth, and in such manner, he suggested that light must travel with finite speed. According to Roemer's results, a few years later Christian Huygens calculated the expected value of c=200 000 km/s (Huygens, *Traite de la lumiere*). This was the best estimate for the propagation speed of light for more than one hundred forthcoming years, and a fantastic scientific breakthrough. Later many sophisticated optical measurements gave more and more precise value for *c*, converging to a value of c=299 792.458 km/s. Nowadays however, following the suggestion made in 1965 by the Hungarian physicist, Zoltan Bay (*Sydenham,* "*Measurement of length*") the value of *c* is postulated, and the unit of distances is built on this postulated value. For laymen, it is hard to understand at this point why this postulate is a logical and acceptable choice, but this should become clear after reading the next sections.

4) Let us begin with the problem of Aether. At the end of the XIX. Century, we had already a vast knowledge about the properties of light. Maxwell's famous equations (see for example Maxwell, "*A Dynamical Theory of the Electromagnetic Field*") forecasted the existence of electromagnetic waves and their universal propagation speed in vacuum. The predicted value was very similar with the experimentally estimated speed of light, so it was a natural step to assume that light is also an electromagnetic wave. Physics faced however a serious catch: all known waves propagated in a medium, and their propagation speed is fixed relative to this background medium. Sound waves for example propagate relative to air. When we state that the speed of sound is approximately 330 m/s we assume this value relative to the medium in which it propagates: air. If wind is blowing, the speed of propagation relative to Earth in the direction of wind is higher, and in the inverse direction is lower. All known mechanical waves in physics propagate relative to a medium, so we have to ask the obvious question what is the situation with electromagnetic waves? What is the medium that fills the whole Universe and relative to which electromagnetic waves propagate? Or in a more scientific approach, a physicist might ask what is the reference frame relative to which Maxwell's equations are valid? This hypothetical medium or universal reference frame for the propagation of electromagnetic waves was named "aether", and a hunt for finding it began. The way physicists attempted to catch aether is by detecting the aether-wind. In a similar manner with propagation of sound waves in air, the existence of aether can be detected by measuring the propagation speed difference in two different direction. If the observer does not move together with aether, we expect that it should be a difference in the measured speed in two different directions of the space. Many cleverly designed experiments (like the one by Michelson and Morley ["*On the Relative Motion of the Earth and the Luminiferous Aether*"]) were carefully performed, most of them exploiting the wave-properties of light, in particular the phenomenon of interference. Experiments become so accurate that aether-winds of a few m/s should have been detected, but independently where and when it has been done, no aether wind was observed. At the end of the XIX. Century and the beginning of the XX. Century physics was in a very uncomfortable situation. We knew that light travels with a finite speed, and light is an electromagnetic wave, but we could not detect the medium relative to which light propagates. The absence of this absolute reference frame was a major problem for physics because physics could not build a consistent space-time entity, and without this there was no physics at all! Strange, isn't? If you understand this, and you are sure that

you rigorously understand it, probably you can skip everything and quit reading anymore, this work will not give you anything new.

5) Proceeding on, and gifted with all the necessary background information, we build the space-time entity of physics. Our first step in this endeavor is the physical space, more precisely the geometry of this space.

The physical space is given and contrary with mathematics we do not have to be concerned with building it, we just have to explore its geometry. In mathematics, the problem is the opposite, we define virtual spaces by defining its geometry. Let us be more specific. In order to have physics in our real space and in order to be able to measure things, a first task is to have distance between any two points. Defining distance between all points in the space it means that we define the geometry of the space. For distance, we first need to postulate a distance unit. Physics postulated this unit, and for a long time it was an etalon rod which has been reconsidered several times (*Cardarelli, Encyclopaedia of Scientific Units*). Beside the distance unit we also need to know the shortest path between any two points, or the trajectory on which one should measure the distance. This is what we call geodesic lines and the space of physics does not come with drawn geodesic lines, Physicists have to discover by experiments which are the relevant geodesic lines, and measure the distances along them. A first possibility would be too look for the shortest distance by playing with a ruler that is calibrated with the etalon meter. This might work on table-top conditions but there too is tedious. How can we do that on microscopic or on cosmologic level? Mathematicians are not concerned about such problems, since for them the space is defined by postulating the geodesic lines or their properties.

Quoting here the thoughts of the famous mathematician, Bernhard Riemann: "It is well known that geometry presupposes not only the concept of space but also the first fundamental notions for constructions in space as given in advance. It only gives nominal definitions for them, while the essential means of determining them appear in the form of axioms. The relationship of these presumptions is left in the dark; one sees neither whether and in how far their connection is necessary, nor a priori whether it is possible. From Euclid to Legendre, to name the most renowned of modern writers on geometry, this darkness has been lifted neither by the mathematicians nor the philosophers who have laboured upon it." ("*Uber die Hypothesen*, welche der Geometrie zu Grunde liegen", 133). In 1876, William Kingdon Clifford raises the problem of defining the geometry in the physical space clearly: "Riemann has shown that as there are different kinds of lines and surfaces, so there are different kinds of space of three dimensions; and that we can only find out by experience to which of these kinds the space in which we live belongs" ("*On the Space-Theory*" 157–58).

In order to have a well-defined geometry (coordinates and distances) in our physical space we first have to find a methodology for constructing geodesic lines. The method should work and allow experiments on all length scales, from atomic to cosmological one. Starting from our experiences in table-top experiments where we notice that in vacuum light rays propagate along the "straight lines" defined by the classical rulers, we might turn the problem around. We could postulate that not the ruler is the straight line (geodesic line) but the trajectory of light rays in vacuum defines the "straight line". This twist than becomes useful on microscopic and cosmological scale. The geodesic line between two points in vacuum is given by the trajectory of light-rays, and finally the whole geometry of the physical space is constructed on light. The trajectories of the light rays will decide which geometry of mathematics fits the properties of the physical space. If this geometry has locally the properties of the Euclidean geometry than we affirm that the physical space is locally Euclidean. If the geometry given by the properties of light rays fits better other non-Euclidean geometries we do speak about "curved spaces", where the laws of the Euclidean geometry are not valid anymore. For instance, in our experiments we might find that a triangle defined by three light rays passing between three points of the physical space does not have the basic property taught to us in school: the sum of the internal angles being $180^0$. This is a clear sign, that the local geometry of our physical space is non-Euclidean, and we do have a "curved space". The postulate of modern physics is thus simple: the geodesic lines defining the geometry of the physical space are given by the trajectory of light-rays. A ruler is straight if it follows the path of light rays in vacuum. If at a given space location the two are not on the same path, then we must conclude that our ruler is curved and not the light ray. After postulating also the distance unit (the etalon meter), we have a consistent method for defining the geometry of the physical space. From this moment on we can define distances between any two points, and physical measurements can be done. The geometry we have imposed thus on the physical space is built on the "kinetic space", defined by the propagation of light-rays. 6) And now, how about time? Does the physical space come with inbuilt time and we just have to unveil it, or we physicist have to define it in order to become a useful tool for us? The question of "what is time?", is probably the most elementary question in philosophy, and again books have been written on this subject. I will keep here a distance from all philosophic debates, and look into the problem strictly from the viewpoint of a physicist, interested to describe through scientific laws the complexity of the Universe. In a completely static Universe time would be meaningless for a physicist. Changes and motion gives sense to time, and once it is properly defined we track changes and motion by using it. Time is not a basic quantity, and it does not come in package with the physical space. As early as the IV. Century St. Augustine attempts to raise this problem: "I heard once from a learned man, that the motions of the Sun, Moon, and stars, constituted time, and I assented not. For why should not the motions of all bodies rather be times? Or, if the lights of heaven should cease, and a potter's wheel run round, should there be no time by which we might measure those whirlings, and say, that either it moved with equal pauses, or if it turned sometimes slower, other whiles quicker, that some rounds were longer, other shorter?" (Saint Augustine, "*Confessions*" *11. 23. 29.* 397–98, AD 397)

Time must be related to motion and changes, but at the end why do we need the concept of "time" in physics? My answer to this question goes back to the stated aim of sciences: understanding repeatable laws of the Universe. We trust in the "holy grail" of sciences: the existence of causality which allows of searching for universal laws: every effect has a cause, and causes have to precede the effect. Without entering in this philosophical subject, we can state that in science we always look for a phenomenon from the viewpoint of causes and effects, and scientific laws are about discovering these relations. In order to use this basic methodological postulate, we have to order events on a time-scale, and only events that have smaller time-coordinates can be the cause of events with higher time-coordinate. This is the reason why time as an ordering relation between the events is needed in physics.

In case we restrict ourselves for a given spatial location, introducing a well-defined time coordinate is definitely not a problem. We just need an apparatus, named from here on as the master clock, that is able to produce repeatable pulses. The interval between these pulses will be considered as unit time length, and is postulated to be the same between all pulses of the master clock. Since this is the postulate on which we define the unit time length, it does not make sense to question the uniformity of the pulses for the master clock.

The Czech physicist and philosopher Ernst Mach, concludes similar thoughts about physical time:

> It is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction, at which we arrive by means of the change of things; made because we are not restricted to any one definite measure, all being interconnected. A motion is termed uniform in which equal increments of space described correspond to equal increments of space described by some motion with which we form a comparison, as the rotation of the earth. A motion may, with respect to another motion, be uniform. But the question whether a motion is in itself uniform, is senseless. With just as little justice, also, may we speak of an "absolute time" – of a time independent of change. This absolute time can be measured by comparison with no motion; it has therefore neither a practical nor a scientific value; and no one is justified in saying that he knows aught about it. It is an idle metaphysical conception. (Mach, *The Science of Mechanics* 224)

Sundial, clepsydra or hourglass were used by our ancestors as clocks, and the motion of the Sun or the Moon was used for defining time-unit. A great advance in time measurement was made by the invention of pendulum clocks by Galileo Galilei and Christian Huygens. Mechanical watches driven by the oscillation of springs took over in the XVIII. Century allowing movable and more handy clocks and nowadays we use in our watches electric pulses controlled by the oscillation of quartz crystals to measure time. The most precise time-keeping tool nowadays is the atomic clock that uses one electronic transition frequency of a specified atom for defining the time etalon (Jespersen and Randolph, *From sundials to atomic clocks*). If the pulses of the master clock can be arbitrary small (like it is now with atomic clocks) for each event that takes place in the given spatial location of the clock we can assign a time-like coordinate, which in principle can be considered as a continuous measure.

Measuring the time in one point of the physical space is not a big challenge thus, assuming that we already have our master-clock and the clock is in the same spatial location with the event. The problem we have to face however is that events are usually happening in different spatial positions and in different reference frames, and we have to time these events too (Flechon, *The Mastery of Time*). By different reference frame we mean here systems that are moving respective to the master clock. Take the case for example of an event that happens in a moving train and the master clock is outside of the train. The elementary problem of measuring the speed of a particle implies already measuring the time for events that take place in two different spatial locations. How can such measurements be done for many moving bodies when our master clock cannot be in all spatial locations where events are happening?

One possibility is to "clone" the master clock, synchronize the clones by bringing them all together at the position of the master-clock, and after that displace them all over the physical space and reference frames where we are timing events. This is similar with what we are doing nowadays here on Earth. The big problem we face is that unfortunately no two clocks are exactly the same, or in other word the clones are not perfect. As a result of any tiny difference between them, the clocks will rapidly desynchronize from the master clock, and for precise timing we have to resynchronize them from time to time. It is not feasible to bring back them at the location of the master clock periodically, since usually moving the clocks also favor desynchronization. A solution that one could follow is to synchronize them by signals that travels in a controlled manner from the master clock to any clock. The signal would carry the time given by the master-clock, and when it arrives to the clones it transmits this information to the clone. If both the coordinates of the master-clock and the clones are known, one can calculate the time necessary for the signal to reach the clone. By adding this time to the time-information carried in the signal the clocks can be resynchronized. For proceeding like this we would need a universally usable signal and we have to know its propagation speed in all direction of space and relative to all reference frames.

Alternatively, we can time events with such a signal in an even simpler manner. Whenever an event happens in one moment of the physical space we transmit this signal to the master clock, and record the time it arrives there. By knowing the distance between the master clock and the event one can subtract from the recorded time the travel time of the signal and we have the time of the event. Seems thus everything solvable once we have this universally usable signal or information carrier. If we would have an infinite propagation speed for this signal, it would be the best, since we do not have to bother ourselves with subtracting the travel time.

Up to our present knowledge nowadays we have only one such usable information carrier, which is the electromagnetic wave and in particularly light. We know that electromagnetic waves travel with finite speed. What we do not know however is relative to what it travels with the known speed, since physics by careful experiments couldn't locate the hypothetical aether. How does light travel than relative to different reference frames, and how we deal with the effect of the aether-wind for precisely timing events if we do not know where aether is? These were serious problems physics had to face after learning that light travels with finite speed and aether couldn't be located. By making a long dilemma short, physics at this moment had no well-defined time and without time it was not trustable for rigorously investigating the laws of the Universe. Even the measured speed of light value is thus highly questionable. By not having a rigorously measurable time in different space points only those time measurements made sense that were made at the location of the master-clock.

7) What is thus the logical way out from this paradox, and how we cut this Gordian knot? Undoubtedly the outcome from this paradoxical situation is due to Einstein. The simple solution was always there for us even before entering in the catch with aether, and physicist had only to clarify again their basic assumptions about space and time and rethink how time is measured and defined. Einstein realized that until the aether problem is not solved we have no time, so nothing makes sense in physics. Detecting aether would also create a complication for precise timing, since it would become really complicate to always keep track of the aether wind in precise timing. We need thus a postulate that allows a simple and consistent method for defining physical time and allowing physics to continue its successful path.

Einstein postulated that there is no absolute reference frame (there is no aether) and consequently there is no aether-wind. This means that the value of the speed of light (and for all electromagnetic waves) in vacuum is a universal constant (Einstein, "*Zur Elektrodynamik bewegter Körper*"). It is independent from the propagation direction of the light rays or even the reference frame of the observer. This is in agreement with what experiments suggested for us before, but the question we might ask now is what kind of time definition was used in those experiments? What was the physical space-time, leading to this conclusion? Thinking now back we realize that in fact it was the same space-time that appears in the Maxwell's equations, and we learned later that this space time is built in an ignorant manner on Einstein's postulate. So, finally is it true in reality that there is no absolute reference frame for electromagnetic phenomena? We still do not know of course, and the question does not even make sense because time was not properly defined before accepting this postulate. Once we have accepted this postulate, it will be very hard to contradict it by experiments. All consistent time measurements should be in agreement with what we have postulated and aether is lost in this paradigm.

Let us do our final step in building a consistent space-time entity. Up to this moment we have postulated the unit of length, the unit of time and the universality of the speed of light. So, time can be consistently defined in all points of the physical space. We can do it even better, and this is what Zoltan Bay proposed in 1965 and was accepted internationally in 1983 (*Cardarelli, Encyclopaedia of Scientific Units*). When postulating that the speed of light is a universal constant independent of the direction of motion or reference frame of an observer, why not postulating also its value. If we do this we can get rid of the etalon meter, and the unit length will be given by the postulated value for the speed of light and the postulated unit time length. Whenever we want to measure any distance, we do it by our synchronized etalon clocks and by using light-rays. If the value postulated for the speed of light will be the best estimate given by experiments, the meter will remain the same with the etalon meter rod, and the space-time of physics becomes simpler. The new meter-rods will be calibrated by time-measurements. This is what we have done, and by this concluded the rigorous construction of the physical space-time.

At this moment an immediate question comes to our mind: why physics was still successful even before constructing rigorously the space-time based on the above discussed postulates, and why did not encountered many paradoxical situations? The answer is simple, it is due to the very high propagation speed of light and the "straight-like" propagation path in the direction of our classical rulers in vacuum. For the lab-scale experiments, physics can freely use the picture of instantaneous propagation of light, so the time moment we detect an event is with a good approximation the moment it happens. Synchronization of clocks is trivially simple and time and distance measurement is also simple assuming an infinite propagation speed for light. In this limit, we do not have to bother ourselves with time-delay introduced by the finite speed propagation of light, and the space of physics approximates well the Euclidean space constructed with a ruler. When physics left the laboratory scale and began investigating astrophysical and cosmological phenomena, or extended its investigation on atomic scales, the classical space-time became contradictory, and the only choice for rigorous measurements and consistent theories is by accepting the space-time built on the above discussed postulates. The space-time of modern physics is thus a kinetic space tailored entirely on light propagation.

8) Our choice for constructing in such manner the space-time of modern physics offers several solutions, but we also have to deal with strange consequences. A well-defined space-time was built on a postulate system that is adjusted to the experimental findings concerning the properties of light. This space-time is different from the space-time of classical physics, introduced by Galilei and Newton which is built on a postulated Euclidean geometry and instantaneous propagation of light. Our basic knowledge about physics and our scientific education is rooted however in the older paradigm, and therefore it comes as a surprise many logical and direct consequences of this newer construct. The most astonishing impact that we have to adjust to is that the absolute nature of time is lost, and therefore relativity has to take over our thinking.

Let us briefly discuss now some consequences related to relativity (*Einstein, Relativity*). Physics has an old postulate concerning inertial systems. Inertial systems are those one in which the laws of inertia hold: an object at rest remains at rest and an object in motion will keep its motion with an unmodified speed and direction, unless an external unbalanced force is acting on it. Inertial systems are those in which the geometry of the space is the simplest one: it is Euclidean. This space is homogeneous and isotropic. The relativity principle rooted in experimental observations states as postulate that all inertial systems are equivalent from the viewpoint of physical laws. This means that the laws of physics should be the same whenever they are written in any space-time that is built in an inertial reference frame. Admitting that in all inertial systems the geometry of the space is the same Euclidean geometry, the relativity principle seems justified. Experiments also show, that if there is an inertial system, all reference systems that are moving with a constant speed relative to this one are also inertial. This is purely an experimental fact so it is again a basic principle of physics. An important question which arises in physics is to describe events from different inertial reference frames. Let us assume that we do have an event in reference frame R, and we know it's time and its spatial coordinates. The question we often pose is to determine the space-time coordinates of the event in another reference frame R', if we do know how R' is moving relative to R. This is what we call coordinate transformations between inertial reference frames.

In the old Galilean-Newtonian space-time the coordinate transformations are the well-known Galilean transformation. According to this, the time-interval of any event measured from different reference frames are the same, the spatial extension of an object measured from difference reference frames are also the same, and if two events are simultaneous (they have the same time-coordinate) in an inertial reference frame it will be simultaneous in all inertial reference frames as well. The law of velocities composition is also simple. If reference frame R' is moving with velocity $\vec{u}$ relative to reference frame R, and an object is moving with velocity $\vec{v}$ relative to reference frame R, then the velocity of the object as measured from reference frame R' will be: $\overrightarrow{v'} = \vec{v} - \vec{u}$.

In the space-time based on the finite propagation speed of light and Einstein's postulate the resulting coordinate transformations are more complicated. These transformations are known as Lorentz coordinate transformations and according to these we have strange results. Simultaneity of events will lose their absolute character. If two events are simultaneous in an inertial reference frame they might not look simultaneous from other inertial reference frames. The time-interval of events and spatial extension of objects might be different if viewed from different inertial systems, and in this context, we use terms like time-dilation or length-contraction. The time length of an event measured from a reference frame that moves relative to the observed event is larger than the one measured from an observer which is in rest relative to the event. The length of an object measured by an observer who is moving relative to the object is smaller in the direction of the motion than the length measured by an observer who is in rest relative to the object. Composition of velocities becomes more complicated, and in agreement with Einstein's postulate the transformations lead to the result that the speed of light added with any speed will result in the speed of light. But we should not be surprised about this, since we have to be in agreement with the postulate on which our whole space-time construction was done. Of course, all the above presented consequences become important only if we consider movements of the inertial reference frames with extremely high velocities. In the limit of velocities much smaller than the velocity of light, the Lorentz transformations will lead to the Galilean coordinate transformations, so these strange effects are hardly observable.

An interesting consequence of the Lorentz coordinate transformations is that we get in problem if we consider velocities bigger than the speed of light. All type of singularities appears in the Lorentz coordinate transformations, causality of events breaks and seemingly Einstein's space-time becomes unusable to describe such motions. In our present space-time paradigm, no object can move faster than light. Definitely, if we would observe that something is moving faster than the speed of light, we have to adjust again our postulates and build another consistent space-time for physics.

9) In the end let us draw some conclusions. Physics after all is a rigorously built science. Its logic is beautiful, unfortunately we do not teach it in a manner that students can enjoy its logical beauty. It is important however to know, that even in Physics there is no ultimate truth. All we understand and do is built on some postulates, our basic quantities and our theories are all true in the chosen postulate system. As physics evolve, the postulates might change, and understanding of the Universe can become more and more evolved, but we should never forget that our knowledge is always bounded by basic assumptions (postulates or

axioms) that we cannot prove. In a logical thinking paradigm postulates are always there, and in order to be rigorous and to avoid unnecessary paradoxes we have to be aware about them. Before searching for the sensational and joggling with expressions that is far beyond our rigorously founded knowledge, let us stop and make order in our thoughts: do we really understand what we are iterating, do we really have the necessary knowledge? It might be easier to achieve this knowledge than we would expect it.

The present work was partially supported by the UEFISCDI grant: PN-III-P4-PCE-2016-0363. I dedicate this study to my high-school physics teacher, **Jenő Tellmann**, on the occasion of his 90th birthday.

## Works Cited

Augustine, Saint. *Confessions, Book XI*. Trans. Vernon J. Bourke. Washington: Catholic University of America Press, 1966.

Bova, Ben. *The Story of Light*. Naperville, Illinois: Sourcebooks Inc., 2001.

Byrne, Oliver *The Elements of Euclid*. London: William Pickering, 1847.

Cardarelli, Franciois Encyclopaedia of Scientific Units, Weights and Measures. London, Springer-Verlag, 2003.

Clifford, William Kingdon. "On the Space-Theory of Matter", *Proceedings of the Cambridge Philosophical Society, 1864-1876*. Printed 1876, 2: 157–58.

Dainton, Barry Francis *Time and space*. New York: Routledge, 2014.

Einstein, Albert. *Relativity: The* Special and General Theory. New York: Henry Holt and Company, 1920.

Einstein, Albert. "Zur Elektrodynamik bewegter Körper." *Annalen der Physik*, 17 (1905): 891–921.

Flechon, Dominique. *The Mastery of Time*. Paris: Flammarion, 2011.

Hawking, Stephen. *A Brief History of Time*. New York: Bantam Books, 1998.

Huygens, Christian. *Traite de la lumiere*. Leyden: Pierre van der Aa, 1690.

Jespersen, Jame and Jane Fitz-Randolph. From Sundials to Atomic Clocks: Understanding Time and Frequency. Mineola, New York: Dover Publications INC, 2011.

Mach, Ernst. *The Science of Mechanics: A Critical and Historical Account of Its Development*. Chicago: The Open Court Publishing CO.,1919.

Maudlin, Tim. *Philosophy of Physics, Space and Time*. Princeton and Oxford: Princeton UP, 2012.

Maxwell, James Clark. "A Dynamical Theory of the Electromagnetic Field." *Philosophical Transactions of the Royal Society of London* 155 (1865): 459–512.

Mermin, N. David. *Space and Time in Special Relativity*. New York: Mcgraw-Hill, 1968.

Michelson, Albert Abraham and Edward Williams Morley. "On the Relative Motion of the Earth and the Luminiferous Aether." *American Journal of Science*. 34 (1887): 333–45.
Reichenbach, Hans. *The philosophy of Space and Time.* New York: Dover Publications,1957.
Riemann, Bernhard. "Uber die Hypothesen, welche der Geometrie zu Grunde liegen." Göttinger Akademische Abhandlungen, published by R. Dedekind in *Abhandlung en der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, Vol.13 (1867): 280-299.
Roemer, Olaf "Démonstration touchant le mouvement de la lumière trouvé par M. Roemer de l'Académie des sciences." *Journal de Scavans*, 12 (1676): 234–36.
Rogers, Eric M. *Physics for the Inquiring Mind: The Methods, Nature, and Philosophy of Physical Science.* Princeton, New Jersey: Princeton UP, 1960.
Rucker, Rudy. *Master of Space and Time*. New York: Thunder's Mouse Press, 2005.
Sydenham, Peter H. "Measurement of length". In Boyes, Walt, ed. *Instrumentation Reference Book* (3rd ed.). Burlington: Butterworth–Heinemann, 2003.
Whitehead, Alfred North and Bertrand Russel. *Principia Mathematica*. Cambridge: Cambridge UP, 1917.
Wolfe, Harold E. *Introduction to Non-Euclidean Geometry*. New York: Holt, Rinehard and Winston, 1945.

## Author's profile:

Zoltán Néda is a professor of Theoretical Physics at the Babeș-Bolyai University. His scientific interests are in the field of statistical and computational physics applied to interdisciplinary problems. He is interested also in the philosophy behind the foundation of modern physics. He published over 100 ISI indexed scientific papers and four university level textbooks for students. E-mail: zneda@phys.ubbcluj.ro