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ZENO'S PARADOXES AND THE QUANTUM MICROWORLD: WHAT THE APORIAS CONVEY[1]

ABSTRACT
The article considers new approaches to four of Zeno's paradoxes: the Arrow, Achilles and the Tortoise, the Dichotomy, and the Stadium. The paradoxes are analyzed in the light of current research in the field of elementary particle physics and some promising directions in the development of the quantum gravity. Physical theories, provided with the necessary philosophical interpretation, are used in order to clarify Zeno's paradoxes and to search for answers to them. The text shows that using modern approaches to solve the paradoxes is not effective, because the paradoxes become irrelevant when analyzed in the context of microworld physics, at very small scales.

The main part of the paper is devoted to demonstrating this circumstance – that the questions posed by the paradoxes are impossible to answer (at least in their classical interpretation). As a possible explanation, the article puts forward that in the formulation of the paradoxes, the properties of the macroworld and the microworld are mixed (which is historically justified, given the intuitive homogeneity of the large and the small, and the fact that non-classical physics – quantum mechanics – did not emerge until the twentieth century); that is, from the observation of large physical objects, a transition is made to the infinitely small in terms of discreteness and continuity. However, the principles of organization of space at very small scales are beginning to be clarified in general terms only now, and, perhaps, these principles may turn out to be quite far from the classical ideas about fundamental physical reality.

KEYWORDS
Zeno's paradoxes, philosophy of science, macroworld, microworld, duality, space, time, motion, continuity

Introduction

Zeno's paradoxes have been discussed in the philosophical and scientific literature for centuries, but even now, more than two millennia after their formulation, there are still discussions about their meaning. Some believe that

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the paradoxes have been resolved and do not pose a serious problem for science and philosophy, while others, on the contrary, insist that a solution has yet to be found.

An interesting and important (though, of course, not complete) overview of the problem is given by Alexandre Koyré in his work *Remarks on Zeno's Paradoxes* (Koyré 1985). He conducts a detailed analysis of each aporia, criticizing the existing approaches and interpreting them in different aspects, and draws conclusions about the reasons why it is so difficult to solve them. Indeed, the choice of the directions for possible solutions may depend on the interpretation of what, in fact, these aporias convey. Also noteworthy is the monograph by V. Ya. Komarova (1988), entirely devoted to Zeno's arguments, their textual, historical-philosophical, and mathematical analysis. A more modern attempt at logical and mathematical understanding of the paradoxes was proposed by A. M. Anisov in his work (Anisov 2000), where their relevance in the context of modern science is once again emphasized. At the same time, another opinion deserves attention – that interpretation of the paradoxes exclusively in the context of modern science does not reveal their authentic content, and that they should be interpreted in the logic of Parmenides, which reveals the inseparability of human beings in their existence (Calenda 2013). Therefore, in order to avoid ambiguities, we stipulate that we are talking about an interpretation which became possible only due to the development of science in the 20th century, and which, quite obviously, the Eleatics and doxographers could not be aware of.

Koyré's approach much coincides with the modern interpretation trend, since he was familiar with general relativity and quantum mechanics, as well as cutting-edge mathematical tools. Koyré contributes a lot to the advanced research in physics and mathematics of the XX century. Thus, we will proceed primarily from the understanding proposed by Koyré, which is within the framework of the traditional discussion (and is based on the formulations of the paradoxes given by Aristotle in books IV (chapters 2, 3), VI (chapters 2, 9) and VIII (chapter 8) of his *Physics* (Aristotle 1976)), but where necessary, we will refer to more recent studies. The analysis will touch upon the Achilles and the Tortoise, the Dichotomy, the Arrow, and the Stadium paradoxes.

The paradoxes suggest the impossibility of motion from two points of view – continuity and discreteness of space and time; regardless of whether space is continuous or discrete, the conclusion is the same: motion is impossible.

It seems to us that the paradoxes should be interpreted as a contradiction between classical logic[2] and classical physics (and also, as will be shown, non-classical physics – quantum theory). In other words, the paradoxes actually do not deny motion; they point to the above-mentioned contradiction between physics and logic: obviously, motion exists, it is an observable fact,

2 It appears that classical logic, which dates back to antiquity, serves as the representation of classical intellectual intuition, which differs from today's many-valued logic, intuitionistic and paraconsistent systems.

but when analyzing motion in space-time, we come to the conclusion that it is impossible from the viewpoint of classical logic. In other words, traditional concepts of time and space, as well as their general interpretation come as controversial: we make observations, notice some action, but when we start contemplating on it, it turns out that it does not exist. Thus, the problem is not that there really is no motion, but that there is a contradiction between the observed reality and the way we think about it.

Why does this contradiction arise? The present study is mainly an attempt to answer this question. It will be shown here that the paradoxes touch upon questions that can hardly be resolved in principle within the framework of classical intellectual intuition and the corresponding physical theories, since they involve an unjustified transition from the macro level of everyday observations (human capabilities formed in the course of evolution) to the micro level, where the key role is played by quantum processes, and even further – to the level where there is no satisfactory theoretical description for those categories that are considered to be fundamental. The idea that the paradoxes cannot be solved is not new, but we will try to explain *why* they cannot be solved. The hypothesis is that the problem as it is currently formulated may not make sense.

I presume, the issue is that fundamental reality lacks an accurate description, thus, there is no clear idea of what space, time and action together with other basic physical principles are. Still, when they are going to be finally realized, it will prompt the apparent contradiction in aporia to vanish.

The Paradoxes and Some Traditional Objections

The Dichotomy and the Achilles paradoxes proceed from the hypothesis of continuous space and time (infinitary hypothesis).

(1) The Dichotomy consists in the fact that if we assume space to be continuous, i.e., divisible to infinity, then motion can never begin, since in order to overcome any negligible distance, it is necessary to overcome part of this distance, and so on ad infinitum, and thus, to even start moving, you need to overcome infinity.

There have been various attempts to solve this; one of them relies on the assumption that motion itself should be considered as a single indivisible process from the moment when it begins and to the moment when it ends. Indeed, if motion is represented as indivisible, then, at first glance, the problem seems to be eliminated. Indivisible motion is smooth, non-quantized motion that simply goes through all the points without stopping anywhere. This seems convincing, indeed, because a moving body "[...] at no moment exists at any point of its motion: the matter is limited only to the fact that it passes through all these points" (Koyré 1985: 37) and "the moving body moves in each point of its trajectory" (Ibid.: 32). But at the same time, it turns out, paradoxically, that at each fixed, indivisible point, there is no motion, and neither is there at the beginning or the end of the motion, and then it is not clear when there is any motion at all.

(2) The Achilles paradox, arguing that Achilles will never catch up with the tortoise, is essentially about the same thing – about infinite divisibility because of which the tortoise will always be ahead (during the time that takes Achilles to reach the point where the tortoise used to be, it will crawl forward a little, so Achilles will now have to reach *that* point, but the tortoise will have crawled forward a little more, and so on ad infinitum). Thereby, it looks as if they fail to even start moving.

A well-known objection is the mathematical argument about the convergence of series: the sum of an infinite number of time intervals converges and equals to 1, as a result of which Achilles will catch up with the tortoise. However, Hilbert and Bernays rightly note that this reasoning absolutely does not take into account one essentially paradoxical moment, namely the paradox which consists in the fact that an infinite sequence of successive events, a sequence the completion of which we cannot even imagine, in fact, still has to be completed (Hilbert, Bernays 1979: 40).

It is possible to establish a one-to-one correspondence: to match a point of the tortoise's motion to each point of Achilles's path, and vice versa; thus, they will go the same way, and he will overtake the tortoise. However, this is not the case; their paths are equivalent but not equal. It is possible to establish a one-to-one correspondence between a set of natural numbers and a set of even numbers, but this does not mean that they are equal. But this solution seems instantly not plausible, since the tortoise has a head start, so even if the same number of points implies equal distance, Achilles would still be behind the tortoise.

One solution to the Achilles paradox, like in the case of the Arrow, is to consider motion itself to be indivisible, in which case it simply passes the points without measuring them at some particular moments. This solution itself is difficult to understand: in this case, we cannot say "the moving object is at point *A*, and it is 12.00 now", because that would mean it is not moving at point *A*.[3] But we can say "the moving object passed point *A* at 12:00," i.e., only in retrospect.

From this point of view, the paradoxes speak not so much about the impossibility of motion as about the impossibility of immobility. Attention has already been drawn to this in (Bathfield 2018: 649–679), and this approach is close to quantum mechanics – elementary particles are never at rest, as it is fluctuations that are typical of microcosm constituents.

The main problem in both paradoxes is the continuity of space: why do we consider it possible to divide it into segments? In that case, it is no longer a continuity, since there are division points (restricting limits) – we no longer assume these points to be divisible (if we assume that a point is an elementary object that has no dimensions); we divide the segments between them. A point is isolated; moreover, there can be no motion at these points, because

3 In the microworld of quantum mechanics, however, this is exactly what happens – we cannot say that some object is in some particular place; this is indicated by the de Broglie wave and the uncertainty relation.

otherwise they would be extended. But there can be no motion outside of the points if we assume that the continuity is composed of them. But then it is not a continuity at all. If we can divide the points (the boundaries of a segment of the continuity), then there are no boundaries as such, they move apart to infinity, and there can be no motion either.

The second group of paradoxes, the Arrow and the Stadium, consider space-time as having limits of division, i.e., as discrete (finitary hypothesis).

(3) The essence of the Arrow is as follows. If there are limits to the division of space and time, i.e., spatial and temporal intervals which are no further divisible, then the arrow will not be able to move, because if it moves, it measures these intervals, and therefore they become divisible. In other words, at every indivisible moment of time at every point in space it is at rest since it cannot move therein. One can only assume that the arrow teleports from point to point (which is physically possible in the microcosm but not observed in the macrocosm), see one of the latest experiments (Ren et al. 2017)).

The Arrow is probably one of the most popular paradoxes in modern physics and mathematics.[4] Patrick Reeder suggests using nilpotent infinitesimal time intervals to solve the paradox (Reeder 2015). This solution does not suit us, because the infinitesimal is actually one of the causes of paradoxes – the gap between the observed and the way of thinking. And this is not so much a solution to the paradox as a confirmation of the main idea of this paper. Moreover, the gap between the observable and the conceivable is apparent. The way of thinking, the thinking process and the conceivable are different things, which are closely intertwined: our contemplation is largely determined by what our way of thinking is. In the end, speculations can reach far beyond than direct observation – which is proved by quantum mechanics and mathematics. We prefer the approach formulated by Leonard Angel (2002): he proposes a new version of the Arrow paradox, which turns out to be a non-classical (quantum mechanical) extension of Newtonian mechanics, and proposes properties such as appearance of a particle in many places at the same time.

(4) The Stadium paradox is based on the same finitary hypothesis. There may be different interpretations; let us consider one of them. Let there be three rows, each consisting of four objects – row *A*, consisting of objects *A1*, *A2*, *A3*, and *A4*; row *B*, consisting of objects *B1*, *B2*, *B3*, and *B4*, and row *C*, consisting of objects *C1*, *C2*, *C3*, and *C4* (we can consider these rows as straight lines, thus regarding them from the point of view of the infinitary hypothesis). Let the first row (*A*) be motionless, and the rows *B* and *C* move at one indivisible moment of time by one indivisible interval of space in different directions (for example, *B* moves to the left, and *C* moves to the right.) What happens is that while rows *B* and *C* are displaced relative to row *A* by one interval of space in one interval of time, they are displaced relative to each other by two intervals. Therefore, according to Zeno, half is equal to the whole. In fact, the problem

4 This paradox gave its name to the quantum Zeno effect (deceleration of changes in a quantum system with frequent measurements) (Bar 2000).

is that there can be no motion within one interval of space (otherwise it would be measured and become divisible), only within at least two; that is, not one interval of space but two must correspond to one interval of time.

This paradox is the subject of the article by Barbara Sattler (2015), who notes that it is underestimated in the history of philosophy and science, and is considered as naive, or misinterpreted as another atomistic paradox. This is true, and we agree that this aporia actually touches upon the deep connection between space, time, and motion. The research reveals that the principal assumption that leads to Zeno paradox is the one that claims time and space to be interdependent with respect to a certain action. This assumption is apparently adequate when we consider the case of a body moving at a constant speed past a succession of stationary objects arranged in a row. Nevertheless, the correct assumption, appears quite close to the latter assumption though allows to avoid the paradox. It emphasizes the time and space relation with reference to such action. In fact, they are so closely interrelated that all other action parameters remain unchanged, we can treat them as interdependent. It is for this reason that Zeno's Route – to make time subordinate to space – may seem effortless. Still, time and space are independent units although they are parts of one fundamental whole. The latter is obvious if altering at least one parameter, when, for instance, the segment to be covered changes its position itself, or, when one row in action overtakes another one (for the historical background and major interpretations of the Stadium see also (Davey 2007)).

Considering all the four paradoxes, Koyré (1985: 29–30) comes to the conclusion that from whatever position we approach each of them – that of the continuity of space and time or that of their discreteness – they are equally insoluble (for example, from the standpoint of the finitary hypothesis, it is possible to apply the objections from the Stadium to the Achilles and the Dichotomy).

Two Viewpoints: Smooth and Quantized Space-Time

In the analysis of the paradoxes, we will proceed from two different viewpoints: the general theory of relativity and quantum field theory (as well as from the viewpoint of the consequences resulting from an attempt to combine them). In the first case (Einstein's theory of gravity) we are dealing with smooth space-time. It means that it is not quantized and is continuous.

The continuity of space-time technically refers us to the first two paradoxes. Here we have the classical interpretation of the paradoxes and the debate about how motion should be understood.

General Theory of Relativity

In modern physics, motion is defined as follows: motion is a change in the spatial position of a body or its parts relative to other bodies over time (Newtonian mechanics regards action in relation to absolute space. Nevertheless, modern physics tends to dispute the concept of absolute space). Indeed, motion occurs in time (recall the Aristotelian "time is a measure of motion" (Aristotle 1976: 97–98) but it can also be put vice versa: motion is a measure of time).[5]

In the theory of relativity, the properties of space and time are not absolute but relative. This, in particular, means that for different observers (different frames of reference) time flows differently; in other words, there are no simultaneous events (relativity of simultaneity). It is possible to transform the theory of relativity so that when similar phenomena take place, objects – in relation to space – will seem different in size to different observers.[6] In the theory of relativity, there is a limit to the speed of motion in space – it is the speed of light (moreover, it is constant; even if the tortoise tries to catch up with light at a speed lower than the speed of light by 1 km/s, light will move away from it not at a speed of 1 km/s but at its maximum speed). When an object moves at the speed of light, time slows down to the extreme – for those observers who observe the object moving at such a speed; for the object itself, time goes on as before; this is a consequence of relativity of time.

In their classical interpretation, Zeno's paradoxes describe what we would call today Newtonian or non-relativistic situations. Newton's space and time are absolute, space is not curved, time flows in the same way everywhere, and gravity spreads instantly. The differences between the theory of relativity and the Newtonian mechanics begin to play a role only in extreme conditions (at very large masses/energies and high speeds). However, the paradoxes in their usual formulations describe purely Newtonian situations and do not take the effects of the theory of relativity into consideration.

In order to try and take those effects into consideration, we can do the following: assume that the tortoise and Achilles are particles capable of developing ultra-high speeds. In this case, the situation is as follows. Achilles is known to be faster than the tortoise. But there is a speed limit – the speed of light. Thus, Achilles's maximum speed is the speed of light. Therefore, the tortoise moves more slowly. Let us assume that Achilles moves at the speed of light. This means that no matter how fast the tortoise runs, Achilles will move relative to it at the speed of light, and from the tortoise's point of view, he will move in space almost without spending any time (and not grow old – which in our case does not matter). Achilles still will not catch up with the tortoise, so long as we single out points in the continuity.

However, in the case of the Stadium, the situation may change. The fact is that in the theory of relativity, not only speed and direction play a role, but also the distance between the moving objects. If the three rows are far enough apart in space (in fact, very far apart in the universe), then this circumstance will play a role – there will be no simultaneous motion of rows *B* and *C* in opposite directions due to the relativity of simultaneity. What appears to be simultaneous to one observer is not to other observers, and either row *C* or row *B* starts motion later. But these are exotic situations that hardly need to

5 For an overview of some relevant studies on time, see (Karpenko 2016).
6 See (Gomes, Koslowski 2012)

be considered here since we are analyzing the classical version of paradoxes, where there is a unity of place, time, and action.

Quantum Theory

Quantum mechanics states that space is quantized. It is assumed that there are elementary, further indivisible particles. In the Standard Model of elementary particle physics, these are quarks, leptons, and gauge bosons. The problem, however, is that from the mathematical point of view, particles in the Standard Model can be infinitely small.

The limit at which quantum field theory works is the Planck length – about 10-35 meters; then the energies and interactions become so large (infinitely large) that particles interact with a probability greater than 1, which does not make sense. One of the main principles of quantum mechanics is that the smaller the distance we want to explore, the more energy is required for this – and more energy means more mass due to the equivalence of mass and energy. This means that at infinitesimal distances (which allows continuity) gravity will become infinitely strong (due to the inverse square law and the relationship between gravity and mass), and such a mass, given small volume and huge density, collapses into a black hole. This is one of the reasons why quantum mechanics and general relativity cannot be combined – the smaller the scale, the higher the energies, masses, and quantum fluctuations, and theories cease to work under these conditions.

Quantization, in contrast to the smooth space of the general relativity, implies discreteness of space (cellularity) and discrete portions of energy (elements can be considered as energy, also due to the equivalence of mass and energy). As already noted, the problem is that in the standard model of elementary particle physics there is no restriction on the minimum size of these particles and cells. Thus, they can be, as it were, infinitely small and continuous – it is not forbidden, although the theory ceases to work in conditions of infinite values. It looks like continuity with all its nuances which is hidden in discreteness.

In this case, it makes sense to consider Zeno's paradoxes from the point of view of how particles move through space. If space is continuous, then, it seems at first glance, the same thing is repeated – particles have to move through infinity, and thus motion is impossible.

However, at the micro level, the effect of tunneling is common.[7] Tunneling is impossible in classical physics, it is of purely quantum mechanical nature. This means that the tortoise can overtake Achilles (if they are elementary particles), and Achilles can overtake the tortoise and appear in front of it without even running past. In principle, there is a possibility of tunneling for macroscopic objects, too (and a real tortoise can, having overcome the energy barrier, get

7 Tunneling is the statistical ability of particles to overcome the energy barrier, the value of which exceeds the energy of those particles. A detailed description of the process is given in (Razavy 2003).

ahead of Achilles), but since macro-objects are very complex (and decohered), one would have to wait for that event for much longer than the universe has existed. But the important point is that it is possible. And it does not matter whether space is continuous or consists of discrete further indivisible cells of Planck length, the situation is the same in either case. Speaking of the Arrow paradox, we can say that the arrow teleports from cell to cell (the same applies to the Stadium), but in this case motion itself is divisible. Can we call it motion sense? We have already introduced the definition of action, which may seem applicable in case of teleportation (there is a change in positioning objects in relation to other ones, while processes are fixed in time).

Traditional physics assumes there are certain parameters of objects, thus, we can know their exact speed and action pattern. This, however, does not apply to quantum mechanics, at the micro level (and it is this level that we are dealing with when we infinitely divide the continuous and even separate the discrete, singling out points in it). It does not work because a particle, until it is localized in the experiment, is characterized by a wavefunction, the time evolution of which is given by the Schrödinger equation. This means that so long as we do not observe the particle, it is located at all possible places at once (which is described as a superposition of all possible positions). Returning to the example with the particle-Achilles and the particle-tortoise, this means the following: it is not that we do not know where they are relative to each other; on the contrary, we know for sure that they are in all possible positions relative to each other (in the Copenhagen interpretation, this is true until an act of measurement; at the moment of measurement, the wavefunction collapses, and the particle is localized in one of its probable places, most often in the most probable one; in the many-worlds interpretation, all outcomes are realized, but in parallel worlds). If we manage to localize with great accuracy the position of the particle-Achilles and the particle-tortoise, then we, in accordance with the Heisenberg uncertainty principle (see (Vilesov 2002) on this issue), know nothing about their speed (velocity and direction of motion), and the speculation about whether one of them will catch up with the other turns meaningless.

Time and Motion

It is hardly possible to consider time as something discrete. To single out indivisible atoms of time means to find intervals of timelessness between them, and it is not clear how, in this case, there can be motion in time. The connection between motion and time seems to be quite obvious. In a mental experiment which involves a complete stop of time, it becomes clear that all motion will also stop – because if something continues to move, you can set the time coordinates of the motion, and, therefore, it occurs in time. In this interpretation, time, in principle, cannot stop because quantum fluctuations (which can again be considered as motion) occur all the time. Thus, time is closely connected with motion, and there can be no absolute stops – no state of absolute rest (immobility and timelessness).

Returning to discreteness – assumption of discreteness implies just such absolute stops of time. Therefore, it is more correct to consider time as continuous (as it is considered in classical physics). But then the same difficulties arise as with space – how is it possible to single out points or segments in a continuity? After all, a continuity cannot have either a beginning or an end, otherwise in some place, the continuity becomes discontinuous. At an arbitrary fixed moment *A*, there is no motion, and there is no motion at any other moment, but motion passes through all these moments. In this respect, a moment is a stop of both time and motion. It remains to assume all these points and segments to be conditional, to consider them as a convenient mathematical technique, an approximation. Basically, it looks like a trick – to talk about the continuous in terms of discreteness.

Version with Restrictions

Let's consider one more version, in which discreteness, nevertheless, arises, and which appeared as an attempt to combine the general theory of relativity and quantum mechanics – the theory of superstrings. The prefix "super" refers to the requirement of supersymmetry, which must be broken in a certain way in order to correspond to the particles and interactions observed in our world (additional spatial dimensions are also required for the theory to give adequate predictions). With the energies available in experiments today, it is not possible to confirm or reject string theory; nevertheless, its mathematical apparatus turned out to be effective in solving a number of problems.

The key idea of the theory is that there are tiny particles – strings – that have a fixed size. They cannot be less than the Planck length. This, as already noted, makes it possible to avoid infinite energies on the microscopic scale. Different string modes (vibration types) correspond to different types of particles. In addition to strings, there are also branes (higher-dimensional objects) that can be both extremely small and infinitely large.

The idea is that there is no need to talk about infinitesimal scales, since there is a limit to division – the Planck length. However, this does not mean classical discreteness like the ancient division into atoms and emptiness – there is no emptiness; the emptiest thing there can be is vacuum, a low-energy state, which means that it has ordinary particles, virtual particles, energy, and weight. One can interpret this in the sense that the minimum possible distance between particles has the scale of the Planck length, which, however, is not empty itself.

In this scenario, an important factor is that there is a minimum size, this scenario presupposes that there is a minimum, which is the least possible option. less than which is not worth considering. This situation can be interpreted as discreteness. How does a particle move under these conditions?

There are two versions of superstring theory. There are two types of strings – closed and open ones. Closed strings are attached at their ends to the surface of the branes on which they are located (they can also be attached to other branes), and can only move in the space of those branes, while open strings are held by branes, and are able to move in multidimensional space (graviton, for example).

The manner of motion is affected by the dimensionality of space, as each new dimension opens up a new possible path. In the microworld of superstring theory, additional dimensions open up and particles can move in these dimensions. In other words, there are many paths from point *A* to point *B*, and the shortest one is not necessarily a straight line between them. This raises the question of what motion is in extra dimensions. From the point of view of the classical approach (the ontology of the macroworld), the problem remains the same, but there is an interesting mathematical trick in the theory that makes it possible to look at the problem in a new way.

What is meant here is duality used in the mathematics of strings. It shows that theories with different numbers of space dimensions can be equivalent to each other and have the same description (and the same consequences).

T-duality (Sathiapalan 1987) postulates that one large dimension can be replaced by another small one (curled up into a circle). This means that two different, at first glance, theories (one with a large dimension, the other with a small one) describe the same physical reality. But the most surprising thing is that if the large dimension of one theory is infinitely large, then the small dimension of the theory dual to it will be equal to zero. Thus, theories with different numbers of spatial dimensions can describe the same universe. It is quite difficult to accept this from the classical point of view, and questions arise regarding the definition of the concept "dimension" and, more broadly, "space".

Another interesting result was obtained by Juan Maldacena in (Maldacena 1998) – the most cited work in high-energy physics to date. He showed that the four-dimensional quantum field theory is dual to the ten-dimensional theory of gravity (in which five of the ten dimensions are curled up, and the remaining five form an anti-de Sitter space). Duality here, again, means that these theories describe the same reality.[8]

Let us point out another interesting model, the so-called matrix theory. The theory studies *D* 0-branes (point-like branes) in ten-dimensional space. This is a very interesting theory for various reasons. It does not have gravity, but *D* 0-branes behave similarly to gravitons, thus making this theory very similar to the theory of supergravity in eleven-dimensional space (apparently it is dual to that theory, which is probably an M-theory (Banks et al. 1997)).

The most interesting property of the theory in the context of this work is that it is impossible to determine the position of *D* 0-branes when they are too close to each other. From the mathematical point of view, this means that the question about the position of a *D* 0-brane in space does not make sense

8 An example of identical consequences is that an object that moves in the fifth dimension looks like an object that grows or shrinks in the dual four-dimensional theory. Achilles and the tortoise that run in the fifth dimension will increase in size (or vice versa) in the four-dimensional reality. Both are forms of motion. Seminal works on the application of duality are (Gubser et al. 1998) and (Witten 1998).

– it cannot be asked in a configuration space. In other words, this means that spatial dimensions disappear when branes get too close together.

The approaches above appearing accurate, this may prove that the concept of space in its traditional understanding can hardly be called a fundamental structure while there is something really crucial underlying what we call space. In this case, the term “space” represents the structure that remains obscure. It is an attempt to interpret something that has no exact scientific description.

In other words, Zeno’s paradoxes under these conditions cannot have a satisfactory solution (in their traditional formulations), since they discuss the results of observing the behavior of macro-objects that do not reflect the fundamental nature of this behavior and the objects themselves – and the problem arises in them precisely because, starting to interpret them in terms of discreteness and continuity, we turn to those very fundamentals of which we do not have a satisfactory theory.

Conclusion

Regardless of whether we consider space and time to be continuous or discrete, the problem persists. Zeno is absolutely right – but he is right precisely in that there is an obvious contradiction between the observed macroscopic motion and the intellectual intuition, which arises at the moment when we turn to the micro level in reasoning, that is, when we begin to single out points in the continuity.

If we try to get around this problem and consider, for example, Achilles and the tortoise as elementary particles, the situation as a whole does not change, except that quantum mechanical effects are included, which present the aporia as meaningless, because the microworld behaves essentially differently than the macroworld.

At the micro level, motion is characterized by an uncertainty relation – we do not know where the particle-Achilles and the particle-tortoise are, and if we manage to localize them more or less, then it is not clear where they are moving to, and at what speeds. Knowing one parameter for sure, we do not know anything about the second one (although even one parameter cannot be known for sure), and are forced (taking into account the tunneling effect as well) to say that Achilles will eventually overtake the tortoise in some scenarios since the probability of such an outcome is not equal to zero.

However, it can be objected to all this that Achilles and the tortoise are not particles but decohered macro-objects, for which the indicated principles of quantum mechanics do not directly work. But Achilles and the Tortoise, as well as the Arrow, and the Stadium, are just convenient constructs (obviously, Zeno and his first interpreters could not assume that the behavior of the microworld is fundamentally different from the behavior of the macroworld), and the real crux of the problem is the problem of motion.

At ultra-small scales (matrix theory), the classical concepts of distance and motion cease to work, and Zeno’s paradoxes start raising questions about something that is not there. Moreover, the aporias describe motion in a three-dimensional world, but it may turn out to be a special case of a multidimensional reality, in which case they are not talking about motion at all.

The problem remains in any case and, apparently, it lies in the fact that there is no complete clarity about what motion, space, time, and a point are.

The considered examples with duality in superstring theory suggest that space is not fundamental (the same can be true for time and motion) and there is another basic physical reality, for which these categories are approximate descriptions of its properties. That is why the paradoxes are insoluble – they propose making a transition from the macroscopic, where the usual ideas about space, time, and motion work, to the microscopic, where the rules of the game are different. As Koyré wrote: "It should be said that all refutations relating only to the problem of motion are fundamentally wrong" (Koyré 1985: 27).

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Ivan A. Karpenko

Zenonovi paradoksi i kvantni mikrosvet: šta govore aporije

Apstrakt

U članku se razmatraju novi pristupi pitanju četiri Zenonova paradoksa: strela, Ahil i kornjača, Dihotomija i Stadion. Paradoksi su analizirani u svetlu aktuelnih istraživanja u oblasti fizike elementarnih čestica i nekih obećavajućih pravaca u razvoju kvantne gravitacije. Fizičke teorije, opremljene neophodnim filozofskim tumačenjem, koriste se kako bi se razjasnili Zenonovi paradoksi i tražili odgovori na njih. Tekst pokazuje da korišćenje savremenih pristupa za rešavanje paradoksa nije efikasno, jer paradoksi postaju irelevantni kada se analiziraju u kontekstu fizike mikrosveta, na veoma malim razmerama.

Glavni deo rada posvećen je demonstraciji ove okolnosti – da je na pitanja koja postavljaju paradoksi nemoguće odgovoriti (barem u njihovoj klasičnoj interpretaciji). Kao moguće objašnjenje, u članku se navodi da se u formulisanju paradoksa mešaju svojstva makrosveta i mikrosveta (što je istorijski opravdano, s obzirom na intuitivnu homogenost velikog i malog i činjenicu da neklasična fizika – kvantna mehanika – pojavila se tek u dvadesetom veku); odnosno od posmatranja velikih fizičkih objekata prelazi se na beskonačno male u smislu diskretnosti i kontinuiteta. Međutim, principi organizacije prostora u veoma malim razmerama počinju da se uopšteno razjašnjavaju tek sada i, možda, ovi principi se mogu ispostaviti kao prilično strani klasičnim idejama o fundamentalnoj fizičkoj stvarnosti.

Ključne reči: Zenonovi paradoksi, filozofija nauke, makrosvet, mikrosvet, dualnost, prostor, vreme, kretanje, kontinuitet