Ivan A. Karpenko
National Research University Higher School of Economics, School of Philosophy
e-mail: gobzev@hse.ru

Physics theories in the context of multiverse[1]

The article analyzes the problem of physical theory nature and its criteria in the context of several concepts of modern physics. Such physical concepts allow multiple possible universes (the last usually happens to be a random consequence of the theory). Since the study requires several universe models, which basic principles (physical laws) can vary, the two theories have become the objects of analysis: the first, which includes the concept of eternal inflation, the second – the string cosmology (the string landscape). Both theories allow for a large variation of physical laws (no matter, whether these are fundamentally different physical laws or different versions of the same basic principles). The amount of dark energy (cosmological constant) has been selected as a physical law parameter, changing its value in possible universes.

The analysis of the physical theories, which allow a multiplicity of universes, has shown that the standard requirements for the theory, which connect its veracity with the criteria of observability and the need for validation of our universe basic principles, are not entirely consistent. Theoretical physics is moving towards the formulization of models that become a real (in some cases, apparently irresistible) challenge for experimental verification. The article proves that such verification probably can not be required in several physical theories, since, in particular, the postulation of this kind of connection between theory and reality is no more than a manifestation of anthropocentrism. However, the theory can trace more general grounds that lie beyond the scope of human observation.

Keywords: philosophy of science, physical theory, physical law, eternal inflation, dark energy, anthropic principle

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Introduction

The notion of physical law (and theory) usually presupposes the existence of some exceptional conditions, of some mostly standing rules for nature. To this extent, the scientist`s intent often comes down to searching for a certain law and formalizing it in the equation – expressing it mathematically. Another kind of intent – the explanation of the laws nature – is more complicated and unacknowledged by some scientists. There are loads of questions for this way of research, such as why the entropy was so low at the start of the lifetime of the Universe, why the amount of dark energy is precisely fixed, why the particles masses have the observed values, but not any different ones, etc.

All these questions themselves presuppose that our Universe is unique and there is its only one possible implementation – the one we observe. Within such an approach, the mentioned issues and their ilk are actually very important: answers mean unraveling of the enigma of origin. At the same time, these questions provoke one more: might the other laws of physics exist (other values of the constants)?

The anthropic principle[2] is one of the attempts to answer the question of whether the values in our Universe are exactly as we observe them and are not something different. The answer is the following: because we would not exist in case of other values. However, this is not the solution for the core of the problem, because another question arises here once again: if the other values (at least, theoretically) might exist (in other possible worlds).

The question is to be declared meaningless by the significant part of the scientific community. We do not have and will not have an opportunity to observe any other worlds even indirectly in the foreseeable future and also to carry out experiments that would reveal them. The scientist`s intent is to predict the results of the experiments and to describe them, but not to frame theories according to the nonobservable.

This rational point of view, however, has seriously dented its confidence at the second half of the XX century. The modern cosmology (and other branches of physics) is forced to take into account the ideas that seem considerably conceptual from a practical perspective.

The ideas of the inflation by Alan Guth and the radiation of black holes by Stephen Hawking are the good examples here. The idea of inflation has become very convenient for the needs of cosmology - it allows explaining some very important up-to-date phenomena that the classical Big Bang theory had failed to explain. Although, there are no strictly scientific grounds to claim its validity. The same applies to the most important Hawking`s insight for no other reason than that we will never probably observe the radiation of black holes.

Despite these strong objections, physicists, however, have successfully used the ideas and got certain results following such theories. The superstring theory is another typical example, which is a long way off from the possibility of correlation with the observed reality, regardless of decades of development.

Therefore, the question arises as to whether a *mathematical argument*, which corresponds to the key standards of our intellectual intuition, such as consistency and completeness, is enough to be considered the theory validity criterion. This question will further show its close connection to the nature of physical laws.

The present research deals with an attempt to define (or, at least, to formulate it properly) the nature of scientific theory[3], its validity criteria, the law in modern physics and to specify the tasks of scientific studies.

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[2] The article will mainly cover the anthropic principle in its strict sense.

[3] There is a certain difference between the concept of theory and the concept of model. In this article the theories are under our consideration, although, this is apparently not quite accurate with respect to the inflationary model. However, according to the inflationary model the focus will be on its characteristics as a theory. For more on models see the book [Morgan, Morrison, 1999].

Problem Statement

Almost all the constants, which appear in equations, can be questioned as if they could be different. At least, in theory. This question is purely theoretical. It is meaningless thus far from the point of view of classical physics - the mechanics of Isaac Newton, Albert Einstein's relativity theory, and from the point of view of non-classical one - quantum mechanics. These theories themselves have become the result of the certain laws discovery, their mathematical formulation and experimental verification. They predict the particular behavior of described systems - the results of future experiments. Thus, the law of physics is a certain mechanism, which underlies the processes in our reality, the one that we are able to observe. Accordingly, the search for alternative laws seems rather strange only because they are not related to our reality, and therefore no supervision or experience can formalize them. Moreover, it would be correct to say that the concept of “experience” and its inseparably associated “observation” have themselves been caused by the same physical laws that govern our universe and are possible themselves only because we are the part of our universe. This is true because the other laws of physics (e.g., in hypothetical worlds with the additional spatial dimensions, the other properties of elementary particles, the vacuum energy values, etc.) tend to exclude the possibility of human existence. Here we see, of course, the anthropic principle in such a formulation - these are the laws of physics because there is no point in referring to some others.

This is right. But, as it turns out, there are situations, when it is reasonable to talk about the other laws or their alterations (at least, these alterations occur themselves, even if we refuse to talk about them). In such cases, the consequences of the assumption of the fundamentally different physical conditions need close analysis. These consequences appear to be extremely important not only for understanding the organization of the universe but for the interpretation of the scientific theory`s and scientific process`s natures.

The present research analyzes the consequences of the principles of inflationary cosmology (first suggested by Alan Guth [Guth, 1997]) and some of the results of the string theory (see, for example, [Becker, 2006]).

Inflationary Scenario

It is revealing that Guth has originally elaborated the problem of magnetic monopoles ['t Hooft, 1974, pp. 276-84] within the Grand Unified Theory (the merge of all fundamental interactions, in addition to gravity). The problem is that the theory has predicted the magnetic monopoles, which are nonexistent in nature (only the dipoles are).

The Guth`s solution[4] is noteworthy because in order to solve the problem of unobservability of the phenomenon he has introduced another unobservable one. He has presumed the existence of the universe with a unique field with specific characteristics in the very early period – the inflaton field[5]. The energy of this field can “roll” from the high value to the low (for example, from the false vacuum state to a true one). The rolling is aligned with the “expansion” of the universe – it happens immediately up to the size of more than 10^{26} times. The fall into the true vacuum means a phase transition when the inflaton field converts to other fields and particles (i.e., to the configuration of the observable universe). Monopoles problem has been solved: they have existed at the moment when the powers have not disunited yet, but their concentration has fallen to almost zero because of the powerful inflation.

Obviously, this is an explanation of the one hypothetical phenomenon by using another hypothetical phenomenon. Nevertheless, the scientific community has actually supported

[4] Alexei Starobinsky has suggested the first working model of inflation – see [Starobinsky, 1980: 99-102].

[5] There is a significant hypothesis that the Higgs boson (comparatively recently discovered), which is in particular responsible for mass of the particles, is a particle of the inflaton. See [Atkins, 2011: 37-40].

Guth right away. This has been caused by the fact that the inflation also explains the more vital problems of flatness and cosmological horizon [Guth, 198, pp. 347-356] in addition to the problem of monopoles. The first one concerns the mysteries of the observed flatness of the space - less probable state from a set of possible states. In other words, some space curvature has most likely existed at the very beginning. And inflation allows it, but the immediate expansion does "straighten" any such curvature, and so far we observe the exact flatness, which is present to observe. As for the horizon problem, the inflation gives the well-known explanation to the nearly constant temperature of the microwave background radiation. All the future fields in their initial infancy have been close and have had the opportunity to interconnect. The immediate expansion has parted these areas far away from each other, but since they had interacted before, this explains their similar properties [Linde, 1982, pp. 389-393].

The special inflation advantage is that it explains the origin of galaxies too. The initial exposed to the inflation area may be whatsoever homogeneous, but the quantum fluctuations are unavoidable - there is always the uncertainty in the description of any state (according to the Heisenberg principle). Perhaps, the same inflationary expansion does transform these early fluctuations into the observable today galaxies [Guth, 1982, pp. 1110-1113].

Fine-Tuning Problem

There is one more significant aspect that makes the inflationary scenario attractive. It is the apparent solution to the problem of fine-tuning. The essence of the problem is that in order to explain the relatively low-entropy state currently observed in the universe we need to assume an even lower entropy state in the past since general entropy always increases. Therefore, at the moment of the Big Bang (at this point we do not consider anything before the Big Bang, in this context the time itself starts from this "moment", so everything "before" makes no sense[6]) the state has shown the relatively low entropy.

The question that has to be answered is: why was the entropy low? This is the least probable state, almost implausible, yet it had taken place. Most probable is the state of high entropy both in the past and in the future, which is the essence of the second law of thermodynamics (see, for example, [Čápek, Sheehan, 2005]). One may try to explain everything with gravity without involving inflation. The initial homogeneous state would have been a high entropy state if it had not been for the gravity: the last provides a relatively small number of indistinguishable from the macroscopic point of view microstates and, consequently, not high entropy (as well as causes the matter to form ordered structures). But this leads to a separate topic of the gravity nature.

Inflation, however, implies the following: let there be an initial inhomogeneous state (here we refer to the state before the start of inflation) and an inflaton field with a certain energy not in the state of true vacuum, then there would be a section which would be inflated to the size of the currently observable universe (this is the scenario the chaotic inflation, see [Linde, 1983, pp. 177-181] and [Linde, 1986, pp. 395-400]). All the initial non-homogeneities would be eliminated in the process, and there would be homogeneous (on a large-scale) universe. This model explicitly assumes that initial conditions, perforce, have high entropy (chaotic), as initially there has been high heterogeneity. The presence of the required inflaton field energy allows the creation of our universe (with a lower entropy) from this state. The fine-tuning problem gets solved: initially, entropy was not low.

However, it is rather peculiar. Let us put another question: what conditions are necessary for inflation to begin? In other words, how probable are such conditions? And, more

[6] As far as is known, this idea (of course, in a very different context) has been introduced by Augustine of Hippo for the first time (see [Augustine, 2009]). It has attracted afterwards the attention of Gottfried Leibniz almost in the same vein (see [Leibniz-Clarke, 1956]).

specifically: what is the entropy of the dominated by the inflaton field area? Most approximate calculations [Carroll, 2011, Chapter XIV] show that such entropy must be many times lower than the observed today one. That is, an area ready for inflation is such a rare occurrence that it requires even more fine-tuning than the classical Big Bang.

It is not necessarily true that the fine-tuning problem can even be solved. All the attempts to solve it might be associated with even more fine-tuning (which, by the way, is entirely consistent with the second law of thermodynamics). But in the context of the present research, another thing is important: the consequences that the inflationary scenario will provide for an understanding of the laws of physics and the nature of physical theories.

The described very scenario of inflation contains something indicative: in fact, there is a vast number of possible variations of the initial conditions. First of all, vacuum energy (and several other parameters) may vary. There is an abundance of variations. The origin of the observable universe requires strictly defined values. Should the physics search for a theory that could explain these values and clarify along the way why other values are impossible? Out of pure theory, any values are probable; nothing stops us from making these values up and fitting them into equations. Is it a fair hold and what would such equations describe? Should such solutions be allowed from a theoretical point of view? If yes, there would be no need for any explanations. Since the answer would be: all the possible values are possible including those that have led to the existence of the observable universe.

Eternal Inflation

The idea of a variety of ways for physical laws to be implemented is especially explicit in the concept of eternal inflation (foundational text – [Vilenkin, 1983, pp. 2848-2855], modern view – [Guth, 2007, pp. 6811-6826]), which is a direct consequence of the inflationary scenario. In fact, eternal inflation, as a theoretical potential, has appeared first; it has been actually described by Guth, but at that time it has not been understood. Roughly speaking, it is a state when the inflaton field energy is in some high position of false vacuum. While the energy is stuck there, the space is expanding with no limits. Periodically, as a result of fluctuations, some areas of true vacuum form where a new inflation scenario is implemented: the inflaton field energy tumbles down (see one of the first key works on the subject – [Albrecht, Steinhardt, 1982, pp. 1220-1223]). Consequently, universes are formed. Depending on the different initial conditions, these universes may differ significantly from the observed one. This raises a question about the limit of possible implementations: is it possible to draw up an exhaustive list of universes (and an exhaustive list of physical laws and their modifications). If such a list hypothetically exists, it means that the task of scientific research still contains an explanation of why these very laws are possible. However, the range is greatly extending: instead of explaining the properties of one universe, science will have to explain the properties of plenty.

Theoretically, the situation may be even more complex. The number of possible implementations can be infinite (here it is important to clarify that we are talking not only about the plenty of universes that are governed by the same laws but about a hypothetical situation where the very laws (constants) are different, thus giving rise to different universes). In this case, trying to explain the reasons behind physical laws of our universe would be pointless, since it turns out that in an infinite variety there must be a random set of laws. This would, in fact, constitute the explanation. Even if their number were not infinite, but still quite large, it wouldn't change the situation that much. It is worth illustrating this concept by string landscape.

String Theory

The specifics of string theory is that in order to construct a gravitational theory which could consider both general relativity and quantum field theory it has rejected the idea of elementary particles in favor of strings (segments or loops of different dimensions). Often, talking about strings, the term *brane* is used. The introduction of branes has led to intriguing consequences. Probably the most important one is that the existing four-dimensional space-time continuum is not enough. For the theory to be consistent and meet certain other requirements of a mathematical nature, it is necessary to consider at least nine spatial dimensions and one temporal. Edward Witten has shown that it is not unreasonable to talk about ten spatial dimensions (see [Duff, 1996, pp. 6523-41] and [Witten, 1995, pp. 85-126]).

This idea is not that strange, Kaluza and Klein had already shown that it is possible to consider an additional spatial dimension (they were limited to a five-dimensional space-time) [Kaluza, 1921, pp. 966-972] [Klein, 1926, pp. 895-906]. Additional spatial dimensions are unobservable only because they are folded to the scale of the Planckian length order. Therefore, there is no contradiction with the observable physical reality.

Complexity arises when we turn to the quite natural task of explaining the properties of elementary particles (in this context, branes). There are, in fact, only three properties: mass, spin, and charge. But there are also properties associated with them: the value of strong and weak interaction, characteristics of the respective fields, etc. Particle properties in string theory are directly dependent on the geometry of the additional dimensions, i.e. their sizes and shapes. Thus, the goal is to calculate (to justify theoretically in mathematical terms) the observed characteristics of the particles within string theory. This would have a powerful result: the theory does not just register (as the standard model does, where the experimentally measured particle values are simply substituted), but does predict these values.

However, the number of possible space forms defined by the configuration of additional dimensions is quite significant (Calabi–Yau space) (see, for instance, [Cumrun, 1996, p. 403-418] and [Douglas, 2003, p. 46]). Given the way they interact with branes and fields, the number of possible forms is about 10^{500} (this number is also suggested to be infinite). The problem is that the theory does not include tools for identifying a space which would correspond to our universe. Obviously, the method of direct search with numbers of such order is not effective.

This implies two conclusions, which are important in the context of our work. Firstly, in all of this plenty of spaces there may be not a single one that would describe our space. How can this conclusion be interpreted? On the one hand, we can say that the theory is wrong because it does not describe the observed reality. And it is fairly true. But one can look at the problem from a different perspective, which is revealed in the analysis of the second possible conclusion.

Let us assume that among possible spaces there is the one that describes our universe (let us even assume having discovered it). In this case, it will be a good way to prove the theory, since it correlates with the observed reality. But, then, what about the rest 10^{500}-1 spaces? What is the meaning of their presence in the theory? They can be treated as unrealized potentials, but, then, another complex issue which is beyond the explanatory scope of the theory arises (thereby weakening it and turning it toward substitution again): why has this particular variant been implemented but not any other? Apparently, a more general theory is required to answer this question.

But the situation can be interpreted differently: all varieties are real and represent configurations of separate universes, and, therefore, there is no need to explain why our universe is the way it is. It is as it is because our universe is one of all possibilities. For example, the question of why a human has this particular height (with the assumption that it is the only height possible) will demonstrate the incompleteness of our knowledge and, most importantly, the pointlessness of the question due to this incompleteness, as the range of possible heights is great and is not limited to one embodiment.

The thought that several traditional research questions make no sense is a very significant assumption from the standpoint of epistemology (we are not saying that they are incorrect, but that they make no sense).

Consequently, there is another possible answer to the question of how to deal with a theory if it does not describe our reality, but describes a plenty of others. Perhaps, the theory is correct but logically incomplete in the sense that it does not describe the whole multiverse variety[7].

String Landscape

These reflections bring us to the anthropic principle in the context of string landscape. In this research, we considered the weakest of its wordings, which satisfies the majority of physicists: observable universe is as it is because we are able to observe it. Meaning that if any of its constants were changed, such as the value of the dark energy, gravitational constant or the value of the electromagnetic field, we would never exist. However, this is not the answer to the question of why the universe is as we know it and why we should even exist.

Steven Weinberg has challenged this question when analyzing the multiverse case [Weinberg, 1987, pp. 2607-2610]. He has assumed the existence of many universes and various possible values of dark energy (which acts as gravitational repulsion and provides the recession of galaxies). Discarding some of the values (which are not worth being considered for objective reasons), he has set a range of possible values.

Weinberg has seen the existence of galaxies as a necessary (but not sufficient) condition for the existence of life (as we know it). Calculations have shown that galaxies will form provided the value of the dark energy does not exceed 10^{-121} (in Planck units), while the observed value is 10^{-123}. Interestingly, this value had not been measured at that time yet, and many considered it equal to zero (the experiments of 1998 have shown this wrong – see [Riess, 199, pp. 1009-1038] and [Perlmutter, 1999, pp. 565-586]). Thus, Weinberg has predicted that it cannot be zero.

To ensure that all possible values of dark energy are implemented, 10^{124} variants (minimum) are required, among which there must be the one corresponding to our universe.

Leonard Susskind has developed these ideas by proposing the concept of *string landscape* [Susskind, 2005, pp. 403]. The idea is to combine some of the conclusions of eternal inflation with the conclusions of string theory.

The energy of each of the 10^{500} possible spaces contributes to the vacuum energy value (note that 10^{500} covers the 10^{124} value proposed by Weinberg). String landscape is a single landscape of all possible universes (taking into account the possible shapes of extra dimensions and the vacuum energy value) where the peaks are high values of inflaton field energy. At high values, inflationary expansion occurs. In contrast to the classical inflation, the quantum tunneling effect plays here the key role (a well-known effect observed in microcosm phenomena). Due to the tunneling, the field value moves from a high value to a lower one by overcoming the landscape obstacles. This leads to the creation of subsidiary universes in the initial ones, where the vacuum energy is lower, and the shape of extra dimensions varies. This process continues indefinitely, and the multiverse looks like the set of recurring universes within which there are other universes, where the process is repeated and so on. It is natural to expect that, amid this diversity, there is at least one (and maybe more than one) universe corresponding to ours. Then, it would be right to assume that there is a theory which fully

[7] Basically, it is not very surprising. The equations of general relativity also allow a variety of exotic solutions. For example, the solutions for universes where going back in time is possible (see, for example, [Gödel, 1949: 447-450]). The question is whether these universes exist.

describes physical reality, even if the theory does not contain any instrument to understand which of the models describes our universe (and why would there be such an instrument; it is a completely unmotivated anthropocentric requirement).

It is far from certain that among all these universes (even if they are an infinite number) there is ours because it is not clear whether the theory takes into account all the necessary elements which describe all possible worlds. However, if it is true, it is not a reason to consider a theory false[8]. It would be more correct to say that it describes a multiverse, and it is not a problem of the theory that we do not live in one of these worlds, but a problem of our own. It is not that important, whether they exist in reality. More important is that they might exist.

Conclusion

The above problems relate to a number of important questions about the nature of scientific theories and goals of scientific cognition. The major among these issues are the following: What is a scientific theory? What are the criteria of its validity? What is a physical law?

The proposed interpretation of a scientific theory assumes it as a theory that describes all the possible worlds and claims that only mathematical proof may serve as a validity criterion to such a theory. Obviously, an objection may occur in response to above mentioned that mathematics is based solely on intellectual intuition, laws of logics, which govern our cogitation, but not necessarily govern all the reality (perhaps, only for a very small part of it).

However, the point remains the same. At the moment, the requirement for a mathematical model to match the observed physical phenomena within scientific theories is becoming less strict: many supposed significant phenomena or laws cannot be observed at present level of technological development, and may never be observable[9].

In this sense, the requirement that a mathematical model should describe only the observed reality is not a requirement of truth, but of the only fact that it should particularly describe the world in which we exist. This is a pragmatic approach to the understanding of the truth. In this interpretation, the truth criterion is as follows: something is true if its existence can be proved within the reality, which we exist in.

It seems the anthropocentric orientation vividly manifests itself here. Of course, from a practical point of view, we are interested in our observable universe. But this is a purely applied approach. A scientific theory in its essence relies not on the applied principles (which are only a consequence), but on fundamental ones (since it is a “theory” in the first place). Thus, the truth criterion mentioned above is inapplicable; it cannot describe the theory as a whole but forces to exclude a significant part of it on the sole ground of its nonqualifying for the observed reality nature.

If we reject such a truth criterion, we would hardly offer something more reliable than a mathematical proof in return (it seems to be impossible). The famous Popper's falsifiability [Popper, 2002] loses not only its strength but also its meaning (this is the mentioned above situation, when the revision of the fundamental principles of science may challenge the meaningfulness of previously considered key issues). If a theory potentially describes a multiverse (with possibly infinite number of worlds), which is typical for some modern physical theories (two of which are covered in this article), and we confirm it as being true on a certain basis (relying not only on the fact that it describes the physical laws of our world as

[8] Another question is whether we should consider such a theory as a still physical one or it becomes more like a philosophical one. The establishment of epistemological differences is not the task of this study but it seems to me that such a theory remains physical, only the validity criteria are changing (but the problem is that the criteria of “physical” are also changing therewith).

[9] For example Hawking radiation.

an isolated case), it is impossible to falsify it. Everything possible is true, but in the case of the string landscape, very nearly everything is possible. The assumption that physical laws may change in time reinforces this conclusion (see more about this scenario in [Smolin, 2013]).

The same applies to objectivity criteria. The very notion of objectivity in this context is losing its scientific sense and starts to mean something familiar to the human as he is able to observe it. Therefore, objectivity is just another anthropocentric directive, which is itself purely subjective. Thus, the development of adequate criteria for a scientific theory, its veracity and understanding of the nature of physical laws requires maximum disassociation of anthropocentrism, which is still very specific to science. May be such criteria can give mathematics.

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