Physics. Quo vadis?

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Abstract

The state of the art in theoretical physics and related issues are discussed.

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Warning

Each phrase in this, as in any other text, contains terms that in turn require explanation, and this process has no end. Discussing all the pros and cons with references would make the text difficult to read. Therefore, this text contains plausible assertions but no proofs. Any of the statements in this text may be supplemented and/or challenged.

1 Introduction

Physics, like all natural sciences in general, begins with wonder. This has been the case in antiquity and continues to the present day. Where does lightning come from? Why is gauge symmetry necessary? Why is the sky blue and the grass green? Why are all observable parameters as if specially adapted to the fact that the mind appears? It is only as a result of wonder that the creative work of the scientist's brain is turned on.

Perhaps, this is the cardinal difference between science and art, in which creation begins for no apparent external reason. It is unlikely that Salvador Dali was first surprised by the world around him and then wrote his paintings. Rather, it was the other way around. Further we will limit ourselves to the discussion of processes that concern only theoretical physics and related phenomena.

2 The evolution of physics in numbers and dates

We will proceed from the assumption that a certain part of society is capable of scientific activity and that the fraction of such people does not change over time. Therefore, a little statistics will not hurt. So, the Earth population:

17th century - 600 million people;
18th century - 800 million people;
19th century - 1.3 billion people;
20th century - 4 billion people;

21st century - 8 billion people.

According to the UNESCO Institute for Statistics, at the end of 2004, there were 5,521,400 scientists in the world (i.e. 894 scientists per 1 million inhabitants). 90% of the scientists who have ever existed are still alive.

There are about 10 times more people alive now than in the 17th century, when two geniuses, Galileo and Newton, lived. If humanity is not getting stupider, there should be about 20 people living right now with comparable intelligence. Why don't we know anything about them? Perhaps one reason is that the set of people capable of doing science and the set of people actually doing it are overlapping but not congruent sets. Or science has become more complex. Let's look at how theoretical physics has evolved.

As usual, development started slowly. Some of significant milestones are

-Ancient Egypt with advanced astronomy, mathematics and medicine

-Ancient Greece with the laws of Thales, Pythagoras and Archimedes.

-Many centuries later, the first university appeared (Bologna, 1088).

Physics began to develop rapidly beginning in the 17th century, peaking in the 20th century. The 20th century was the most fruitful in theoretical physics, which is not surprising. The population grew, and so did the number of scientists. However, for the last 50 years - half a century, a considerable period of time - not a single confirmed theory has been created! The last theory worthy of textbooks (the Standard Model of Weinberg , Salam and Glashow) appeared in the 1960s of the 20th century. Yes, there is internal work in progress, which may (or may not) lead to discoveries in the future. But the fact remains that there are no new confirmed theories yet.

Such an abrupt stop requires understanding, especially since experimental physics, technologies, and computing capabilities continue to develop at an accelerated pace. What happened to theoretical physics, and why exactly did it stop producing new discoveries? The following text is devoted to this question.

3 Theoretical physics at the present time

The main thing that is happening in theoretical physics in the 21st century is the birth and initial development of many directions and competing models. Yes, the idea of inflationary expansion of space in the early universe was proposed and developed, the ideas of multidimensional gravity, string theory, loop gravity, supergravity, high-temperature superconductivity were

proposed. But all of these are not complete theories. Each mentioned direction can be realized in many ways, the number of which is constantly increasing.

Many important events have occurred on the experimental front: gravitational waves, the Higgs boson, early quasars, and dark energy have been discovered. But no established physical theory has emerged. At this stage, the focus is on developing methods that will be used in the future to build a higher-level theory. What does this qualitative change mean? A preparation for a future breakthrough?

Next we will discuss how such a theory might look like, but first we need to define the problems worth solving. The list evidently depends on the individual preferences of a particular author. So:

LIST OF UNSOLVED PROBLEMS

1. Where are the laws of Nature written down?
2. Unification of quantum theory and gravitation.
3. The arrow of time.
4. Wave function reduction.
5. Hierarchy of scales.
6. Fine-tuning the parameters of the universe
7. Dark matter
8. Dark energy
9. Baryon asymmetry
10. Number of fermion generations
11. Improvement of the Standard Model.
12. Properties of the strong interaction
13. Inflation
14. Primordial black holes

15. Is there a multidimensional world?

To begin with, there are already many solutions for almost every point. The problem is that it is not known whether there is a correct one among them. For example, about a hundred models of inflation are known. Some of them explain experimental facts better, others worse. New, more accurate data exclude some models, but new ones emerge. The only exception is point 1 of the List.

Let's explain the essence of these problems without going into details, which can be found in abundance on the Internet or with the help of Artificial Intellect (AI).

1. The triumph of physics is that predictions of system evolution based on invented equations coincide with real dynamics. But Nature has no equations. How does a stone know what trajectory it should follow? How does a photon know that it must be radiated by an electron? We have the equations, but Nature does not.

2. Unification of Quantum Theory and Gravity. There are two great, repeatedly confirmed theories on the basis of which devices work reliably. At the same time, the simultaneous use of quantum theory and gravitation leads to contradictions that are embedded in the very foundations of these theories. For example, in quantum theory, time plays a special role, while in gravitation it is just one of the equal coordinates. In the Schrödinger equation, time is explicitly emphasized, in contrast to the Einstein-Hilbert gravitational equations. So far there is no satisfactory solution to this problem. Perhaps it is related to mystery number 3 - the irreversibility of time flow.

3. The Arrow of Time. Briefly and very roughly, this problem consists in the question: "The concept of the arrow of time was introduced by A. Eddington in 1927. The study of this phenomenon, as usual in physics, has taken different paths, but there is no definitive clarity. The most discussed are The thermodynamic arrow of time, as well as the quantum mechanical, cosmological, causal, and psychological arrows of time.

There is another question related to this problem: Why is a time zigzag of a single particle unobservable? The answer from the classical point of view is clear. Consider the figure, which shows a typical example of a time zigzag. The abscissa axis is the coordinate of the particle or the amplitude of the scalar field in a small volume. It is obvious that at the turning points, e.g. t_c, the time derivative goes to infinity. So the kinetic energy at this moment is infinite. Therefore, energy is not conserved in such a process,

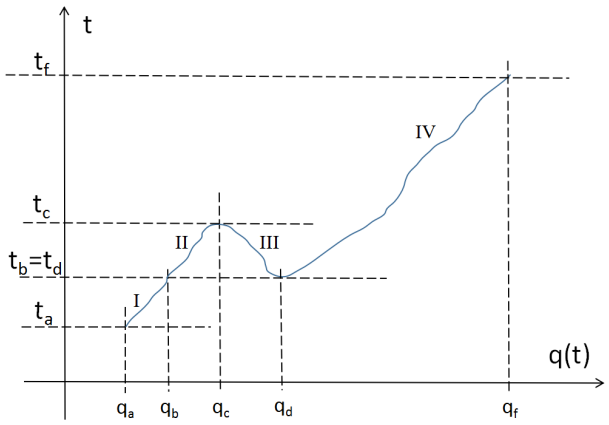


Figure 1: Typical zigzag trajectory of particle.

which is impossible under normal conditions, e.g. in Minkowski space. If we mean a particle but not a field, then there is another argument. The intersection of the light cone is impossible, because it also contradicts the law of conservation of energy.

The analysis of quantum time reversal is not so trivial and leads to a curious result: it can be proved [1] that temporal zigzags of arbitrary duration are possible, but unobservable.

4. Wave packet reduction is a process in which the quantum state of an object described by a wave function changes instantaneously when measured. This process seems to be at the heart of quantum theory, not clear until now. However, quantum mechanics makes accurate predictions, so the advice summarized in the middle of the last century, "Shut up and calculate", remains relevant to most physicists. However, such a prescription will hardly help in uniting quantum theory and gravitation.

5. Hierarchy of scales. After the idea of inflation as an early stage in the formation of the Universe has been reliably substantiated, it can be considered proven that our Universe with all its fields and parameters appeared when wavelengths of the order of 10^{-30}cm plus minus 2-3 orders of magnitude prevailed. The same order of magnitude was the size of the causally connected volumes. So it seems implausible that modern parameters like the Higgs mass, which correspond to wavelengths of the order of 10^{-14}cm, i.e. 16 orders of magnitude larger, could have been formed at that time. It remains

[1] e-Print: 2203.04200 [quant-ph]

to assume that the initial physical parameters corresponded to the Planck scale and only then, with the expansion and cooling of the Universe acquired modern values. This is what is meant by the hierarchy of scales. The mechanism of evolution of parameters on 16 orders of magnitude is not clear yet. The idea of the multidimensionality of space can significantly facilitate this task [2].

6. Fine-tuning the parameters of the Universe To understand the problem, we have to first define the concept of "life". We will consider a system "alive" if it maintains its existence by processing external information. Such a definition, being brief, nevertheless covers a large number of cases. And like any definition consisting of a finite number of words, it does not describe individual borderline cases. Now we can formulate what is meant by the words "Fine-tuning of the parameters of the Universe". Namely, it is a fact that all physical parameters are such that complex structures and intelligent life can arise in the Universe. At the same time, only minor deviations in the parameters are allowed for our Universe to be populated by intelligence. This is a firmly established **experimental** fact that must be taken into account when discussing future theory. Of course, if we remember about the silent-fish and bdelloid rotifers, we can see that life also adapts to external conditions, though at the expense of mental development. The idea of the plurality of universes allows us to naturally explain this surprisingly precise choice of parameters made by Nature. The existence of infinite set of causally unrelated universes unambiguously follows from the inflationary scenario of the birth of our Universe. It is important, however, that their properties are different and the set of universes is large enough. This is the subject for future research.

7 – 14. There are many models available to explain certain experimental facts related to these problems. Singling out the correct model will be a serious success in a particular direction.

15. Multidimensional world. This problem stands apart from the others. Indeed, the first two problems naturally follow from the logic of physics as a science, items 3 through 14 are experimental facts requiring their explanation. The idea of the multidimensionality of our world does not follow from any observational facts. But it has been surprisingly productive in explaining observed phenomena. It is the basis of such directions as Kaluza-Klein theories, String Theory, supergravity, the theory of the world on the brane,

[2] e-Print: 2307.03005 [gr-qc]

the model of universal extra dimensions. Therefore, the idea of multidimensionality is included in the questions to be addressed.

4 Ways to the Next Generation Theory

Obviously, the Next Generation Theory is designed to explain the properties of the Universe, at least those mentioned in the List above, as well as the origin of these properties. The idea of the divine origin of our Universe is interesting for a physicist only if it allows to study the properties of God himself. But let us leave this subject and try to understand, at least in general terms, what tools should be used in the creation of such theory. Here it is appropriate to reproduce

Imaginary dispute between a proponent of multiple universes and a supporter of the Unified Theory.

Let's imagine a conference on cosmology where two scientists meet on the sidelines. (If more than two scientists meet, the discussion is unpredictable.) They are respectful of each other, but hold different views on the question of interest. One is a proponent of a multiplicity of universes (M), the other a proponent of the Unified Theory (U). A dispute begins between them, which might look something like this:

E: The whole development of science is aimed at unification of postulates, the ultimate goal of this unification should be a Unified Theory. At present, the successes are obvious (e.g., the Standard Model). You want to abandon this path, don't you?

M: Why do you think this approach will always be successful? The Standard Model was developed decades ago. There has been little or no progress since then. It is not excluded that the desire to explain, for example, the mass of the electron from the original postulates will be similar to the desire to explain the mass of the planet Earth.

E: Well, the development of the inflation idea is also significant progress. At least we are moving in a positive direction: combining theories and testing conclusions experimentally. And how can you test the idea of the multiplicity of worlds? If, as you yourself admit, getting to another universe is impossible, then there is no direct evidence that it is true. Which means it's no better than creating a theory of the mass of the Earth.

M: It is true that we cannot make observations in the "other" universe, and it is widely believed that this argument is crucial. But is it? If we follow this logic, then everything we know about reactions in the Sun must also be questioned - after all, we are unlikely to be able to perform experiments directly from the interior of the Sun. Fortunately, in both cases we have to use indirect experimental evidence. And in both cases it can be relied upon with equal justification.

On the other hand, your way of building a Unified Theory will never lead to the final result. No matter what wonderful theory you create, the next question will be why your "Theory of Everything" contains these parameters and not others. For example, if M-theory explains all existing phenomena, the next question will be: why are there 11 (10) extra dimensions?

E: And who said that the process of cognition is finite? Asymptotic approximation to the Unified Theory is not the worst option either. At least in comparison with what you suggest. If all theories are possible, albeit in different universes, why study anything?

M: Not really. After all, the existence of many stars does not prevent a detailed study of our Sun. There is still much that is not clear in our own Universe. Besides, it is interesting to understand the mechanism of production of essentially different universes, as well as ways to test this idea, as you mentioned earlier. Well, asymptotic aspiration to the Unified Theory is indeed a worthy endeavor. Only in this direction one can't see the ways of answer to the experimental fact: the finest selection of parameters of the Unified Theory, as if specially for the reason to arise intelligent life.

E: I hope that the Unified Theory will answer this question as well.

M: I see that the two approaches do not differ as much as they initially seem. Most likely, there will be a merger of both directions and the Multiverse will serve as one of the elements of the Unified Theory.

Here their imaginary dialogue was interrupted by the news of the continuation of the conference. Our scientists went to drink coffee, while we will specify the above dispute.

So, a single theory or many different theories? In order to decide on the choice, let's see what Nature is guided by when creating complex long-lived systems. Here are some examples from various fields of knowledge showing that chaotic movements are as important as "smooth" ones for the development and preservation of complex systems. The alternation of random and purposeful movements rules the Nature.

4.1 Random motion

It is usually assumed that a theory should be "beautiful" (more on beauty later) and contain 1) minimum number of numerical parameters, preferably one, 2) a given number of fields, and 3) a symmetry group describing their dynamics and interactions. This should be sufficient to describe all observable physical phenomena and can predict new effects which are out of our observations.

Nevertheless, a number of serious questions remain about such a theory. First, it is difficult to imagine how an observable set of physical parameters could arise from several parameters. Most likely, much in such a theory will be hidden "under the carpet" - the initial symmetry may be broken, leading to a complex relief of stationary states, each described by additional parameters. Secondly, why was this particular symmetry realized? Are there universes with different initial symmetries? Third, why these particular fields? Are there universes with a different set of fields? Fourth, why were these particular postulates and numerical values realized, which led to the formation of complex structures and mind - see item. 6 from the problem list above?

The development of Next Generation Theory is a worthy endeavor, but it seems that there are existential questions that will not be answered even if it succeeds. Fine-tuning is one of them, and it is very instructive to study how Nature overcomes such problems.

Biology

The first example comes from the life of an amoeba. Having no organs of sight and hearing, it nevertheless lives long enough to produce offspring. Its modus operandi is impressively simple. To find food, it sends out false legs in different directions. Then it analyzes the information and moves in the most promising direction, thus alternating random fluctuations with purposeful movement.

Darwin's evolutionary theory is also based on this principle. It is obvious that one of the reasons for changes in a certain species of animals or plants is spontaneous mutations. Without sudden changes in DNA, there is no change in species or their adaptation to changing conditions.

Ants, having lost the trail, begin to move chaotically in search of the right path.

Plants, deprived of the opportunity to plant their seeds in the right places,

use the chaotic wind transport of their seeds. Those seeds that happen to land in the right soil begin purposeful growth.

Nature acts simply but effectively: random fluctuations are widely used for the development of a species. However, if mutations are too frequent, the species will dissolve without a trace, so a period of smooth movement is necessary.

So Nature uses the combined effect of two modes of action: random fluctuations to find a promising solution, and a calm, "assimilation" of what has been achieved. Often, it happens simultaneously.

Society

The development of society also occurs through the interference of these two processes. The market economy has been more successful because it has opened up opportunities for a large number of random attempts, which entrepreneurs take advantage of. Many of them lose in the race for survival, but the community as a whole survives and progresses. Socialism, on the other hand, suppresses fluctuations, which eventually leads the society to a dead end.

Jared Diamond's book " Guns, Germs, and Steel" suggests a similar explanation for the progress in Europe in the Middle Ages compared to China, for example. Europe was a conglomeration of states that developed according to their own laws. The price of a mistake by a particular ruler could be fatal for his state, but not for all the states of Europe. And the more successful ones developed at the expense of less successful ones.

Natural Sciences

Interestingly, the scientific community unintentionally uses a similar trick. It all starts with the fact that theorists are faced with a problem that requires an explanation, such as dark matter, cosmological redshift, neutrino mass, and so on. Immediately, many models/theories appear that claim to be correct. After one of the models/theories wins, there begins a long period of its refinement, searching for limits of applicability - a purposeful movement. A typical example is the Standard Model of elementary particles.

The initial stage of any scientist's work goes through a jumble of vague ideas - fluctuations - during which the scientist finds an acceptable one. A classic example is the brilliant inventor T.A. Edison, about whom Tesla said

the following: "If a needle is lost in a haystack, Edison will not invent a way to find it faster, Edison will start moving the straw one by one"À̇t present, theoretical science seems to be dominated by the fluctuation period. By creating many models, we are going through a haystack without being sure that the needle exists.

Mathematics

Eugene Wigner's famous remark: "The incredible efficiency of mathematics in the natural sciences is something bordering on mysticism, for there is no rational explanation for this fact. Perhaps the explanation is contained within the same fluctuation mechanism. I strongly suspect that the number of directions/discoveries/results in mathematics is huge and no less than in theoretical physics. It is not surprising that some of them turned out to be suitable for describing Nature. By the way, I wonder what fraction of them is now used in theoretical physics? My guess, it is quite small. The rest are waiting for their time, and some of them probably will be.

So, it is not very surprising that a small part of mathematical tools are effective in the physical application. More surprising is the fact that non-living systems are clearly subject to laws expressed in mathematical form, since they change in complete conformity with them (item 1 of the List above).

We can conclude that Nature is guided by the principle of alternating fluctuations and directional motion in creating long-lived complex systems. Why should Nature deviate from this rule when creating such a complex system as our Universe? This statement is very important and will be used for future discussion.

4.2 Why do we need Multiverse?

Several words about Anthropic Principle

Let us recall the Anthropic Principle (AP), closely related to our discussion. The essence of the AP is the statement, "Intelligence appears in areas where the right conditions are created for it." If you like, you can elaborate on this statement to make it less trivial, which will complicate the discussion. The conversion of physics to AP rails raises many objections, the leitmotif of which is the claim that "this is the end of science" and "then everything

is already explained" . For other prominent scientists, it is a guideline for action . It is one of the most debated assumptions in physics. Generally speaking, the word "principle" is very binding. Moreover, it provokes people to criticism. However, if we make this name less solemn, the irreconcilable positions of the opponents could be softened.

From Anthropic Principle to Anthropic Fact + Multiverse

Nowadays, we have firmly established fact: the fine-tuning of physical parameters to produce the intelligent life - the Anthropic Fact (not Principle). It is hard to argue with the observation that small changes in any physical parameter lead to the disappearance of complex structures and therefore intelligent life. Of course, one can debate the nuances - what "small" means, what the word "life" means. However, the majority will agree with this fact, which can be considered as a universal phenomenon and which requires theoretical justification.

Many examples of fine tuning have long been known and discussed. Some of them are mentioned in the discussion of item 6 in the List of Problems above. Let us dwell on just one parameter - the Fermi constant, responsible for the weak interaction, is extremely small. Let's see on a qualitative level how this fact is related to the existence of life in the Universe.

It is obvious that intelligent life arises around stars, which in this case provide a reliable and long-term source of energy through nuclear reactions. A chain of nuclear reactions is triggered by the interaction of two protons to form a deuteron, a positron and a neutrino. For the origin of life it is necessary for a star to live for a long time, the heat from nuclear reactions is released very slowly, which is achieved by the smallness of the Fermi constant. The cross section, and thus the rate of reactions involving neutrinos, is roughly proportional to the square of the Fermi constant. If it were not so small, the life of a star would resemble a nuclear explosion. A doubling of the Fermi constant would reduce the lifetime of a star by a factor of four. For the Sun, this means that it would go supernova in 2.5 billion years, and humanity would not have time to emerge. A decrease in the Fermi constant causes the temperature inside the star to drop and nuclear reactions to stop.

Another example involving neutrinos. We need supernova explosions to eject heavy elements from a dying star into space. Without them, all elements heavier than helium will remain inside the star, in an environment not conducive to the formation of intelligent life. Nuclear reactions inside the

star eventually involve heavier and heavier nuclei, more energy is released, and the temperature and internal pressure rise. Under the pressure, the outer layer expands and the star grows in size. There comes a point where the nuclear reactions stop, and if it weren't for neutrinos, the temperature of the inner layers would slowly decrease, the star would slowly shrink. No supernova explosion, all the heavy elements would be left inside the dead star.

But the final nuclear reactions inside stars release a lot of neutrinos. Because they interact weakly with matter, they fly through the outer shell, carrying their energy into space. The temperature and pressure drop dramatically, and the outer shell of the star collapses into the center. The matter falls into the center and then the star explodes. Incidentally, if the Fermi constant were even smaller, the nuclear reactions at the end of the chain would not be as effective, and the outer layers would slowly shrink toward the center, leaving the heavy elements in the star's remnant.

And there are plenty of examples like these can be found on the Internet or represented by AI.

We conclude that the anthropic fact (fine-tuning of physical parameters) is difficult to refute. It must be explained by a future theory without any doubt. Therefore, it must contain a mechanism for solving this impressively difficult problem. And such a mechanism exists. Remember that Nature resorts to the alternation of random and directional motion to solve its problems. The natural way to generate random numbers in such a situation is provided by multiverse. At present we have enough tools to restore this way and we will discuss them in next subsections.

Let us think outside the mainstream for a moment and suppose that the multiverse really does exist, containing universes with ANY properties, and in particular that there are universes with properties suitable for the formation of complex structures. Does this mean that physics is finished? Not at all. The major unsolved problems mentioned in the list remain valid. Only problem number 6 becomes trivial. However, new concerns arise. First, a great scope opens up in the study of the processes responsible for the formation of universes with different properties, and second, in the search for phenomena within our universe that indicate the existence of other universes.

The AF is worth considering as a guide for action. Our Earth is inhabited by life, which, according to the AF, means that there must be many planets with different characteristics even if we know nothing about stars. Rather, it encourages the development of the mechanisms of star and planet

evolution. To continue the analogy, the fact that our universe is inhabited by life encourages us to investigate how such universes were formed, and that is already good physics.

However, there is a question about the verification of such mechanisms - the standard argument is: "we cannot verify it because there is no way to move to other universes". A similar argument is used by skeptics of the inflationary scenario. To understand the issue, let us discuss what can be considered as verification of a particular model.

Direct and indirect observations.

It is generally believed that direct observations are much preferable to indirect ones. It is one thing to see how a metal melts when heated, and quite another to place it in a closed vessel and find the time dependence of the emission spectrum of this metal. And only on the basis of the obtained spectrum to draw a conclusion about its melting.

Let me cite the words of A. Vilenkin, one of the proponents of the Anthropic Principle (aka Fact): "The observed value of the cosmological constant is a strong argument in favor of the existence of a really colossal multiverse. It falls within the range of values predicted from anthropic considerations, and there are apparently no plausible alternatives. Of course, this evidence in favor of the multiverse is indirect and will always remain so. This case is built on circumstantial evidence, and it is not intended to hear eye-witnesses or examine the crime weapon. But if with some luck we make a few more successful predictions, we can consider the case solved beyond a reasonable doubt." He looks like apologizes for the indirectness of the arguments.

However, a closer look reveals that the situation with direct and indirect measurements is not simple. In fact, not everything that is directly observed is correct, such as the apparent motion of the Sun around the Earth. The Copernican idea, which explicitly opposes direct observation, is supported by indirect considerations. Recall also the example already mentioned: everything we know about reactions in the Sun must also be questioned - since we can hardly perform experiments directly from the interior of the Sun. And it is indirect experiments and observations that convince us that our understanding of the Sun's interior is correct. Well, and the study of the internal structure of black holes in general is meaningless from the point of view of the apologists for direct observations.

Moreover, if we follow the logic of the critics of inflation theory and hence the idea of the Multiverse, then even the existence of electrons should be questioned. No one has ever seen them, just as no one has ever been present at the act of emitting an electron from an atom. Yes, Thomson, using cathode tubes, made measurements that he considered proof of the existence of electrons. But to a consistent opponent of indirect measurements, this was a weak argument. Thus, W. Kaufmann, who performed similar experiments and obtained similar results, was not prepared to claim the discovery of a particle not directly observed by him. And too pity for him. The possibility of "direct" proof of the existence of electrons, appeared only this year, 2023, thanks to Nobel laureates in physics Ferenc Krausz (Ferenc Krausz), Anne L'Huillier (Anne L'Huillier) and Pierre Agostini (Pierre Agostini) used for this attosecond flashes of light.

We can conclude that all or at least the vast majority of evidence in physics is indirect. Returning to the idea of the existence of the Multiverse, we come to the following conclusion. On the one hand, the Anthropic Fact is firmly established by multiple manifestations. On the other hand, the only current substantiation of the AF is the existence of the Multiverse, an infinite set of universes, which unambiguously follows from the inflationary theory. This is hard to argue with, and what we are left with is:

- decide that physics is over and get busy collecting stamps, according to Rutherford's advice;

- propose another explanation for AF.

However, it is also possible to:

- get busy studying the physics of a particular (our) Universe; give answers to the main problems enumerated in the List above.

- find a mechanism allowing to diversify the properties of universes, since inflation leads to an infinite number of similar universes.

The aim of this activity is to build a (Unified) Theory capable of explaining a maximum of phenomena and based on postulates, one of which is the existence of the Multiverse. At the same time, it seems dubious that all prediction can be proved by direct observations by scientists even at distant future.

The above reasoning leads to the following conclusion. A future Theory of Everything should explain all observable facts. In addition, it could predict some phenomena that cannot be verified by mankind. This could be, for example, the internal structure of black holes, processes near the Planck scale and properties of neighboring universes.

At the same time, the idea of the Multiverse opens up new, sometimes unexpected possibilities. And one of them is the answer to the question

4.3 Why do correct theories usually seem attractive?

It is commonly believed, and not without reason, that only a beautiful theory can be correct. Although the notion of beauty of a scientific theory is somewhat vague, it is interesting that correct theories do appear beautiful to us. This is somewhat strange because the laws of Nature predate the emergence of man, and hence, before the very concept of beauty from a human perspective was formed. One might think that after working for a long time with the right theory, people get used to it, and it seems beautiful to them. But many theories from the very beginning seemed beautiful - GR, the Weinberg-Salam model, the idea of supersymmetry (the latter, unfortunately, has not yet been confirmed has not been confirmed yet).

There is an instructive example from the 17th century. Kepler and Galileo did not like the elliptical orbits of the planets. Strictly circular orbits seemed much more aesthetic and attractive. But when Newton discovered his law of gravity, the situation changed dramatically. One formula was able to describe the whole variety of orbits, and even the motion of bodies in the Earth's gravitational field! Isn't that beautiful? The "inelegant" elliptical orbits turned out to be part of a remarkably beautiful theory.

The criterion of beauty can be related to the degree of economy of resources with the help of which the goal is achieved - explanation of a certain range of phenomena and prediction of new ones. And this range should not be small. Let us introduce a "beauty parameter" for a hypothetical theory describing a particular universe

$$R = N/P \tag{1}$$

Here R is the quality coefficient of the theory: the higher it is, the more beautiful it is by definition; N is the number of explained natural phenomena inherent in a universe, P is the coefficient of complexity of the theory - the amount of information (in bits) used in listing the initial postulates of the theory.

The value of N is difficult to determine unambiguously, but in this case it is not very important. Note that the formula also applies to the constituent "subtheories" of such a theory. For example, if Maxwell's equations would

not seem beautiful, then the Standard Model, of which they are a part, would lose its luster considerably.

Now we can rephrase the question: why do theories with a large value of R turn out to be valid? Within the framework of the idea of the multiplicity of universes, the problem of the beauty of theories can be further reformulated.

Consider a truncated set ℵ of universes in which the origin of life is possible. Then the problem is reduced to the following question: why the fraction of universes with a large coefficient R is large compared to the fraction of other universes belonging to the set ℵ? In that case, it would not be surprising that our civilization originated in such a universe. So, the original problem is the following: we need to justify why this fraction of universes $W_{universe}$ is proportional to R:

$$W_{universe} \propto R$$

or any other monotonically growing function. We will proceed from the assumption that there exists a large set of universes with very different properties (Multiverse). Then it is reasonable to consider that the more complex a particular universe is, i.e. the larger the parameter P, the rarer the universes of this type appear.

Of course, intelligent life does not arise in very simple universes, which most of them are. There is a certain threshold of complexity, below which one should not go. Intelligence appears in those universes where that threshold is exceeded. Their number is much smaller than simple universes, but they are the only ones that are taken into account.

In other words, if we categorize the set of universes by their complexity, we get the set of

$$K(P_1), K(P_2), ..., K(P_U), K(P_{U+1}).....$$

$K(P)$ is the number of universes with a certain value of the parameter P (degree of complexity of universes). It is natural to assume that

$$K(P) > K(P') \quad if \quad P < P',$$

i.e. there are more simple universes than complex ones. It is worth recalling that only universes where intelligence is possible are considered - they belong to the set ℵ. The number of the simplest universes, where the appearance of life is possible, is denoted as $K(P_U)$ while $K(P_{U+1})$ is the number of

more complex universes, compared to $K(P_U)$. As stated above, we proceed from the assumption that the more complex universes are, the smaller their fraction is. This means that

$$K(P_U) > K(P_{U+1}) > K(P_{U+2}).....$$

That is, the number of simple universes inhabited by intelligence is greater (or rather, much greater) than the number of more complex universes inhabited by intelligence. This means that the probability of an intelligent civilization to find itself in a simpler universe is higher (rather, much higher) than in a more complex one. The term "simple" in this case means that the properties of this universe are determined by the smallest number of postulates - the parameter P is small. Which is exactly what it means that our universe, populated by intelligent life, should be described by a beautiful theory. Of course, what is written above is only a chain of plausible reasoning, which is enough in this case.

4.4 On the importance of inflation

Let us systematize what has been done in order to better understand the strategy applied in building of Next Generation Theory (NGT). We will base ourselves on some advances that are accepted by the majority of the scientific community. It seems that no one objects to the Standard Model of Elementary Particles and to the Standard Cosmological Model. Their main postulates seem to be quite firm so we will focus on less evident issues.

The idea of inflation appears to be Nature's greatest achievement in creating infinite number of separate spatial regions - future universes - at high energies, expands them to the appropriate scales and cools them down to low energies where complex structures could be formed. It remains only to endow these universes with different properties to obtain Multiverse. We will postpone the discussion of this question until the next subsection.

The inflationary paradigm for the formation of the Universe has been confirmed by numerous observations and has become a standard for model building. Briefly, it consists of the following: at high energy densities a region of the Universe was born by the quantum fluctuations. Consequently, the preconditions for the formation of the Universe, i.e. the laws of Nature, were formed at very high energies. The same valid for the set of fields and values of physical parameters - they are formed at high energies with specific

values that should be determined when constructing the future theory. The parameters measured by us are effective parameters, such as, for example, viscosity of a liquid.

It is convenient to use the Hubble parameter H to determine the energy scale, since it is directly related to the energy density: $H \sim \sqrt{\rho}/m_P$. The observed inflation starts on the scale $H_I \sim 10^{-6} m_P$ and, therefore, the laws of physics originate somewhere in the interval $H \sim (10^{-6} \div 1)m_P, (m_P \simeq 10^{19}$, GeV - Planck mass). The natural values of the physical parameters of the emerging universe are of the order of the Hubble parameter, the only parameter at that time.

However, the observed physical parameters at low energies - particle masses and coupling constants - are many orders of magnitude smaller. For example, the vacuum average of the Higgs field is from 10 to 16 orders of magnitude smaller than the Hubble parameter at the origin of the Universe. The question "how did the Universe manage to reduce the parameters by so many orders of magnitude?" represents the essence of the Scale Hierarchy problem (point 5 in the List of problems). An analogy with Platonic shadows is suggestive.

Here it would be natural to apply to the Wilsonian approach, where the initial Lagrangian is defined at the highest energies (or smallest distances) and then there is a gradual descent to low energies by integration over layers of 4-momentum in the Euclidean space.

Thus, inflation necessarily produces an infinite number of universes. To make the properties of the universes different, another tool must be involved. A desirable goal is to obtain physical parameters such as particle masses that vary continuously in different universes - a Multiverse. This non-trivial task is discussed below.

4.5 Extra dimensions

Extra dimensions is widespread tool in modern theoretical research. This deep idea capable of solving problems like the formation of the Multiverse and the solution of the Hierarchy problem. This idea is highly likely to be involved in the construction of the NGT. The idea of the existence of extra dimensions is not proven, and perhaps we will not wait for "direct" evidence. However, it opens up such a wide range of possibilities that Nature might well have used them.

Let us consider what possibilities appear if we accept the idea of the existence of extra dimensions. Let the number of extra dimensions be n and thus the total number of the space-time dimensions is $4 + n$. The action involves integration over all coordinates and depends on the initial parameters and metrics, in particular, the metric of the extra space. Since the theory of quantum gravity has not yet been created, we cannot say with what probability this or that metric emerges from the space-time foam. However it is natural to assume that there is a non-zero probability that any metric will emerge. Some of them survive this time and influence the properties of universes.

To obtain the low energy action described by four coordinates it is necessary to integrate by internal coordinates. In this case, the metric of the additional space does not disappear without a trace, but is included in the definition of effective four-dimensional physical parameters. The general transition from multidimensional action to 4-dimensional action looks as follows:

$$S_{4+n}(\lambda_{4+n}, g_n) \to S_4(\lambda_4[g_n]) \tag{2}$$

Therefore, 4-dimensional parameters λ_4 inevitably depend on the extra metric g_n,

$$\lambda_4 = \mathcal{Z}(g_n, \lambda_{4+n}). \tag{3}$$

A functional $\mathcal{Z}$ is specific to each extra dimensional model with initial parameters λ_{4+n}. This points to the way to solving the scale hierarchy problem: equation (3) can be used to find the extra metric g_n provided that $\lambda_4 \ll \lambda_{4+n}$ [3]. Besides, if the metric of extra dimensions is different in different causally unrelated regions, it means that we have obtained a mechanism for the formation of universes with essentially different properties. In fact, we have obtained a way to solve fine-tuning problem (item 6 in the List).

Presence of symmetry in our world is a paramount important aspect. However it seems obvious that the birth of metrics at the expense of quantum fluctuations should not lead to appearance of metrics possessing symmetries, since the measure of such metrics in comparison with others is equal to zero. Nevertheless, it is possible to show that at evolution of the Hubble parameter from high energies to low energies there is a symmetrization of the extra space which appears in our world as presence of Killing vectors. This happens due to the entropy flow from the extra compact space into the large

[3] e-Print: 2004.12798 [hep-th]

four-dimensional space in which we live. Although the total entropy grows, the entropy of the extra space decreases, which leads to the symmetrization of the extra space. in this way, for example, one can explain the baryonic asymmetry of our Universe.

If the above is true and the "true" values of physical quantities are on the sub-Planckian scale, then difficulties await us. For example, how to find these true values if we work with quantities 13 orders of magnitude smaller? In addition, quantum effects of gravity at high energies begin to dominate, so the exact relationship with parameters at different energy scales cannot be established. That means that the solution of problem number 6 - fine-tuning of the parameters of the Universe - is extremely problematic.

However, there is a positive point. Usually quantum corrections are compared to low-energy values of parameters, for example, to the Higgs field mass. As a rule, the corrections are much larger than the values of parameters at low energies. If to consider as initial physical parameters determined at high energies, the corrections appear comparable to them.

5 Physics and market

Above we have discussed possible elements of Next Generation Theory and the mental difficulties of its construction. But some problems of a more practical nature have appeared in recent decades. Let us return to the question of the sharp decrease in the rate of discovery of new laws in physics.

Theoretical and experimental physics have always been closely connected. The discovery of a new phenomenon in experimental physics generated an explosion of activity in theoretical physics. Nowadays, obtaining new information about physical phenomena is becoming increasingly difficult. While in past centuries funding for scientific research was not a big problem, now countries have to join their forces to create new facilities. Theoretical research accounts for a small fraction of funding, which is quite acceptable given the current productivity of theorists. However, the interaction with experimental physics is gradually breaking down.

Theoretical ideas are either difficult or impossible to test experimentally. For example, if the size of the extra dimensions is smaller than the inverse Hubble parameter during inflation, i.e., of the order of 10^{-28} cm, it would take particle energies of 10^{14} GeV for the LHC collider to "feel" them. This is 10 orders of magnitude higher than the energies now achieved at colliders.

By extraordinary strain of all resources, both mental and financial, it was possible to confirm the existence of gravitational waves and the Higgs field. Confirmation of the ideas of string theory or multidimensional space may be orders of magnitude more difficult and may take decades.

Thus, new ideas are no longer verifiable, which means that it is possible to identify the right idea or model only in the form of expert evaluation. And this is precisely the cornerstone. Indeed, in any systems, including our civilization, development is carried out by means of fierce competition. The strongest survive, and the rest simply cease to exist. Our civilization is not so cruel to individuals, but nevertheless, financial flows to unsuccessful projects decrease for natural, market reasons. This mechanism of progress works everywhere except theoretical physics!

The test of the "correctness" of any industrial idea is carried out automatically and directly by the reaction of society. The important thing is that the losers are eliminated from the competition. However, this does not work in the case of theoretical physics. Simply because there is no criterion of automatic selection of correct models.

The scientific environment is trying to solve this problem. The grant system, peer review of papers is a barrier to erroneous papers, but most models(theories,ideas) are self-consistent and contain no internal contradictions.

As an example, I will cite the inflationary paradigm underlying cosmology. At the moment there are about a hundred models, to a greater or lesser extent realizing this idea and consistent with observational data. The set of the latter is very limited, due to the astronomical cost of the facilities.

Therefore, every self-consistent paper proposing a new model of inflation has the right to be published as the next - one hundred and first - candidate for the correct theory. And after how many decades the strongest one will win, nobody knows. The experts evaluating the papers will not miss the wrong ones, but they cannot say anything about the fate of the consistent ones. And the flow of articles describing models that "may be useful in the future" is growing..... This is analogous to those very fluctuations, which are interspersed with progressive movement - future development of a successful theory.

However, what drives scientists in this race, in which it is known that one theory out of hundreds will survive? Does a scientist, realizing that the probability of success of his model is extremely low, continues to work and lays down his life for the benefit of society? Perhaps, but not a fact. Let's

ask ourselves, what is the main desire of a young scientist? The answer seems obvious: a great job, which includes the title of professor, grants, and conference participation. Articles in highly rated journals as a prerequisite for the previous joys of life. The last phrase is key.

Often, articles are written to get a grant or a good position. That is why there are a lot of passing articles that add to the already huge stock of models, one of which may turn out to be correct (or may not) in the uncertain future. There is no time to pursue deep ideas. This is one of the reasons why successful theories have not appeared for a long time.

In theoretical physics there is a multiple excess of ideas, and only one of them can be correct. Therefore, based on purely statistical considerations, any new work with a new model is wrong with high probability. The second reason seems even sadder: we have approached the limit of development of theoretical physics. But about it - in the section "The Future of Physics".

Unstable fluctuations.

There are four actors involved in scientific activity devoted to theoretical physics: individual scientists, universities, scientific journals, and grant funds. Their interrelationships have been established for a very long time, and there seems to be no alternative.

However, this, well-functioning system, has flaws. In particular, it creates self-sustaining theoretical ideas, no matter how correct they are. Let us consider an example, assuming the actions of all participants are natural. Suppose that a known scientist publishes a new idea, and thus sets off the next chain of actions. Other scientists, upon reading the article, realize that they have knowledge that will help expand the idea. And they publish a refinement. The topic becomes relevant, and new researchers get involved. Grant funds are seeing an increase in the number of articles and are becoming more willing to fund projects in this area. Universities realize that grant support in this area is more likely and become more willing to offer positions to scientists related to this topic. A broader set of scientists get involved, and the circle is closed. And it doesn't matter whether the idea is right or wrong. A bit like a natural phenomenon called the "death circle of ants".

Trying to replace the market with a rating system based on article citations only partially solves the problem. Of course, articles with the right ideas will be cited many times, and this is good. However, it does not solve the problem of the closed circle described above. A new idea that has gener-

ated many followers will be cited many times whether it is confirmed in the future or not.

Nevertheless, it is difficult to propose another form of funding, all because theoretical physics has become so complex that the validity of a particular idea can only be assessed in the distant future. This point turns out to be critical. All other areas of human endeavor can be evaluated fairly quickly. If a large firm has launched a new product on the market, its test of attractiveness by the consumer is quick and automatic. A substandard product will fade away, no matter what that firm does.

Modern experimentalists are luckier. Creation of new tools for studying Nature is an expensive pleasure, but it brings real results. Approbation of gravitational wave detectors was successful and the possibility of practical use is already being discussed. In addition, many developments in the creation of instruments are moving into technology. The latter are already having a direct impact on the quality of life. The connection with the market remains, which allows to separate more effective scientific teams from less effective ones, progress "knows" in which direction to move.

And theorists, due to the lack of natural market relations, have to rely on grants, both private and public. And spend time on searching and writing both grants and reports on them. In addition, there are many interesting areas of activity other than theoretical physics, which leads to an overflow of intelligent and motivated young people into them.

6 The future of physics is cloudy. Or not?

There is a well-known story connected with Max Planck. As a young man, he came to the 70-year-old professor Philippe Jolly and told him that he had decided to pursue theoretical physics.

- Young man, - answered the venerable scientist, - why do you want to spoil your life, because theoretical physics is already basically finished... Is it worth to take up such unpromising business!

More than a century has passed and the situation has turned into its opposite: the problems have modernized and deepened so that there are still no visible ways to solve them. Below we will discuss the state of affairs in more detail.

6.1 Branching of theories

Let us consider the prospects for the development of theoretical physics, and more precisely, its area that deals with new laws. At the moment (2024) there are a number of phenomena listed in Section 3, that have no unambiguous explanation, such as the dark matter. Out of the many models explaining some phenomenon, it is not so easy to select the only correct one. In any case, this will require extraordinary combined efforts of theorists and experimentalists.

To solve them - to create a Unified Theory or at least a Theory of the Next Generation - serious efforts are already underway, new ideas and directions are being developed. And this is where the fundamental difficulty lies. As an example, let us look at the progress in the theory of gravitation. Since its development by Einstein in 1916 and after its triumphal march for decades, alternative theories began to appear.

The family of theories of gravitation continues to be enriched with more and more new members. As an example, I will give my correspondence (User) with AI:

User

list 40 alternative theories of gravity

Assistant

Unfortunately, I don't have a complete list of all the alternative theories of gravity, as the number can be quite large and is constantly changing according to new research and hypotheses. However, here are a few different theories of gravity:

Modified Newtonian Dynamics (MOND)
The f(R) theory of gravity
Tensor-vector-scalar gravity
Einstein-Cartan theory
Freeman-Dyson theory
Modified Einstein-Hilbert theory of gravity
Gravity with large dimensions
Einstein-Clerk theory
Fath theory of gravity
Yang-Mills theory of gravity

User:

And the other 10 theories?

Assistant:

Gravity with extra dimensions (ADD)

Brans-Dicke theory of gravity
Jordaan-Brans-Dicke theory of gravity
Gravity with inversion symmetry
Yakovlev gravity
Teitelboim theory of gravitation
Kaluza-Klein theory of gravitation
Supergravity
Casimir theory of gravitation
Theory of Torsion Gravitation
Modified Einstein-Maxwell Theory of Gravitation
Lesage Theory of Gravitation
Sakharov theory of gravitation
Non-tree gravity
Mozart's theory of gravitation
Tensor gravity theory
Gravitation with additional scalar fields
Carrera's theory of gravitation
Penrose theory of gravitation
Gravitation with complex numbers

Assistant:

These theories represent only a small fraction of the variety of ideas concerning gravity that have been proposed in scientific research.

++++++++++++

Eloquent answer. What matters to us is not which theory is more developed, but their number and variety. Some of them are in active development, which requires extraordinary efforts, almost at the limit of human capabilities.

The same happens in any other area of theoretical physics dealing with new laws - supersymmetry, extension of the Standard Model, multidimensionality. Each of them has many intensively developing branches. And each publication implies that the result described in it will be used in the future, when building the Next Generation Theory.

Since there are hundreds of directions, it is obvious that the probability of applying a specific result is extremely low. What drives scientists in this case? Faith in their theory and curiosity? Probably, for some people, this is important. But why do the majority, realizing that their work will be used in the distant future, and even then with a low probability, continue to work

actively in the chosen direction? This question was addressed in the section "Physics and the Market".

Nevertheless, in which of modern directions should work a physicist really interested in his contribution to the NGT changing the basic postulates? Of course, there is no unambiguous answer, but some conclusion can be obtained from the following chain of reasoning. There are many ideas developing a particular direction, for example, the theory of gravitation, based on some postulates, but still far from explanation of observable phenomena. There are quite a lot of such postulates, let us estimate their number as $N \sim 100$. Suppose that among these works there is one, yet unknown, which will be used further in the NGT. This means that the probability of success of a scientist's work containing a new postulate is $p_1 \sim 1/N \sim 10^{-2}$ and, therefore, is rather small. Let us also take into account that the probability decreases as the number of branches N increases with time. Combination of two new postulates in one work reduces the probability to the value $p_2 \sim 1/N^2 \sim 10^{-4}$. It can be concluded that the probability of success increases if the idea contains a minimum of new postulates and explains some experimental facts.

Let us return to the discussion of the future of physics. Let us be optimistic and suppose that among hundreds of possibilities there will appear those several directions, which can be included in the NGT. It means that there will appear an individual who will be able to select from the whole set of theories, models and mechanisms suitable for unification into one consistent entirety. To do this, he or she must first understand the whole kitchen of each of the directions that are the result of the hard mental work of the previous generation of scientists. It is hard to believe that this can be done by one person.

The option of a group of smart scientists also seems dubious. It is not so easy to gather a few patient geniuses to work together.

Artificial intelligence? Already, AI is beginning to be used to facilitate data analysis. Perhaps by teaming up with AI, humanity will be able to build NGT. But can we then claim that humanity has advanced in its understanding of Nature? How much can we trust the conclusions drawn by AI? By the way, this problem has already arisen among mathematicians and is intensively discussed, for example, on the site

https://avva.livejournal.com/127385.html

The next step in the development of the theory will be even more compli-

cated and gradually theoretical physics will start to be dealt with exclusively by AI. If, of course, it wants to.

Modern experimentalists have more opportunities for development, as a result of the mutual influence of physics and technology. However, even here there are natural limits. One reason for the limitation is obvious: the financial possibilities of mankind are not infinite, others are not so trivial. Consider as an example

6.2 Energy limit for colliders.

Our Universe has been around for 14 billion years and we can hope that it is at least in a metastable state. This means that it would take a large enough energy to trigger a phase transition that would cause our Universe to move to another metastable state with lower energy. A fatal outcome for humanity.

The most energetic electrons recorded in cosmic rays have energies of the order of $W \sim 10^{21}$ eV. In terms of the energy at the center of mass, at the moment of collision the energy $E = (2mW)^{1/2}$ would be released if the electron collided with a particle of mass m. Most likely it is a quark whose mass is ~ 10 eV, let's assume for simplicity. So $E \sim 10^{11}$ eV ~ 0.1 TeV. This means that in the universe constantly, although rarely, there are collisions of cosmic ray particles with the surfaces of planets and stars, energy of the order of 0.1 TeV is released, and the phase transition has not yet occurred. If a collider creates a beam of particles with such energy, nothing terrible should happen - the universe is stable enough when releasing such energy. However, we do not know what will happen if the collider energy is an order of magnitude higher.

Let's estimate what energies are released when colliders work. The modern collider at CERN produces counter beams of protons with energies on the order of 10 TeV. Directly in the collision participate quarks, whose energy is an order of magnitude lower, i.e., the released energy is about 1 TeV, which is already an order of magnitude higher than the limit of 0.1 TeV defined above. We can further increase the collider energy, but the risk of triggering a phase transition increases. Whether taxpayers will like it is a rhetorical question.

All of the above difficulties belong to the future, whether distant or not. At present, however, there are a number of phenomena that we can hope to make progress in explaining or proving. These are listed in the list of unresolved problems beginning with item 5. Identifying the models that

Nature used in constructing our universe among the many existing models is an important and very interesting task. It is hoped that the combined work of theorists and experimentalists can lead to impressive results in the next few decades.

7 Artificial Intelligence and Human Laziness

A little bit about artificial intelligence and its impact on the development of mankind. There is an extensive discussion on this subject on the fields of the Internet, so let's leave all the arguments FOR and AGAINST aside and discuss only one unpleasant phenomenon that seems cannot be avoided yet.

It is obvious that AI will improve, so that humans will be able to delegate more and more routine work to it. Actually, this has been happening continuously with the development of new tools when AI did not exist yet. However, now the process has accelerated dramatically. Artificial intelligence is taking over more and more aspects of activities that were previously the prerogative of humans. And humans are willingly handing over their powers to artificial intelligence following their instincts.

Previously, it was thought that a person would engage in creative endeavors in return. However, who needs billions of artists, composers and writers? Not to mention that artificial intelligence is getting better at these aspects of human activity. It seems that in the future, humanity will outsource all creative activity, the science including, to artificial intelligence. Given the results of a biological experiment called "Universe 25", it's disturbing. In this experiment, the ideal conditions created for a colony of mice led to their death finally.

Another argument in favor of humanity's good prospects is usually expressed as follows: "Humans will leave the boring jobs to the robots, and will themselves take on new, more complex and interesting fields that are constantly emerging. This has been the case throughout the history of civilization." There is only one argument against such a hopeful prospect - it is based on extrapolation to an infinite time interval on the basis of a finite time interval, which is notoriously unreliable. Well, speaking of extrapolation, the workweek has steadily decreased from 75 hours in the 18th century to 35 hours today. Why shouldn't this process continue up to zero?

It seems that the only things people will not want to hand it over to the artificial intelligence are various kinds games and theology.

8 Conclusion

Humanity has reached a new threshold in the study of the Universe. Despite the difficulties encountered, progress toward a next-generation theory seems likely. At least the problems listed on p. 4 and many others do not seem insurmountable. The assumption of the existence of extra dimensions greatly facilitates approaches to solving problems such as, for example, the Hierarchy of energy scales and Fine Tuning of parameters. It is not necessary that all predictions of the future theory can be proved by experiment. The absence of contradiction with all observable facts is sufficient.

9 Appendix. Number of physical laws as a function of time.

The Appendix lists discoveries that can be attributed to theoretical physics (pure mathematics and experimental physics are excluded) since the 17th century. Moreover, here and hereafter "theoretical physics" refers to its narrow component - the discovery of new laws. The most important branch of theoretical physics, which is connected with prediction or explanation of phenomena on the basis of already known laws, is not discussed here. A classic example is the theories of superconductivity and superfluidity based on standard particle properties.

Advances in theoretical physics over the last five centuries.

Written with the help of AI.

17th century

1609 - Two laws of planetary motion (I. Kepler)
1620 - Law of refraction of light (W. Snellius, R. Descartes)
1638 - Law of free fall (G. Galileo)
1653 - Basic law of hydrostatics (B. Pascal)
1660 - Discovery of diffraction and interference of light (F. M. Grimaldi)
1660 - Discovery of Hooke's Law (R. Hooke)
1666 - Discovery of dispersion of light (I. Newton)
1666 - Discovery of the law of universal gravitation (I. Newton)
1675 - Corpuscular theory of light (I. Newton)
1676 - Calculation of the speed of light (O. Römer)

1687 - Basic laws of classical mechanics, law of gravitation (I. Newton)
1690 - Wave theory of light (H. Huygens)

18th century

1718 - Justification of the proper motion of the stars (E. Halley)
1738 - Bernoulli's Law (D. Bernoulli)
1775 - Law of conservation of mass of matter (A. L. de Lavoisier)
1784 - Theoretical prediction of the existence of black holes on the basis of classical ideas (J. Michell)
1785 - Basic law of electrostatics (Ch. Coulomb)

19th century

1802-1808. - Law of volume relations of gases (J. L. Gay-Lussac)
1824 - Carnot cycle (S. Carnot)
1826 - Basic Law of Electric Current (G. Ohm)
1826 - Non-Euclidean geometry (N. I. Lobachevsky, J. Bolyai)
1827 - Inner geometry of surfaces (C. F. Gauss)
1827 - Brownian motion (R. Broun)
1831 - Discovery of electromagnetic induction (M. Faraday)
1832 - Quantitative description of the laws of electrolysis (M. Faraday)
1840 - Discovery of the Joule-Lenz Law (J. Joule, E. Lenz)
1842 - Law of conservation of energy, first beginning of thermodynamics (J. R. von Mayer)
1842 - Discovery of the Doppler effect (C. Doppler)
1845 - Discovery of Kirchhoff's laws (G. Kirchhoff)
1851 - Second law of thermodynamics (N. Carnot, R. Clausius, W. Thomson)
1854 - Theory of n-dimensional curved spaces (B. Riemann)
1855 - First mathematically sound formulation of the theory of electromagnetism without displacement currents (J. Maxwell)
1855 - Quantitative description of the diffusion process (A. Fick)
1856 - Discovery of the Thomson effect (W. Thomson)
1859 - Spectral analysis (R. W. Bunsen, H. R. Kirchhoff)
1864-1865. - Basic equations of electromagnetism (J. C. Maxwell)
1869 - Periodic Law of Chemical Elements (D. I. Mendeleev)
1869 - Discovery of the forces of intermolecular interaction and the equation of state of a real gas (Van Der Waals).

1880s - Foundations of chaos theory (A. Poincaré)

1895 - Classical electrodynamics in its final form (H. Lorentz)

20th century

1900-1917. - Quantum character of radiation and absorption of energy, discovery of the photon (M. Planck, A. Einstein)

1905 - Special Theory of Relativity (A. Einstein)

1905 - Mathematical description of Brownian motion, confirmation of the fairness of the molecular-kinetic theory, foundations of statistical physics (A. Einstein, M. Smoluchowski).

1906 - The Third Beginning of Thermodynamics (W. Nernst)

1911 - Discovery of the atomic nucleus, planetary model of the atom (E. Rutherford)

1911-1913. - Discovery of cosmic rays (W. Hess)

1913 - Quantum theory of the atom (N. Bohr)

1915 - General Theory of Relativity (A. Einstein)

1916 - Theoretical prediction of the existence of black holes on the basis of the general theory of relativity, consistent with modern ideas (C. Schwarzschild)

1918-1924. - Calculation of the distance to the Andromeda Nebula, discovery of the existence of other galaxies in the Universe (E. Epic, H. Shapley, G. Curtis, E. Hubble)

1922 - Model of an expanding Universe (A. A. Friedman)

1924 - Hypothesis of wave properties of microparticles (L. de Broglie)

1925 - Discovery of the Pauli ban principle (W. Pauli)

1925 - Theoretical prediction of the existence of the Bose-Einstein condensate, confirmed in 1995 (S. Bose, A. Einstein).

1925-1927. - Uncertainty principle, quantum mechanics (W. Heisenberg, E. Schrödinger)

1926 - Proof of the stellar nature of galaxies (E. P. Hubble)

1928 - Relativistic theory of electron motion, theoretical prediction of the existence of antiparticles (P. Dirac)

1928 - Combinational scattering of light (Raman effect) (Chandrasekara Venkata Raman).

1928 - Theory of alpha decay, discovery of the tunnel effect (G. Gamow).

1930-1933. - Theoretical prediction of neutrino existence, experimentally confirmed in 1951 (W. Pauli)

1932 - Development of the proton-neutron model of the atomic nucleus (D. D. Ivanenko, W. Heisenberg)

1932 - Theoretical prediction of the existence of the Oort cloud (E. Epic)[10]

1933 - Theoretical prediction of the existence of neutron stars (W. Baade, F. Zwicky)

1933 - Theoretical prediction of the existence of the antiproton (P. Dirac)

1933 - Discovery of the phenomenon of complete displacement of the magnetic field from a superconductor (W. Meissner, R. Ochsenfeld).

1934 - Theoretical prediction of the existence of dark matter (F. Zwicky)

1935 - Theoretical prediction of particle-carriers of the strong interaction (H. Yukawa)

1938 - Discovery of the splitting of the uranium nucleus (O. Gan, F. Strassmann)

1938 - Theory of thermonuclear reaction as a source of stellar energy (K. von Weizsäcker, H. A. Bethe).

1940s - Quantum electrodynamics (R. Feynman, J. Schwinger, S. Tomonaga, F. Dyson)

1947 - Discovery of the interaction of the atom with zero fluctuations of the electromagnetic field (W. Lamb, R. Rutherford)

1948 - Theoretical prediction of the phenomenon of attraction of bodies at short distances under the action of quantum fluctuations in vacuum (H. Casimir)

1957 - Theory explaining the phenomenon of superconductivity at the microscopic level (J. Bardeen, L. Cooper, J. Schrieffer)

1957 - Theoretical prediction of mutual transformations of neutrinos of different varieties (B. M. Pontecorvo)

1960-1967. - Standard model, theory of electroweak interaction (S. Glashow, S. Weinberg, A. Salam)

1964 - Theoretical prediction of the existence of quarks, discovery of the s-quark as part of kaons (M. Gell-Mann, J. Zweig).

1964 - Discovery of relic radiation (A. Penzias, R. Wilson).

1964 - Discovery of the phenomenon of non-invariance of the laws of physics with respect to specular reflection and change of sign of electric charge (J. Cronin, W. Fitch).

1964 - Development of the Higgs mechanism of spontaneous breaking of electroweak symmetry, theoretical prediction of the existence of the Higgs field and the Higgs boson (P. Higgs, R. Braut, F. Engler).

1965 - Postulation of the color charge, quantitative description of the strong interaction, foundations of quantum chromodynamics (N. N. Bogolyubov, B. V. Struminsky, A. N. Tavkhelidze, Han Mo-Young, Y. Nambu, O. Greenberg).

1980 - Theories of inflation. Prediction of the existence of dark energy responsible for the accelerated expansion of the Universe.

1993 - Prediction of massive primary black holes.

21th century

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