PHYSICAL SCIENCES

QUANTUM FIELD THEORY AND STRING THEORY

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Abstract

It is known that scientific innovations discovered in modern times prove that the structural dynamics of the Universe are subject to very complex laws. Combining all these laws into one theory is an issue that scientists have always believed in and worked on. It is this theory that can fully explain the dynamics and structure of the Universe, as well as many phenomena in terms of quality and quantity. This theory also has the potential to answer important questions about the beginning of the Universe. Today, quantum field theory is considered the closest theory to this theory. Quantum field theory is an important framework that plays a fundamental role in modern theoretical physics, unifying quantum mechanics and special relativity. The emergence of this theory arose from the need to overcome the separation of classical field theories and quantum mechanics - which occurred separately. At the beginning of the 20th century, it became possible to explain the effects of combining quantum mechanics with the concept of fields to clarify the properties of subatomic particles, as well as the properties of particles. It is currently considered one of the most accurate theories in physics. However, on the other hand, there is also String theory, which could be worthy of being a theory of everything. String theory suggests that the smallest structural unit of the universe consists of strings vibrating at different frequencies. Since the universe was actually created from a single point by the Big Bang, we conclude that matter and the physical field have the same source. This source is the smallest structural unit of the universe, namely strings. From this it becomes clear that quantum field theory can actually be described by string theory, and this description can unite these two theories around one goal. In this article, all the features of quantum field theory are examined, and an attempt is made to explain these features and the contradictions it encounters with string theory. The issues that string theory and quantum field theory can explain are reviewed. The shortcomings of quantum field theory are examined and the reasons for this are touched upon. Finally, ways to combine quantum field theory and string theory and include it in the final theory of the universe are mentioned.

Keywords: physical field, quantum mechanics, quantum field theory, Casimir effect, quantum vacuum waves, standard model, grand unified theory, string theory.

İntroduction. Quantum field theory was formed as a result of the successful synthesis of quantum mechanics and special relativity and was created to explain the fundamental forces of nature, as well as the interactions of elementary particles. The emergence of this theory arose from the need to overcome the limitations that classical field theories and quantum mechanics faced separately.[1] Quadratic mechanics, which was created in the early 20th century to explain the world of subatomic particles, when combined with the concept of a local field, allowed us to dynamically explain both the behavior of matter and its interactions. Although quantum mechanics was successful in explaining the discrete and probabilistic behavior of nature at the subatomic level, it was unable to account for phenomena such as the creation and disappearance of particles.[2] To understand why quantum mechanics and classical field theory face these difficulties and to understand the bridge between these fields, it is necessary to consider the origin and properties of this field. Only then can we speak of a definitive explanation of quantum field theory. In 1831, the English physicist Faraday made one of his greatest discoveries. He showed that a changing magnetic field can induce a changing electric current in a wire. This phenomenon is called the law of electromagnetic induction.[3] In the following years, Faraday conducted a series of experiments to investigate the close relationship between electric and magnetic fields. During these years, he developed the concept of the electromagnetic field. According to Faraday, electric and magnetic fields are in fact different manifestations of a single electromagnetic field.[4] In 1845, Faraday discovered the Faraday effect, which is named after him. He showed that a magnetic field can affect the polarization of light. This was one of the first pieces of evidence that light is also electromagnetic in nature.[5] In 1855–1862, Faraday's work was put into mathematical form by James Clark Maxwell.

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

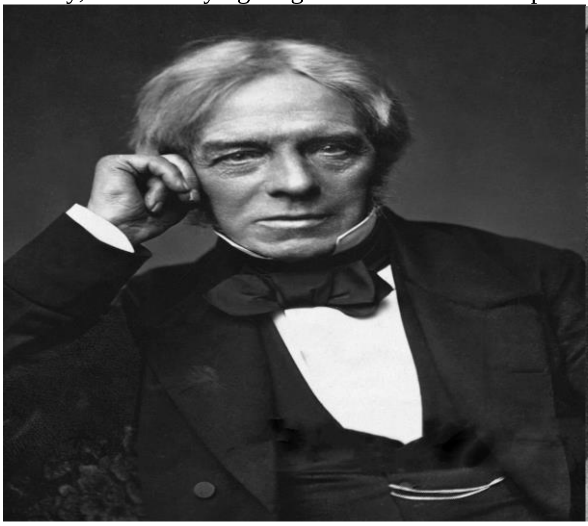
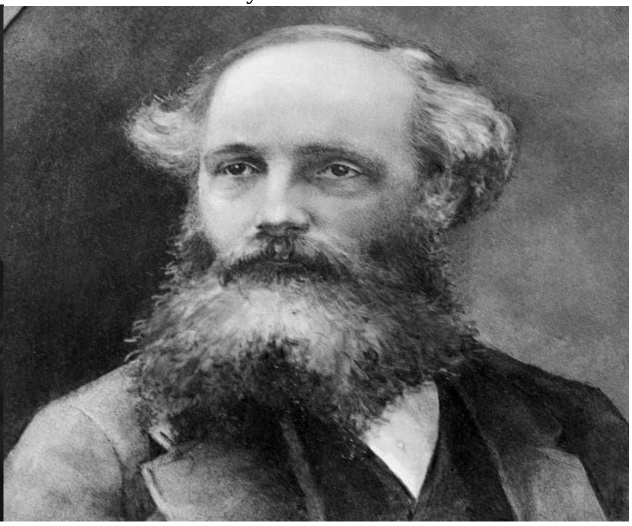
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

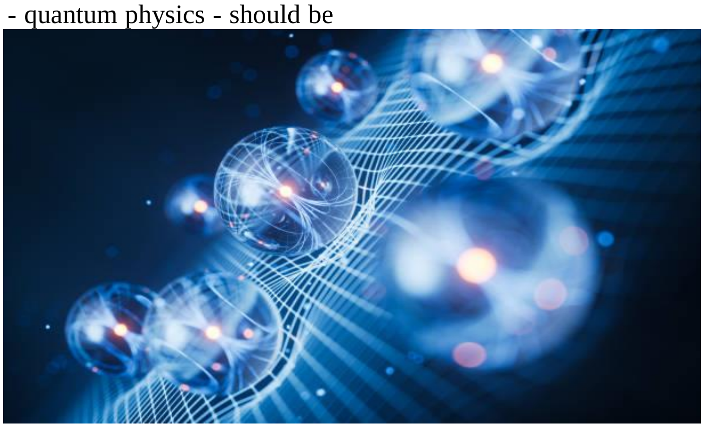
Maxwell's equations

The second and third equations clearly show the law of electromagnetic induction: a time-varying electric field creates a space-varying magnetic field, or conversely, a time-varying magnetic field creates a space-varying electric field.[6] Maxwell developed these ideas and fully formulated the theory of electromagnetism. The ideas of Faraday and Maxwell led physics towards field theory.

Michael Faraday James Clerk Maxwell

Until now, the laws of classical physics worked in a certain way. However, at the beginning of the 20th century, a number of phenomena were discovered that could not be explained by classical physics. It turned out that in order to fully explain these phenomena qualitatively, a new physics - quantum physics - should be created, which explains the properties of subatomic particles.[7] Because the movements of elementary particles are much more harmful than macroobjects. The reason for this is that particles have dual properties - wave and particle properties.



Wave-particle duality of particles

Unlike macroobjects, the concept of trajectory was not used for particles, which complicated the study of their properties and movements. It became clear that the movements of particles with strange properties could not be determined by classical physics expressions until now[8]. The lack of a description of their motion made it difficult to study the nature of these objects. For this reason, physicists focused their attention on this issue. An equation of motion explaining the motion of subatomic particles had to be discovered. Erwin Schrödinger gave his non-relativistic equation, which was very close to classical mechanics, could be understood intuitively, and described atomic and molecular systems very well.

$$i\hbar\frac{\partial\psi(\mathbf{r},t)}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V(\mathbf{r})\right)\psi(\mathbf{r},t)$$

where i is an imaginary unit; ħ- Reduced form of Planck's constant; m- mass of the particle; ∇^2- Laplace operator (spatial derivative); V(**r**)- potential energy function; Ψ-is a wave function.

This equation is simply a first-order equation in time and a second-order equation in space.[9] Although a useful equation, the Schrödinger equation had its drawbacks. First, it does not hold for relativistic systems and is not suitable for many-electron elements other than hydrogen and hydrogen-like atoms due to the complex mathematics involved. On the other hand, it does not describe the spin, a unique property of particles.[10] However, the Schrödinger equation was one of the first steps towards quantum field theory. In 1926–1927, another equation, the Klein–Gordon–Fox equation, was proposed. This equation was an equation for relativistic scalar particles.

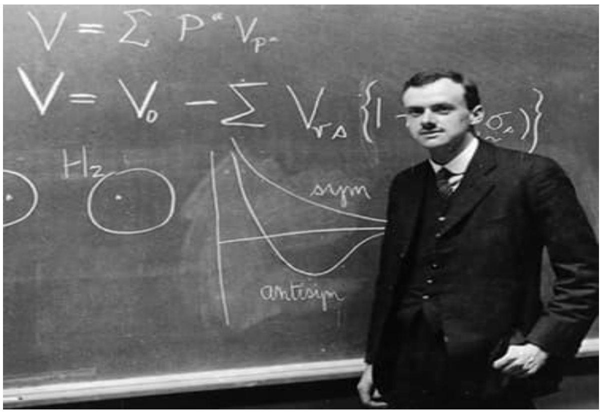
$$(\breve{E}^2 - m_o^2c^4 - c^2\breve{p}^2)\Psi = 0$$

Or $$-\hbar^2\frac{\partial^2\Psi}{\partial t^2} + \hbar^2c^2\nabla^2\Psi - m_o^2c^4\Psi = 0$$

Here É-energy operator; c- is the speed of light.

This equation is a second-order differential equation in both time and space. The advantage of this equation is that it is Lorentz invariant, that is, it is fully consistent with the special theory of relativity[11]. This equation can also be used to describe scalar fields. This equation is also used in the quantization of scalar fields, which we will discuss later. However, as can be seen, this equation does not include spin either. What we need is an equation that is both relativistic and includes spin. Then, the English physicist Paul Dirac proposed an equation that was compatible with both quantum theory and the theory of relativity. . This equation is a first-order relativistic equation.

$$(i\hbar\gamma^\mu\partial_\mu - mc)\psi = 0$$



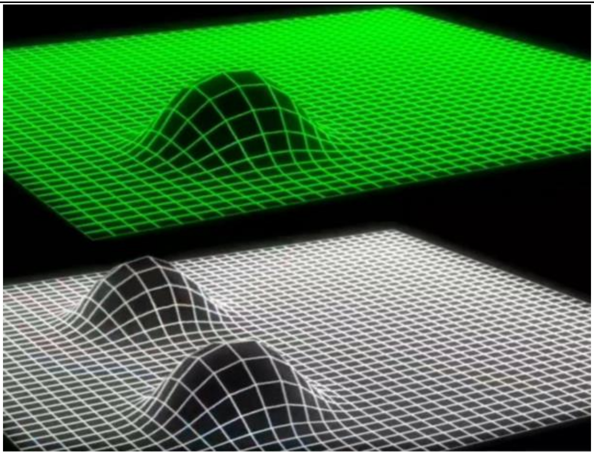
Dirac equation Paul Dirak

This equation also contains the Dirac gamma matrices and the 4-gradient operator in the first term in parentheses.

This equation also gave rise to the idea of antiparticles, and most importantly, it takes into account the spin properties of particles, i.e. it naturally introduces spin 1/2 into the equation[12]. However, Dirac's equation also had some shortcomings. This equation only works for particles with spin 1/2, and it is also directional, meaning that it is not enough to explain the particle and field dynamics with a single equation[13]. However, Dirac is considered one of the founders of quantum field theory with these works. Dirac gave the idea of defining a quantum field as an operator. This approach led to the mathematical formalism of the operators used to create and destroy particles[14]. By this time, quantum mechanics had already been sufficiently developed. As we have mentioned here, it turned out that energy is received and given in the form of discrete quanta. However, quantum mechanics explained the behavior of individual particles, but how fields behaved was not yet known. We know that matter has two manifestations: matter and physical fields. We know that matter is composed of elements, and elements are composed of particles[15]. It can be concluded that if there is quantization in the form of matter, then there must also be quantization in the form of field manifestation. Therefore, the concepts of field and quantum were combined. Thus, the quantum field theory, which is currently the most accurate theory in nature, was created. Quantum field theory is an important framework that plays a fundamental role in modern theoretical physics, unifying quantum mechanics and the theory of special relativity[16]. The problem that the previous equations could not fully explain the problems of changing particle numbers and interactions was eliminated by quantum field theory, which described and eliminated the quantum excitations of fields. The main motivation of quantum field theory was to explain phenomena such as the creation and disappearance of particles, which was solved by quantizing fields[17]. As a result of squaring the fields, the creation and disappearance of particles and their interactions could be explained naturally. According to the most accurate laws of physics, the smallest structural parts of nature are not individual particles at all, but something rapidly flowing throughout space[18]. We call this system fields.

Quantum fields

The most well-known of these fields are the electric and magnetic fields. The fluctuations in these fields give rise to what we call light, or electromagnetic waves in general. If we look closely at electromagnetic waves, we see that they are made up of particles called photons. Photons are the carriers of electromagnetic waves[19]. When the effects of quantum mechanics are included in the fluctuations of electric and magnetic fields, the field takes the form of a particle. This is true for all other particles. It also exists in the electron field that is spread throughout the universe. The fluctuations of the electron field are transformed into a particle by the effects of quantum mechanics, and we call this particle an electron[20]. Similarly, there is a quark field, a gluon field, and a Higgs boson field. It is clear that the conclusion from quantum field theory is that there is no such thing as a particle in the universe. That is, it describes each elementary particle as a quantum of a corresponding quantum field.

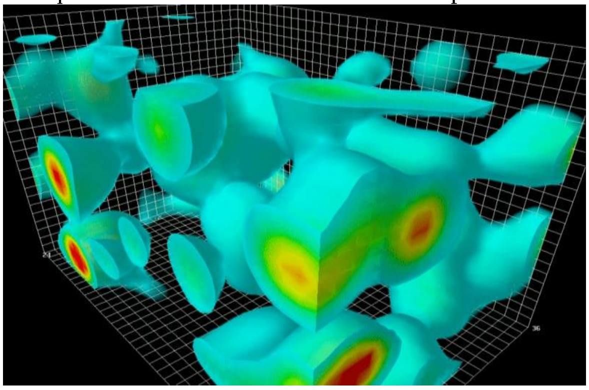


The creation of particles as a result of fluctuations in quantum fields

This approach allowed photons, electrons, and other fundamental particles to be naturally conceived within field theory.[21] Over time, this theory has evolved from being just a theoretical model to becoming a central pillar of modern physics. It has the potential to provide new answers to the most fundamental questions of modern physics, as well as to open up radical directions for future research. Although quantum field theory has answered many problematic questions, it has also encountered some problems. First of all, a quantum field is a very complicated thing. One of the reasons for this is that it uses all fields of physics to explain it. Quantum field theory is at the heart of new research in particle physics and cosmology. It perfectly explains the interactions of particles, the behavior of critical phenomena, etc. [22]. As a result of the formation of this field theory, several research areas of physics have emerged. When classical electromagnetism was quantized, quantum electromagnetism emerged. Later, the weak and strong nuclear forces were also modeled with quantum field theory.

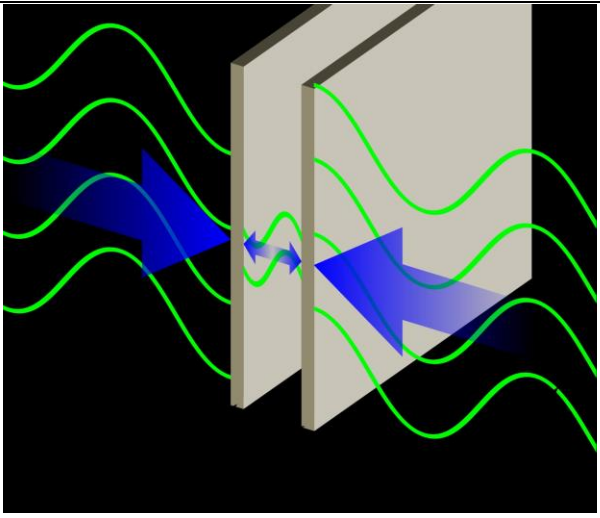
•Quantum chromodynamics - for the strong forces
•Electroweak theory - unifies the electromagnetic and weak forces. [23]

Yet the difficulties of quantum field theory do not end there. An empty space is not as empty as we think. Heisenberg's uncertainty principle leads to the conclusion that a quantum field cannot be motionless, and this confusion is something that quantum field theory complicates[24]. It is difficult to understand even nothingness in quantum field theory. Despite the fact that decades have passed since the discovery of quantum field theory, we are still far from understanding all the subtle nuances it contains. In order to examine the reasons for the emergence of these problems, it is necessary to touch on all the features of quantum field theory. One of the most fundamental and interesting concepts in quantum field theory is the concept of quantum vacuum waves. From the point of view of classical physics, a vacuum is a complete void. Quantum physics, however, has shown that a vacuum is not actually empty, but rather quantum fields exist and oscillate in space.



A model showing that a vacuum is not empty

These fields, even in their lowest energy state, are not completely stable. These fluctuations manifest themselves in the form of virtual particles and energy fluctuations. These waves are called quantum vacuum waves[25]. Quantum vacuum waves are the dissipation and energy change of fields even in a vacuum. Quantum vacuum waves show that there is no such thing as "nothing". Even a complete vacuum is an active energetic structure, meaning that matter and particles can be created from these field fluctuations[26]. As a result, the existence of quantum vacuum waves leads to some important consequences in quantum field theory. Quantum vacuum waves show that fields are not stable even in a vacuum, produce real physical effects, prove that vacuum is actually an active and energetic medium, and constitute one of the fundamental concepts of modern quantum physics and cosmology[27]. Small energy level shifts in atomic spectra (Lemb shifts) are also caused by vacuum fluctuations.[25] Recent developments concern the dynamics of the quantum vacuum and the instantaneous creation and disappearance of pairs of particles and space energy.[28] These developments are seen as important steps towards understanding the nature of dark energy. The experimental confirmation of quantum field theory is the Casimir effect. The Casimir effect is one of the most interesting and fundamental results of quantum field theory. This effect is a phenomenal observation that proves that the vacuum energy is not zero, but rather full of quantum fluctuations. The Casimir effect was proposed by the Dutch physicist Henrik Casimir in 1948. When two neutral, parallel, and conducting metal plates are placed very close together in a vacuum (for example, on the micrometer scale), the plates are attracted towards each other by a gravitational force. This force does not arise from any classical electromagnetic interaction and is caused purely by quantum effects[29].



Experiment with the Casimir effect

Here, the vacuum energy is the lowest energy state, and even in this state, quantum fluctuations, i.e. the creation of particle-antiparticle pairs that "disintegrate in time", occur. Each quantum field vibrates not with zero energy even in a vacuum, but with zero-point energy. This energy is equal to the sum of the quantized energies of the field:

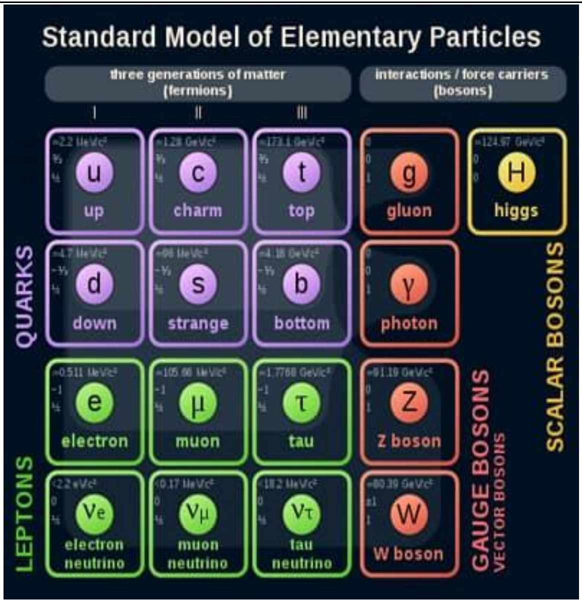
$$E_0 = \frac{1}{2} \sum_{\vec{k}} \hbar \omega_{\vec{k}}$$

here $\omega_{\mathbf{k}}$ - is the energy of each module of the field; is the **k**-wave vector.

•The plural sign takes into account all quantum modules.

The problem of this sum being infinite arises, but we are only interested in the energy differences. This is the main point of the Casimir effect[30]. The Casimir effect plays an important role in fields such as nanotechnology and microelectrotechnical systems. Casimir-type vacuum energy and models are also considered in understanding the nature of dark energy. In the 1970s, all these field theories were combined to create the modern standard model. This model is the result of the quantum field revolution that began in the mid-20th century and is still the most accurate theory in nature[31]. This model can predict the magnetic moment of the electron with an accuracy of 11 digits. This model was the first successful model that combined the electromagnetic field mentioned earlier with quantum physics and has been consistent with all experiments to date. According to the Standard Model, there are 12 fundamental particle fields that exist in nature, which are called fermion fields. Each of these fields corresponds to a particle of matter. These are the particles that make up the form of matter and have spin 1/2. They are classified as follows:

1. Lepton fields (6 pieces)--} these fields make up the electron and its family. 2. Quark fields (6 pieces)--} these are the particles that make up protons and neutrons. The 12 particle fields refer to the 6 leptons and 6 quark fields in the Standard Model.



The particles that make up the Standard Model

They represent the fundamental matter components of nature and are represented in quantum field theory as fields that each oscillate in a different way.[32] The energy of each field is also quantized. Each of these 12 fields is represented in quantum field theory by a separate field operator. Each excitation of the field corresponds to a quantum particle. For example;

•An electron particle is created as a result of the quantization of the electron field.

•quantization of the quark field creates quarks.

• The quantization of neutrino fields creates neutrino particles.

These 12 fields are for fermions. In addition, there are particle fields that carry forces:

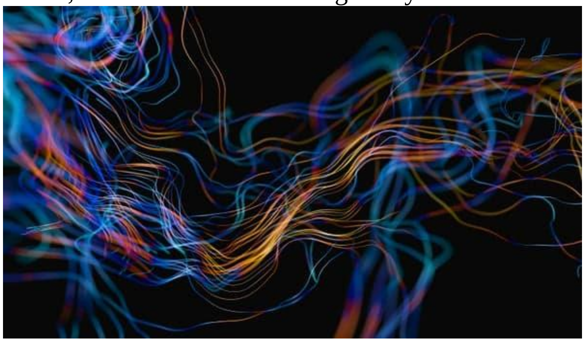
• Photon field (electromagnetic force)

•Gluon fields (strong force-8 fields)

•W and Z fields (weak force)

•Higgs field (source of mass) [33].

In quantum field theory, calculations often produce infinite results. This problem can be solved by a technique called renormalization. This technique is the process of replacing infinitesimal subtractions with the quantities that are being discovered.[34] This technique has become a fundamental part of quantum theory and other theories. Scientists have made many advances in this theory, including the discovery of anomalies and new symmetries.[35] This has shown how some anomalies can be explained. On the other hand, the great successes of this theory have led to an increase in attention to it. Many scientists believe that quantum field theory could be a "theory of everything". According to scientists, this goal can be achieved if the theory is further expanded. The main difficulty here is the inclusion of the gravitational field in this theory. Recent developments in the unification of quantum field theory and the gravitational field may help to better understand the initial moments of the Big Bang. [36] Initially, quantum effects dominated. Quantum fluctuations at the beginning of the universe expanded and grew during the cosmic inflation period. Bu fluktuasiyalar nəticəsində qalaktikaların və ulduzların yaranmasına səbəb olan ilkin sıxlıq fərqləri formalaşdı. Kvant sahə nəzəriyyəsində Böyük partlayışdan sonra yaranan enerji elementar zərrəciklərə çevrildi[37]. Böyük partlayışdan sonra zərrəciklərin necə formalaşdığını izah edən model isə məhz standart modeldir. Alimlər məhz Böyük Partlayış nəzəriyyəsinin kvant sahə nəzəriyyəsi ilə birləşməsinə Böyük Birləşmə nəzəriyyəsi kimi baxırlar. Digər tərəfdən alimlər "hər şeyin nəzəriyyəsi" olma potensialının sim nəzəriyyəsində də görürlər. Sim nəzəriyyəti Kainatın ən kiçik quruluş vahidlərinin titləşən simlər olduğunu önə sürür. Simlər fərqli şəkillərdə titrəşərək fərqli zərrəcikləri meydana gətirirlər[38]. Simlərin həm fiziki sahəni, həm də maddəni əmələ gətirdiyi də məlumdur.



Strings vibrating in different shapes in space

From this perspective, it is conceivable that the two theories could be combined. It turns out that some of the contradictions in quantum field theory can be explained by string theory. These phenomena include absorption and emission, particle binding, and rotational motion and direction[39]. In other words, string and M theory can be considered extensions of quantum field theory.

Problem statement: It is known that scientists want to complete the final theory of the Universe by gathering theories that explain many phenomena occurring in the universe around one goal. This theory is thought to eliminate the contradictions between the branches of physics. It is clear from the above results that quantum field theory and string theory are considered very close to this goal.Many phenomena in the universe can be fully explained by these two theories. At this point, we conclude that it may be possible to unify these two theories around a common goal. This unification can be determined by the compatibility between the common areas of both theories, that is, if the phenomena covered by quantum field theory can be fully explained with the help of string theory and the results obtained coincide, we will have achieved our goal. Both theories are worthy candidates for the title of "theory of everything". However, there are a number of issues that quantum field theory has difficulty answering. It can be expected that this unification will be able to solve this problem. The main issues we face here are related to gravity, mass, dark matter and dark energy. For example, to achieve this goal, where is gravity? How did interactions and quantum fields separate after the big bang? Where did mass come from? How can dark energy be explained by quantum field theory? Why is vacuum energy not zero? etc. We need to give appropriate answers to questions such as. Finally, the issue of being able to include this theory in the general theory of the Universe must be taken seriously.

Solution to the problem: It is clear that in order to achieve this goal, it is necessary to approach these events from the smallest starting point. In general, as we have noted, the most convincing theorem about the beginning of everything is the "Big Bang Theorem", and it is not expected that any discovery will be made in the near future that will prove this theorem to be wrong[40]. In this regard, these issues should be explained starting from the Big Bang. After the Big Bang, the Universe we live in began to form, and at this time the Universe gradually expanded, that is, the amount of energy entering our space increased (the number of strings increased). Since the strings are characterized by specific parameters, the distance between the strings and, accordingly, the binding energies changed from the point of explosion to the direction of expansion. In this regard, particles formed in one part of space due to the high binding energy, and in other parts a physical field was formed. Since this event occurred in a 3-dimensional space, the energy passing through changed its form in accordance with the laws of this space. Energy forms mass in a 3-dimensional space, that is, there are masses of strings and the number of strings forms the total mass of particles[41]. It is clear that the gravitational field exists in a higher-dimensional space, as Einstein said[42]. Every object with mass creates a hole in this space-time fragment. Objects with large masses affect the direction of movement of objects with small masses. The difference in the number of strings and the change in distance due to movement leads to different shapes and numbers of string vibrations, which in turn leads to differences in the particles. It should be noted that the encounter of strings with such conditions causes them to collide with each other and move in different directions. This in turn leads to the emergence of a number of properties related to the position of the strings within the particles and the direction of movement, and thus the creation of corresponding physical fields. String theory also suggests that all particles and fields are interconnected through strings. The same particles are distinguished from other particles in space by the number of their internal strings and the difference in the communication strings between them. Thus, each type of particle in the string network creates its own field. Therefore, as many different types of particles as there are, they have their own quantum fields in space. Due to the connection of these fields with each other and the presence of external influences, particles are recreated and destroyed on these quantum fields. The fact that these quantum fields are finite in number is due to the fact that the strings are characterized by specific parameters. This approach meets the requirements of quantum field theory and describes it through string theory.

Quantum fields connecting to each other through strings

However, we should note that since the gravitational field exists in four-dimensional space, we can only add its energy of influence on three-dimensional space to the calculations. Dark matter is directly related to the gravitational field[43]. Dark matter manifests its influence more as a result of cosmic defects[44]. In this regard, it is natural that physicists have problems with both the gravitational field and dark energy, and this is why this approach clearly manifested itself.

Result: At the moment of the big bang, energy flowed into 3-dimensional space in the form of strings with a certain mass and vibrational form. During this flow, the part of the 3-dimensional space of the Universe that belongs to us gradually expanded. As a result of the influence of the gravitational field existing in 4-dimensional space and the direction of expansion of the Universe on the existing massive strings, differences in the distance between the strings and, accordingly, in the binding energy appeared. The fact that the strings have mass, shape and motion depends entirely on the properties of 3-dimensional space. The difference in these parameters caused a different distribution of the energy of the flow in different parts of space. As a result, a physical field was formed in a certain part of space with particles containing more strings, and in another part with fewer strings. Since everything is made of strings, each point in 3-dimensional space has energy, which means that what we call a vacuum is actually made of strings, that is, it has a certain energy. Since the number of strings in the composition of similar particles and between them approximately matches each other, it is as if each type of particle has formed its own quantum field. Fluctuations in these quantum fields are considered as particles. Since the energy transfer between the smallest structural unit, the strings, does not occur instantaneously, but at a certain speed, these fields are considered quantized. The value of the minimum energy of the gap should be taken as the part of the field with the least number of strings. As can be seen, this approach is fully consistent with the principles put forward by quantum vacuum waves and the Standard Model. Therefore, each of the particles that make up the Standard Model differs from the others in the number of strings inside and between them. The absorption and absorption of energy by particles can be explained by the exchange and exchange of strings within them. At the same time, each of these fields is interconnected by strings. All of these strings form the final spatial network. These facts bring string and quantum field theory closer to the theory of the Universe. As a result, we can say that various quantum fields have arisen in the string network as a result of high-dimensional spaces and the distance and interaction between them. Due to the oscillation of these fields, the creation and disappearance of corresponding particles in space occur. Since these particles are created in accordance with different types of vibrations and movements of the strings in different directions, their corresponding parameters (mass, charge, spin, etc.) are formed [41]. These parameters lead to the emergence of various fundamental interactions in space. Since the gravitational field and the dark matter associated with it exist in high-dimensional spaces in a form that we cannot imagine and existed before the Big Bang, they cannot be directly included in the final theory, but only certain values of their influence, and this influence must be included as an additional parameter in the final mathematical expression. Finally, it should be noted that since we also perceive the Universe together with high-dimensional spaces and other concepts, quantum field theory is still far from the final theory of the Universe.

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