A New Look at the Baryon Asymmetry of the Universe

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Abstract

We propose an approach where the baryon asymmetry of the universe is a consequence of the following facts: 1) at earlier stages of the universe the characteristic p of the ring or field in a quantum theory based on finite mathematics was small and therefore the notions of particle-antiparticle and of the baryon number did not have a physical meaning; 2) those notions have a physical meaning at present because now the value of p is extremely large. As a consequence, in the general case, the present stage of the universe cannot contain equal numbers of baryons and antibaryons.

1 Introduction

The problem of the baryon asymmetry of the universe (BAU) is a long standing problem of modern physics described in a vast literature (see e.g. Ref. [1] and references therein). According to modern quantum theories, the baryon number is a conserved quantum number, and, according to modern cosmological theories, the universe was created with equal numbers of baryons and antibaryons. Then a problem arises why there is an imbalance in baryonic matter and antibaryonic matter in the observable universe.

As noted by Sakharov in 1967, the three necessary "Sakharov conditions" for the asymmetry are baryon number non-conservation, C and CP-symmetry violation and interactions out of thermal equilibrium. So, the baryon number non-conservation is the first and probably the most important condition. This condition was investigated in Grand Unified Theories and extensive experiments on the search of the proton decay have been performed. However, the result of all those experiments was negative, i.e. no proton instability has been found.

Modern quantum field theories and string theories are based on Poincare invariance in spaces with dimensions four or greater. In those theories the baryon number conservation is a must.

In his famous paper "Missed Opportunities" [2] Dyson notes that de Sitter (dS) and anti-de Sitter (AdS) theories are more general (fundamental) than Poincare invariant theories not only from physical but also from pure mathematical considerations. The matter is that dS and AdS groups are more symmetric than Poincare one. The transition from the former to the latter is described by a procedure called contraction when a parameter R (see below) goes to infinity. At the same time, since dS and AdS groups are semisimple, they have a maximum possible symmetry and cannot be obtained from more symmetric groups by contraction.

The paper [2] appeared in 1972 and, in view of Dyson's results, a question arises why general theories of elementary particles (QED, electroweak theory and QCD) are still based on Poincare symmetry and not dS or AdS symmetries. Probably, physicists believe that, since the parameter R is probably much greater than even sizes of stars, the dS and AdS symmetries can play an important role only in cosmology and there is no need to use them for description of elementary particles. We believe that this argument is not consistent because usually more general theories shed a new light on standard concepts, and the discussion in this paper is a good illustration of this point.

In Sec. 2 we give a popular explanation why, as follows from the most general symmetry on quantum level, the baryon number is not a conserved physical quantity. In Sec. 3 we describe important properties of de Sitter and anti-de Sitter symmetries in standard quantum theory and in quantum theory based on finite mathematics. In Sec. 4 we explain why BAU is natural and Sec. 5 is discussion.

2 Symmetry on quantum level

In relativistic quantum theory the usual approach to symmetry on quantum level follows. Since the Poincare group is the group of motions of Minkowski space, quantum states should be described by representations of this group. This implies that the representation generators commute according to the commutation relations of the Poincare group Lie algebra:

$$\begin{aligned}&[P^\mu,P^\nu]=0,\quad [P^\mu,M^{\nu\rho}]=-i(\eta^{\mu\rho}P^\nu-\eta^{\mu\nu}P^\rho),\\ &[M^{\mu\nu},M^{\rho\sigma}]=-i(\eta^{\mu\rho}M^{\nu\sigma}+\eta^{\nu\sigma}M^{\mu\rho}-\eta^{\mu\sigma}M^{\nu\rho}-\eta^{\nu\rho}M^{\mu\sigma})\end{aligned}\qquad(1)$$

where $\mu,\nu=0,1,2,3$, P^μ are the operators of the four-momentum and $M^{\mu\nu}$ are the operators of Lorentz angular momenta. This approach is in the spirit of Klein's Erlangen program in mathematics.

However, as discussed in detail in Refs. [3, 4], in quantum theory the notion of space-time background does not have a physical meaning. Although for constructing modern theories of elementary particles (QED, QCD and electroweak theory) local Lagrangians are used, the goal of the theory is to construct the S-matrix in momentum space, and, when this construction has been accomplished, one can forget about space-time background. This is in the spirit of the Heisenberg S-matrix program according to which in quantum theory one can describe only transitions of states from the infinite past when $t\to-\infty$ to the distant future when $t\to+\infty$.

As argued in Refs. [3, 4], the approach should be the opposite. Each system is described by a set of linearly independent operators. By definition, the rules how they commute with each other define the symmetry algebra. In particular, *by definition*, Poincare symmetry on quantum level means that the operators commute according to Eq. (1). This definition does not involve Minkowski space at all. Such a definition of symmetry on quantum level has been proposed in Ref. [5] and in subsequent publications of those authors. I am very grateful to Leonid Avksent'evich Kondratyuk for explaining me this definition during our collaboration.

By analogy with the definition of Poincare symmetry on quantum level, the definition of dS symmetry on quantum level should not involve the fact that the dS group is the group of motions of dS space. Instead, *the definition* is that the operators M^{ab} ($a, b = 0, 1, 2, 3, 4$, $M^{ab} = -M^{ba}$) describing the system under consideration satisfy the commutation relations *of the dS Lie algebra* so(1,4), *i.e.*,

$$[M^{ab}, M^{cd}] = -i(\eta^{ac}M^{bd} + \eta^{bd}M^{ac} - \eta^{ad}M^{bc} - \eta^{bc}M^{ad}) \tag{2}$$

where η^{ab} is the diagonal metric tensor such that $\eta^{00} = -\eta^{11} = -\eta^{22} = -\eta^{33} = -\eta^{44} = 1$. The *definition* of AdS symmetry on quantum level is given by the same equations but $\eta^{44} = 1$.

The procedure of contraction from dS and AdS symmetries to Poincare one is defined as follows. If we *define* the operators P^ν as $P^\nu = M^{4\nu}/R$ where R is a parameter with the dimension *length* then in the formal limit when $R \to \infty$, $M^{4\nu} \to \infty$ but the quantities P^ν are finite, Eqs. (2) become Eqs. (1). This procedure is the same for the dS and AdS symmetry.

In Ref. [4] it has been proposed the following

Definition: *Let theory A contain a finite parameter and theory B be obtained from theory A in the formal limit when the parameter goes to zero or infinity. Suppose that with any desired accuracy theory A can reproduce any result of theory B by choosing a value of the parameter. On the contrary, when the limit is already taken then one cannot return back to theory A and theory B cannot reproduce all results of theory A. Then theory A is more general than theory B and theory B is a special degenerate case of theory A.*

As proved in Ref. [4], dS and AdS symmetries are more general than Poincare symmetry. The latter is a special degenerate case of the former in the formal limit $R \to \infty$. As noted above, in contrast to Dyson's approach based on Lie groups, the approach to symmetry on quantum level should be based on Lie algebras. Then, as proved in Ref. [4], classical theory is a special degenerate case of quantum one in the formal limit $\hbar \to 0$, and nonrelativistic theory is a special degenerate case of relativistic one in the formal limit $c \to \infty$. In the literature the above facts are explained from physical considerations but, as shown in Ref. [4], they can be proved mathematically by using properties of Lie algebras.

As proved in Ref. [4], classical mathematics (involving the notions of limits, infinitely small, continuity etc.) is a special degenerate case of finite mathematics in the formal limit when the characteristic p of the ring or field in the latter goes to infinity. Therefore standard dS and AdS symmetries over the field of complex numbers can be generalized to dS and AdS symmetries over a finite ring or field of characteristic p. We now briefly describe the idea of the proof.

In the *technique* of classical mathematics there is no number ∞, infinity is understood only as a limit (i.e. as a potential infinity) and, as a rule, legitimacy of every limit is thoroughly investigated. However, the *basis* of classical mathematics involves actual infinity from the very beginning. For example, the ring of integers Z is involved from the very beginning and, even in standard textbooks, it is not even posed a problem whether Z should be treated as a limit of finite rings. Moreover, Z is the starting point for constructing the sets of rational, real and complex numbers and the sets with greater and greater cardinalities.

On the other hand, finite mathematics rejects infinities from the beginning. It starts from the ring $R_p = (0, 1, 2, ...p-1)$ where addition, subtraction and multiplication are performed as usual but modulo p, and p is called the characteristic of the ring. In the literature the ring R_p is usually denoted as Z/p. In our opinion this notation is not adequate because it may give a wrong impression that finite mathematics starts from the infinite set Z and that Z is more general than R_p. However, although Z has more elements than R_p, Z cannot be more general than R_p because Z does not contain operations modulo a number.

One can rigorously prove [4] that any operation in Z can be reproduced in R_p if p is chosen to be sufficiently large, and that is why Z can be treated as a limit of R_p when $p \to \infty$. This result looks natural from the following considerations. Since all operations in R_p are modulo p, R_p can be treated as a set $(-(p-1)/2, ...-1, 0, 1, ...(p-1)/2)$ if p is odd and as a set $(-p/2+1, ...-1, 0, 1, ...p/2)$ if p is even. In this representation, for numbers with the absolute values much less than p, the results of addition, subtraction and multiplication are the same in R_p and in Z, i.e. for such numbers it is not manifested that in R_p operations are modulo p. This example also demonstrates that in finite mathematics the notions of positive and negative cannot be fundamental. For example, the numbers $(-(p-1)/2$ and $(p+1)/2$ represent the same element of R_p because they are the same modulo p.

We use the abbreviation FQT (finite quantum theory) to denote quantum theory over the ring or field of characteristic p. By using the fact that Z is a limit of R_p when $p \to \infty$, one can prove [4] that FQT is more general (fundamental) than standard quantum theory. In view of **Definition**, this implies that, by choosing a sufficiently large value of p, FQT can reproduce any result of standard quantum theory (SQT) with any desired accuracy while SQT cannot reproduce all results of FQT: it cannot reproduce results where it is important that p is finite and not infinitely large. In Ref. [4], several physical phenomena where it is important that p is finite have been considered, and, as discussed in the present paper, this fact is also important for understanding BAU.

One can now consider the commutation relations (2) in spaces over a finite ring or field of characteristic p. In this way we get a generalization of standard dS and AdS quantum theories to dS and AdS quantum theories over a finite ring or field (see Ref. [4] for details).

3 Properties of quantum theories based on Poincare, dS and AdS symmetries

Let p^ν be the four-momentum of a particle in Poincare invariant theory. Define $p^2 = p^\nu p_\nu$, where a sum over repeated indices is assumed. Then for usual particles $p^2 \geq 0$ while for tachyons $p^2 < 0$. The existence of tachyons is a problem, and we will consider only usual particles. Then the mass of the particle can be defined as a nonnegative number m such that $m^2 = p^2$. If $m \neq 0$ then one can define the four-velocity v of the particle as $v = p/m$ and then $v^2 = 1$.

Elementary particles in Poincare invariant theory are described by irreducible representations (IRs) of the Poincare algebra by selfadjoint operators. The energy E of a particle with the momentum $\mathbf{p}$ and mass m equals $(m^2 + \mathbf{p}^2)^{1/2}$. The choice of the sign of the square root is only the matter of convention but not the matter of principle. Depending on this sign, there are IRs where the energy is either strictly positive or strictly negative while the probability to have zero energy is zero. By definition of IRs, a particle wave function ψ cannot be a superposition $\psi = \psi_1 + \psi_2$ where ψ_1 belongs to the IR with positive energies and ψ_2 belongs to the IR with negative energies.

In Poincare invariant theory, elementary particles can be characterized not only by their energies, momenta and spins but also by additional additive quantum numbers, e.g. electric charge, baryon quantum number etc. If particle 1 is described by a positive energy IR with some mass, spin and additive quantum numbers, and particle 2 is described by a negative energy IR with the same mass and spin but all additive quantum numbers for particle 2 are opposite to the corresponding additive quantum numbers for particle 1 then particle 2 is called the antiparticle for particle 1.

When we consider a system consisting of particles and antiparticles then the energy sign of both, particles and antiparticles should be the same. Indeed, consider, for example a system of two particles with the same mass m and let the momenta $\mathbf{p}_1$ and $\mathbf{p}_2$ be such that the total momentum $\mathbf{p}_1 + \mathbf{p}_2$ equals zero. Then, if the energy of particle 1 is positive, and the energy of particle 2 is negative then the total four-momentum of the system would be zero what contradicts experimental data. By convention, the energy sign of all the particles in question is chosen to be positive. For this purpose, the procedure of second quantization is defined such that after the second quantization the energies of antiparticles become positive. Then the mass of any particle is the minimum value of its energy in the case when the momentum equals zero. If all additive quantum numbers characterizing a particle equal zero then after the second quantization the particle and its antiparticle are described by the same IRs. Such particles are called neutral.

In theories where the symmetry algebra is the AdS algebra, the structure of IRs is known (see e.g. Refs. [6, 4]). The operator M^{40} is the AdS analog of the energy operator. Let W be the Casimir operator $W = \frac{1}{2}\sum M^{ab}M_{ab}$ where a sum over repeated indices is assumed. As follows from the Schur lemma, the operator W has only one eigenvalue in every IR. By analogy with Poincare invariant theory, we will not consider AdS tachyons where the eigenvalue is negative and then one can define the AdS mass μ such that $\mu \geq 0$ and μ^2 is the eigenvalue of the operator W.

As noted in the preceding section, the procedure of contraction from the AdS algebra to the Poincare one is defined such that if R is a parameter with the dimension *length* then $M^{4\nu} = RP^{\nu}$. This procedure has a physical meaning only if R is rather large. In that case the AdS mass μ and the Poincare mass m are related as $\mu = Rm$, and the relation between the AdS and Poincare energies is analogous. Since AdS symmetry is more general (fundamental) then Poincare one then μ is more general (fundamental) than m. In contrast to the Poincare mass and energy, the AdS mass and energy are dimensionless. From cosmological considerations, the value of R is usually accepted to be of the order of $10^{26}m$. Then the AdS masses of the electron, the Earth and the Sun are of the order of 10^{39}, 10^{93} and 10^{99}, respectively. The fact that even the AdS mass of the electron is so large might be an indication that the electron is not a true elementary particle. In addition, the present accepted upper level for the photon mass is $10^{-17}ev$. This value seems to be an extremely tiny quantity. However, the corresponding AdS mass is of the order of 10^{16}, and so even the mass which is treated as extremely small in Poincare invariant theory might be very large in AdS invariant theory.

By analogy with IRs of the Poincare algebra, in the AdS case there are IRs with positive and negative energies [6, 4] and therefore one can also define particles and antiparticles. As shown in Ref. [6] (see also Ref. [4]), in the AdS case, elementary particles are described by IRs of the discrete series. For positive energy IRs, the energy spectrum contains the eigenvalues $\mu, \mu+1, \mu+2, ...\infty$, and for negative energy IRs, the energy spectrum contains the eigenvalues $-\infty, ... -\mu-2, -\mu-1, -\mu$. Therefore the situation is pretty much analogous to that in Poincare invariant theories. In particular, the notion of neutral particles can be defined.

The descriptions of elementary particles in the dS and AdS cases are considerably different. In the former case all the operators $M^{4\nu}$ $(\nu = 0, 1, 2, 3)$ are on equal footing. Therefore M^{40} can be treated as the Poincare analog of the energy only in the approximation when R is rather large. In the general case, the sign of M^{40} cannot be used for the classification of IRs. As shown by Mensky [7], states belonging to IRs can be characterized by wave functions $\chi(v)$ on the upper and lower Lorenz hyperboloids characterized such that $v_0 > 0$ on the upper hyperboloid and $v_0 < 0$ on the lower one.

In his book [7] Mensky also describes another implementation of dS IRs when the representation space is the three-dimensional unit sphere in the four-dimensional space. In this implementation, the northern hemisphere corresponds to the upper hyperboloid and the southern hemisphere — to the lower hyperboloid. The equator corresponds to states with infinite Poincare momentum, but in this implementation of dS IRs, the operators of IRs are not singular in the vicinity of the equator and, since the equator has measure zero, the properties of wave functions on the equator are not important.

Since the number of states in dS IRs is twice as big as the number of states in IRs of the Poincare and AdS algebras, one might think that each IR of the dS algebra describes a particle and its antiparticle simultaneously. However, a detailed analysis in Refs. [8, 4] shows that states described by dS IRs cannot be characterized in terms of particle-antiparticle, and this is clear from several considerations.

For example, let us call states with the support of their wave functions on the upper hyperboloid (or the northern hemisphere) as particles and states with the support on the lower hyperboloid (or the southern hemisphere) as antiparticles. Then states which are superpositions of a particle and its antiparticle belong to the IR under consideration, and therefore they are not prohibited. However, this contradicts the superselection rule that the wave function of an elementary particle cannot be a superposition of states with opposite electric charges, baryon and lepton quantum numbers etc. Also, with such a definition of particles and antiparticles, the representation operators from the enveloping algebra of the IR can perform transformations *particle* $\leftrightarrow$ *antiparticle*. Therefore, in the dS case there can be no conserved additive quantum numbers such as electric charge, baryon quantum number etc. Those quantum numbers can be only approximately conserved when R is very large. In addition, in the dS case it is not possible to define the notion of neutral particles.

Breaking the representation space into two independent subspaces corresponding to a particle and its antiparticle looks especially unnatural when the representation space is implemented as a space of functions on the sphere. As already noted, in this implementation there are no singularities in the vicinity of the equator, the representation operators of the enveloping algebra can transform states with the support in the northern hemisphere to the states with the support in the southern hemisphere and vice versa. Therefore breaking the IR into two independent IRs defined on the northern and southern hemisphere obviously breaks the initial symmetry of the problem. As shown in Refs. [8, 4], this symmetry is broken in the formal limit $R \to \infty$ because one IR of the dS algebra splits into two IRs of the Poincare algebra with positive and negative energies. This fact is in agreement with the Dyson observation (mentioned above) that dS group is more symmetric than Poincare one.

When $R \to \infty$, the notions of particle-antiparticle and the conservation of electric charge and baryon and lepton quantum numbers are restored. Therefore those notions arise as a result of symmetry breaking, i.e. they are not fundamental.

As noted in the preceding section, FQT is more general (fundamental) than SQT, and in FQT it is also possible to define the notions of dS and AdS symmetries. In SQT the difference between IRs of the AdS and dS algebras is that an IR of the AdS algebra where the operators $M^{\mu 4}$ ($\mu = 0, 1, 2, 3$) are Hermitian can be treated as IRs of the dS algebra where these operators are anti-Hermitian and vice versa. As discussed in Ref. [4], in FQT, a probabilistic interpretation is only approximate and hence Hermiticy can be only a good approximation in some situations. Therefore, in the general case, in FQT, the dS and AdS cases are physically equivalent. A detailed construction of dS and AdS IRs in FQT has been given in Ref. [4].

The description of the energy spectrum in standard IRs of the AdS algebra has been given above. We will now explain why in FQT the spectrum is different. Let us note first that, while in SQT the quantity μ can be an arbitrary real number, in FQT μ is an element of R_p. As noted above, if p is odd then R_p contains the elements $-(p-1)/2, ... -1, 0, 1, ...(p-1)/2$ and the case when p is even is analogous. For definiteness, we consider the case when p is odd.

By analogy with the construction of positive energy IRs in SQT, in FQT we start the construction of the IR from the rest state, where the AdS energy is positive and equals μ. Then we act on this state by raising operators and gradually get states with higher and higher energies, i.e. $\mu+1, \mu+2, ...$ However, in contrast to the situation in SQT, we cannot obtain infinitely large numbers. When we reach the state with the energy $(p-1)/2$, the next state has the energy $(p-1)/2+1 = (p+1)/2$ and, since the operations are modulo p, this value also can be denoted as $-(p-1)/2$ i.e. it may be called negative. When this procedure is continued, one gets the energies $-(p-1)/2+1 = -(p-3)/2, -(p-3)/2+1 = -(p-5)/2, ...$ and, as shown in Ref. [4], the procedure finishes when the energy $-\mu$ is reached.

So, one can say that the representation contains equal numbers of positive and negative energies: positive energies $(\mu, \mu+1, ...(p-1)/2)$ and negative energies $(-(p-1)/2, ... -\mu-1, -\mu)$. However, since in finite mathematics the numbers are defined modulo p, then, in contrast to the situation in standard dS case, one can also say that the representation contains only positive energies $(\mu, \mu+1, ...(p-1)/2, (p+1)/2, ...p-\mu)$.

Therefore, in contrast to the situation in SQT, in FQT, IRs are finite-dimensional (and even finite since the ring R_p and its complex extension R_p+iR_p are finite). By analogy with the dS case in SQT, one can say that in FQT, one IR contains states with both, positive and negative energies. However, in FQT it is also illegitimate to call states with positive energies as particles and the states with negative energies as antiparticles. For example, with such a definition, the representation operators of the enveloping algebra can perform transformations *particle* $\leftrightarrow$ *antiparticle* and the states which are superpositions of particle and antiparticle states are not prohibited. Therefore, by analogy with the dS case in SQT, there can be no conserved additive quantum numbers such as electric charge, baryon quantum number etc., and it is not possible to define the notion of neutral particles. In addition, the fact that in FQT, such a definition of particles and antiparticles is illegitimate, is obvious from the fact that, as noted above, in finite mathematics the notions of positive and negative are not fundamental, and one also can say that the whole energy spectrum is positive.

As shown in Ref. [4], in the formal limit $p \to \infty$, one IR in FQT splits into two standard IRs of the AdS algebra with positive and negative energies, and therefore in this limit one can define the notions of particles and antiparticles. In turn, in situations when one can define the quantity R such that the contraction to the Poincare algebra works with a high accuracy, one can describe particles and antiparticles in the framework of Poincare symmetry.

Since FQT is more general (fundamental) than SQT, then, by analogy with standard dS case, we conclude that the notions of particle-antiparticle and the conservation of electric charge and baryon and lepton quantum numbers (which are restored when $p \to \infty$) arise as a result of symmetry breaking, i.e. they are not fundamental. Therefore particle theories in FQT will considerably differ from the particle theories in SQT. We believe that the construction of particle theories in FQT is one of the most fundamental (if not the most fundamental) problems of quantum theory.

4 Explanation of baryon asymmetry of the universe

As proved in Ref. [4] and explained in Sec. 2, FQT is the most general quantum theory. Then the fact that at present Poincare symmetry, electric charge conservation, baryon number conservation, lepton numbers conservation etc. work with a very high accuracy means that at present the values of p and R are very large. As already noted, the usual choice for R is $R \approx 10^{26}m$, and, as follows from the approach to gravity proposed in Ref. [4], p is a huge number of the order at least $exp(10^{80})$.

As noted in Ref. [4], the fact that finite mathematics is more general (fundamental) than standard one is clear even from the philosophy of verificationism and the philosophy of quantum theory. Every computing device can perform mathematical operations only modulo some number p which are defined by the number of bits this device can operate with. It is reasonable to believe that finite mathematics describing physics in our universe is characterized by a characteristic p which depends on the current state of the universe, i.e. the universe can be treated as a computer. Therefore it is reasonable to believe that the number p is different at different stages of the universe.

The problem of time is one of the most fundamental problems of quantum theory, and this problem is discussed in a vast literature (see e.g. Ref. [4] and references cited therein). In quantum theory it is not correct to operate with the time t which is a continuous quantity belonging to the interval $(-\infty, +\infty)$. In Ref. [4] it has been discussed a conjecture that standard classical time t manifests itself because the value of p changes, i.e. t is a function of p. We do not say that p changes over time because classical time t cannot be present in quantum theory; we say that we feel t because p changes.

At the present stage of the universe the number p is huge but it is reasonable to assume that at earlier stages the value of p was much less than now. As explained in the preceding section, if p is not anomalously large then the notions of particles and antiparticles and the conservation of electric charge and baryon and lepton quantum numbers do not have a physical meaning. We have also noted that FQT is more general (fundamental) than SQT, and, at present, particle theory in FQT is not developed. This poses a problem whether cosmological theories describing early stages of the universe are reliable.

However, when p increases then for a greater and greater number of particles the notions of particle-antiparticle, the electric charge and the baryon number work with a greater and greater accuracy. Finally, at the present stage of the universe those notions work with an extremely high accuracy.

Usually the BAU problem is formulated such that, according to symmetry between baryons and antibaryons, at the very earlier stages of the universe their numbers should be the same and then, according to the baryon number conservation, their numbers should be the same at the present stage. However, at this stage their numbers are not the same.

However, as explained above, the notions of baryon-antibaryon and the baryon number conservation work only at the present stage while at early stages of the universe those notions do not have a physical meaning. Since the particle theory in FQT is not developed yet, the existing theory cannot predict what the relation between the numbers of baryons and antibaryons should be at present. However, there are no reasons to think that those numbers should be the same.

For example, suppose that those numbers have arisen as a result of pure random circumstances. Then, the probabilities of different numbers can be described by the Poisson distribution.

For illustration, consider the case when one throws a coin N times and calculates the numbers of tails and heads. The probability of each event is $1/2$ and therefore when N is very large, one can expect that approximately $N/2$ events will be heads and approximately $N/2$ events will be tails. However, it is extremely improbable that the corresponding numbers will be exactly $N/2$ and $N/2$. Indeed, the root-mean-square-deviation is proportional to $N^{1/2}$. If, for example, $N = 1000$ then the most probable number of the deviation is approximately 32, and therefore the most probable difference between the numbers of heads and tails is 64. The real difference can considerably differ from 64 but it is extremely improbable that there will be exactly 500 heads and 500 tails.

Since we do not know what happens when p is not anomalously large, we cannot exclude a possibility that the numbers of baryons and antibaryons depend not only on pure random circumstances. For example, if something analogous to spontaneous symmetry breaking happens then the numbers of baryons and antibaryons at the present stage of the universe can be considerably different. Probably the future development of FQT will make it possible to estimate realistic differences between the numbers. However, let us stress again that even for a scenario when the numbers of baryons and antibaryons in the universe are fully random, it is extremely improbable that those numbers will be the same.

5 Discussion

The problem statement on the baryon asymmetry of the universe (BAU) follows. According to present quantum theory and cosmological models, the universe has been created with equal numbers of baryons and antibaryons. Then, as a consequence of the baryon number conservation, at the present stage of the universe, the numbers of baryons and antibaryons should also be the same. However, those numbers are not the same.

In the present paper we propose the explanation of the BAU problem based on the following facts.

In our publications (see e.g. Ref. [4] and references therein) we have proposed an approach to quantum theory called finite quantum theory (FQT). Here quantum theory is based not on standard mathematics (involving the notions of limits, infinitely small, continuity etc.) but on finite mathematics based on a finite ring or field of characteristic p. It has been proved that FQT is more general (fundamental) than standard quantum theory because the latter is a special degenerate case of the former in the formal limit $p \to \infty$.

It has been proved that the notions of particle-antiparticle, the electric charge and the baryon quantum number arise as a result of symmetry breaking at $p \to \infty$ when FQT is replaced by standard quantum theory. In the present paper we try to explain these facts in a simplest possible way. Therefore those notions are not fundamental. At the present stage of the universe they work with a very high accuracy because the number p at this stage is huge. However, there is no guaranty that this number was huge at earlier stages of the universe. We argue that it is reasonable to believe that at those stages the number p was much less than now.

Therefore for understanding what happens at early of the universe we need to develop particle theory based on FQT. The construction of this theory is one of the most fundamental (if not the most fundamental) problems of quantum theory. At present this construction has not been developed yet and therefore at the present stage of quantum theory it is not possible to describe physics at earlier stages of the universe. *In particular, this implies that existing cosmological theories describing earlier stages of the universe are not reliable.* We can only say that, because at these stages the notions of particle-antiparticle, the electric charge and the baryon quantum number do not have a physical meaning, the statement that the numbers of baryons and antibaryons at those stages are the same also does not have a physical meaning. In particular, there is no guaranty that at the present stage of the universe, when the notions of particle-antiparticle, the electric charge and the baryon quantum number work with a very high accuracy, the numbers of baryons and antibaryons will be the same.

Since the existing theory cannot estimate the numbers of baryons and antibaryons at the present stage of the universe, we can only guess what those numbers can be. As noted in the preceding section, even if those numbers arise as a consequence of pure random circumstances, the probability that those numbers are the same is extremely low. *Therefore the BAU problem does not arise because there is no reason to expect that the numbers of baryons and antibaryons at the present stage of the universe will be the same.*

Let us now discuss the following point. As noted above, the notion of electric charge also arises as a result of symmetry breaking when, as a result of taking the limit $p \to \infty$, FQT is replaced by standard quantum theory. Therefore, the notion of the electric charge conservation also cannot be fundamental, as well as the notion of the baryon number conservation. Therefore the problem of the electric charge conservation can be discussed in full analogy with the above consideration of the BAU problem. According to the present quantum theory and cosmological models, the universe has been created as electrically neutral, and then, in view of the electric charge conservation, it should be electrically neutral at the present stage. *However, in full analogy with the above consideration, one can conclude that the present state of the universe is not electrically neutral.*

The usual statement is that the total electrical charge of stars is typically positive because electrons can escape from thermonuclear reactions inside stars, but the total electric charge of the universe is zero. In view of the above considerations, it is important to understand whether it is possible to perform experiments and/or theoretical investigations on the problem of total electric charge of the universe.

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