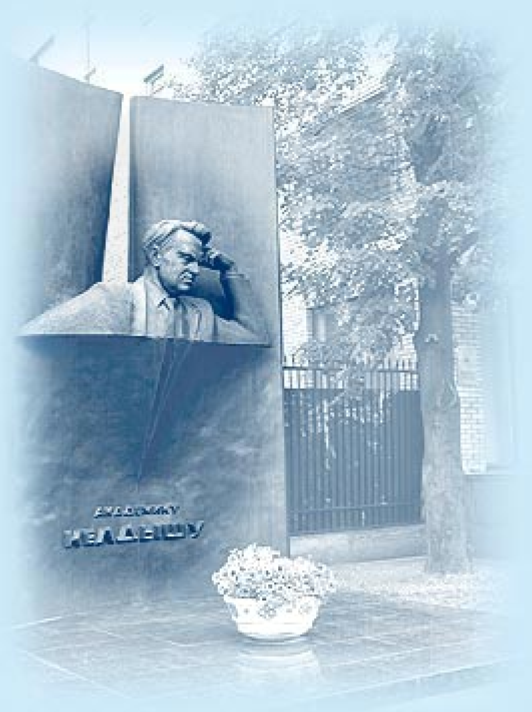

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Quantum nonlocality and Special Theory of Relativity

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В.Д. Лахно

Квантовая нелокальность и специальная теория относительности

Квантовая механика приводит к непримиримым противоречиям с классической специальной теорией относительности (СТО). Эти противоречия отсутствуют, если считать пространство дискретным. В данной статье в простейшем случае одномерного дискретного пространства получено дискретное уравнение Дирака. Показано, что отказ от континуального описания пространства снимает противоречия между квантовомеханическим описанием и СТО. Рассмотрены возможности экспериментальной проверки теории.

Ключевые слова: одномерное уравнение Дирака, операторы скорости и координаты, блоховские осцилляции, энион

V.D. Lakhno

Quantum nonlocality and Special Theory of Relativity

Quantum mechanics leads to irreconcilable contradictions with the classical special theory of relativity (STR). These contradictions are absent if we consider space to be discrete. In this paper, the discrete Dirac equation is obtained in the simplest case of one-dimensional discrete space. It is shown that the rejection of the continuous description of space removes the contradictions between the quantum-mechanical description and STR. The possibilities of experimental verification of the theory are considered

Key words: one-dimensional Dirac equation, velocity and coordinate operators, Bloch oscillations, anyon

Contents

1. Introduction

The purpose of this paper is to discuss some difficulties in reconciling quantum mechanics and the special theory of relativity (SRT). Apparently, the most striking ideological contradiction is the Einstein-Podolsky-Rosen (EPR) paradox, which demonstrates the non-local nature of interaction in quantum mechanics.

Another equally striking evidence of the contradiction is the demonstration of the superluminal velocity of particle movement in tunneling processes.

The special theory of relativity, which underlies classical physics, has never been doubted by the qualified majority of physicists. It followed that quantum mechanics had to undergo some modification. Such a modification was carried out a hundred years ago by Dirac, who postulated the relativistic equations of quantum mechanics. These equations themselves contained a number of irremediable contradictions, which had to be accepted for lack of anything better. Among them, first of all, is the equality of the eigenvalues of the velocity operator to the value of the speed of light. Another fundamental contradiction is the appearance of antiparticles in the original single-particle Dirac equation. These contradictions were automatically transferred to the relativistic quantum field theory, which postulates the commutativity of field operators for spatially similar intervals, which is necessary for the implementation of cause-and-effect relationships.

All attempts to correct quantum mechanics remained unsuccessful. The validity of the conclusions of quantum mechanics was confirmed by numerous experiments, of which the most important were experiments to verify Bell's inequalities.

It followed that something was wrong not with quantum mechanics, but with SRT.

Within the framework of the postulates on which SRT is based, and which, like quantum mechanics, is confirmed by many experiments, nothing can be changed either.

This means that some postulates of the theory of relativity, should be abandoned in order to reconcile it with quantum mechanics, and such an abandonment should be quite radical.

2. Preliminary Remarks

We will proceed from the fact that, since classical mechanics is only a limiting case of quantum mechanics, then SRT is also its limiting case.

SRT, in turn, is based on the concept of space and time. However, the concept of space does not appear in the original postulate of quantum mechanics, describing the evolution of the wave function. Indeed, in the most general case, such an equation has the form:

$$i\hbar \frac{\partial}{\partial t}|\Psi\rangle = \hat{H}|\Psi\rangle \qquad (1)$$

where Hamiltonian *H* is written as:

$$\hat{H}_{\text{кв}} = \sum_{i,j} v_{ij}|i\rangle\langle j| \qquad (2)$$

The indices *i* and *j* both discrete and continuous, define an infinite-dimensional matrix that determines the evolution of the Dirac vectors $|\Psi\rangle$. Thus, equation (1) describes not the motion of particles in space, but the evolution of their states in time. Of course, equations (1), (2) can be transformed to the evolution of the wave function in ordinary coordinate space, but this will only be a special limiting case of these equations.

The use of postulate (1), (2) instead of a spatial description removes many questions and paradoxes. In particular, the question of the possibility of superluminal speed in such a formulation becomes meaningless, since there is no space. The comparison of some of the set of indices *i* with spatial coordinates is only a convention accepted for describing phenomena in space. Numerical modeling of the evolutionary processes described by (1), (2) leads to the fact that if the state of a particle at the initial moment of time corresponded to i, then at any other moment of time there is a non-zero probability of finding the particle in some state j. When interpreted spatially, these indices can correspond to the idea of superluminal motion, for example, the tunneling of a particle with a superluminal velocity. The idea of SRT about simultaneous events in the absence of a spatial description is also meaningless. In quantum theory, there is an absolute uniform time, which leads to a natural explanation of the EPR paradox: all particles are connected to each other regardless of whether the interval is time-like or space-like when introducing a spatial description.

In the approach under consideration there are no time paradoxes at all, such as the possibility of a time machine: you can return to the past, but this will be a return to exactly the state that corresponded to that past, that is, "killing grandfather" is simply impossible.

3. Formalism

The formalism of quantum mechanics is based on the concept of a state $|\Psi\rangle$ and a superposition of states. According to the principle of superposition of states, the superposition of any states of a system taken with arbitrary (in the general case, complex) coefficients is also a state of the system. In other words, the states of the system form a linear vector space. This makes it possible to use a formal mathematical apparatus for linear vector spaces.

We will denote the state vector by the symbol $|\lambda_i\rangle$ if the system is in a state in which the physical quantity F has a certain value λ_i. Such a state is called an eigenstate, and λ_i is an eigenvalue. In addition to addition and multiplication by a complex number, the state vector can be projected onto another vector. In other words, it is possible to form a scalar product $|\Psi\rangle$ with any other vector $|\Psi\rangle$, which is denoted as $\langle\Psi'|\Psi\rangle$ and is a complex number, and:

$$\langle\Psi'|\Psi\rangle = \langle\Psi|\Psi'\rangle^*. \tag{3}$$

In a particular case $|\Psi'\rangle = |\Psi\rangle$ the scalar product is a positive number and determines the norm of the vector. In quantum mechanics, each physical quantity F corresponds to a linear Hermitian operator $\hat{F}$, whose eigenvalues are the possible values of a physical quantity, and whose eigenvectors are its eigenstates:

$$\hat{F}|\lambda_i\rangle = \lambda_i|\lambda_i\rangle. \tag{4}$$

The eigenvectors $|\lambda_i\rangle$ of a Hermitian operator belonging to different eigenvalues are orthogonal to each other, i.e. $\langle\lambda_i|\lambda_j\rangle = 0,\ i \neq j$. From them, one can construct an orthogonal basis in the state space, normalized to unity: $\langle\lambda|\lambda\rangle = 1$. An arbitrary vector $|\Psi\rangle$ can be expanded in this basis:

$$|\Psi\rangle = \sum_\lambda c_\lambda\,|\lambda\rangle. \tag{5}$$

To normalize the state vector $|\Psi\rangle$ to a unit, the expansion coefficients c_λ satisfy the relation:

$$\sum_\lambda |c_\lambda|^2 = 1. \tag{6}$$

The sign of the sum in formulas (5), (6) means summation over a discrete and integration over a continuous spectrum of values. In the case of a continuous spectrum of values, the vectors are assumed to be normalized to the δ-function: $\langle\lambda|\lambda'\rangle = \delta(\lambda - \lambda')$. From (5), (6) it follows that in the expansion (5) of an arbitrary state vector $|\Psi\rangle$ of a physical quantity F the values of $|c_\lambda|^2 = |\langle\lambda|\Psi\rangle|^2$ are equal to the probabilities of detecting the system in states $|\lambda\rangle$, i.e. the probabilities that when measuring F, its value will be equal to λ.

Any linear operator chosen in the basis $|\lambda\rangle$, can be represented by a matrix, in particular, the matrix elements of a Hermitian operator $\hat{F}$ have the form:

$$F_{\lambda_i,\lambda_j} = \langle\lambda_i|\hat{F}|\lambda_j\rangle \tag{7}$$

and satisfy the relations: $F_{\lambda_i,\lambda_j} = F^*_{\lambda_j,\lambda_i}$.

For $|\lambda\rangle$, which are eigenvectors of the operator $\hat{F}$, the matrix corresponding to it is diagonal.

If we compare an arbitrary vector $|\Psi\rangle$ with a column of coefficients:

$$|\Psi\rangle = \begin{pmatrix} c_1 \\ c_2 \\ \vdots \end{pmatrix} \tag{8}$$

in the chosen basis (5), then the action of the operator, on $|\Psi\rangle$: is reduced to matrix multiplication. The vector $|\Psi'\rangle$ resulting from such an action may differ from $|\Psi\rangle$ in length and direction, i.e. it is a column in which, instead of coefficients c_i, there are coefficients c_i' corresponding to the coordinates of the vector $|\Psi'\rangle$ in the same basis: $c_i' = \sum_j F_{ij} c_j$.

Accordingly, the conjugate vector in a given basis is written as:

$$\langle\Psi'| = \left(c_1'^*, c_2'^*, \cdots\right) \tag{9}$$

so that the scalar product:

$$\langle\Psi'|\Psi\rangle = \sum c_1'^* c_i \tag{10}$$

is calculated according to the rules of matrix multiplication and, in the case of equality of $|\Psi'\rangle$ and $|\Psi\rangle$ leads to the normalization condition (6).

If we choose an orthonormal basis of unit vectors as the basis vectors of the state:

$$|i\rangle = \begin{pmatrix} 0 \\ \vdots \\ 0 \\ 1_i \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{11}$$

then any linear operator $\hat{F}$ in this basis can be represented as:

$$\hat{F} = \sum_{i,j} |i\rangle \langle j| \tag{12}$$

using the rules of matrix multiplication for (11) it is easy to verify that (12) is a matrix with matrix elements F_{ij}:

$$\sum_{i,j}^{N} F_{ij} |i\rangle\langle j| = \begin{pmatrix} F_{11} & F_{12} & \cdots & F_{1N} \\ F_{21} & F_{22} & \cdots & F_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ F_{N1} & F_{N2} & \cdots & F_{NN} \end{pmatrix}. \tag{13}$$

In quantum mechanics, the state of a system is determined by specifying a set of physical quantities that characterize the system – the so-called complete set.

Any vector of the system's state can be represented as a decomposition into states $|\lambda\rangle$ of a complete set chosen by us, where λ is the set of eigenvalues of the quantities included in this complete set. If μ is a set of eigenvalues of the quantities that make up another complete set chosen to describe the same physical system, then in this new representation:

$$|\Psi\rangle = \sum_{\mu} b(\mu) |\mu\rangle, \;\; b(\mu) = \langle \mu | \Psi \rangle \tag{14}$$

the coefficients $b(\mu)$ satisfy condition (6), i.e. $|b(\mu)|^2$ are equal to the probability of finding the system in the state μ. Thus, the coefficients $b(\mu)$ have the meaning of the wave function of the system in the representation of μ, which are related to the wave function $c(\lambda)$ in the representation of λ by the relation:

$$b(\mu) = \sum_{\lambda} \langle \mu | \lambda \rangle \, c_{\lambda}. \tag{15}$$

4. Quantum Mechanics of a Relativistic Particle

Let us apply the outlined general scheme of quantum mechanics to describe a relativistic quantum particle and, as an example, obtain an equation that, corresponds to the one-dimensional Dirac equation in the space-time description. For this purpose, let us consider a one-dimensional discrete regular lattice.

To describe the states of a particle in a chain, we will proceed from the Hamiltonian

$$\hat{H} = \sum_{i,j} \nu_{i,j} \, |i\rangle\langle j|, \tag{16}$$

where matrix elements ν_{ij} are independent of time.

The Schrödinger equation for the wave function of a particle $|\Psi\rangle$ has the form:

$$i \frac{\partial}{\partial t} |\Psi\rangle = \hat{H} |\Psi\rangle. \tag{17}$$

We will seek the wave function of a stationary state for which the probability of finding a particle at any site in the chain does not depend on time in the form:

$$|\Psi(t)\rangle = e^{-iWt} |\Phi\rangle, \tag{18}$$

where the wave function $|\Phi\rangle$ does not depend on time, we assume that Planck's constant $\hbar$ is equal to 1.

Substituting (18) into (17) leads to an equation for determining the eigenvalues of the particle energy W:

$$W |\Phi\rangle = \hat{H} |\Phi\rangle. \tag{19}$$

Let us denote by W_k the energy of the k-th state of the particle, corresponding to the wave function $|\Phi_k\rangle$, which we will seek in the form:

$$|\Phi_k\rangle = \sum_n R_{nk}\,|n\rangle, \tag{20}$$

where the summation is performed over all sites of the chain. For the Hamiltonian (16), the eigenvalue equation (19) with the wave function (20) takes the form:

$$W_k R_{nk} = \sum_{n'} \nu_{nn'}\, R_{n'k}. \tag{21}$$

Let us consider the case when the matrix elements $\nu_{nn'}$ are nonzero only if $n' = n - 1, n, n+1$. In this case, from (21) we obtain:

$$W_k R_{nk} = \nu_n R_{nk} + \nu_{n,n+1} R_{n+1,k} + \nu_{n,n-1} R_{n-1,k}. \tag{22}$$

We will look for a solution to equation (22) in the form:

$$R_{nk} = C\exp(ikn). \tag{23}$$

We will consider in the equation for the eigenvalues (22), assuming for even and odd sites of the chain:

$$\begin{gathered} n = 2j\colon\ \ \nu_{n,n} = \nu_{2j,2j} = -m_0,\ \ \nu_{n,n+1} = \nu_{2j,2j+1} = \nu, \\ \nu_{n,n-1} = \nu_{2j,2j-1} = -\nu \\ n = 2j+1\colon\ \ \nu_{2j+1,2j+1} = m_0,\ \ \nu_{n,n+1} = \nu_{2j+1,2j+2} = -\nu, \\ \nu_{n,n-1} = \nu_{2j,2j-1} = \nu, \quad j = 0, \pm 1, \pm 2, \dots \dots \end{gathered} \tag{24}$$

As a result, from (24) we obtain:

$$\begin{gathered} W_k R_{2j,k} = -m_0 R_{2j,k} + \nu R_{2j+1,k} - \nu R_{2j-1,k} \\ W_k R_{2j+1,k} = m_0 R_{2j+1,k} - \nu R_{2j+2,k} + \nu R_{2j,k} \end{gathered} \tag{25}$$

We will look for solutions of the system of equations (25) in the form:

$$R_{2j+1,k} = u_2 \exp[ik(2j+1)], \qquad (26)$$
$$R_{2j,k} = u_1 \exp[ik2j],$$

Substituting (26) into (25) leads to the equations:

$$(W_k + m_0)u_1 = \nu\left(e^{ik} - e^{-ik}\right)u_2 \qquad (27)$$
$$(W_k - m_0)u_2 = \nu\left(e^{-ik} - e^{ik}\right)u_1$$

Hence, for the spectrum, we obtain the expression:

$$W_k = \pm\sqrt{m_0^2 + 4\nu^2 \sin^2 k} \qquad (28)$$

For a massless particle $m_0 = 0$ and small k, the spectrum (28) must correspond to the photon energy. Thus, from (28) it follows that for this to happen $2\nu = c$, must be satisfied, where c is the speed of light.

In dimensional units $2|\nu| = \hbar c/a$, where $\hbar$ is the Planck constant, a is the lattice constant. As $a \to 0$ from (28) follows the relativistic expression for the particle energy:

$$W_k = \pm\sqrt{m_0^2 c^4 + \hbar^2 k^2 c^2}\,, \qquad (29)$$

which does not depend on the value of a. Thus, in dimensional form, the dynamic Dirac equation corresponding to (25) takes the form:

$$i\hbar \frac{\partial R_{2j}}{\partial t} = -m_0 c^2 R_{2j} + \frac{\hbar c}{2a} R_{2j+1} - \frac{\hbar c}{2a} R_{2j-1} \qquad (30)$$

$$i\hbar\frac{\partial R_{2j+1}}{\partial t}=m_0c^2R_{2j+1}-\frac{\hbar c}{2a}R_{2j+2}+\frac{\hbar c}{2a}R_{2j}$$

To bring the Dirac equation to its usual form in spatial description, we denote:

$$R_{2j+1,k}=R_k^{(1)}(j) \tag{31}$$
$$R_{2j,k}=R_k^{(2)}(j)$$

We will consider $R_k^{(1)}(j)$ and $R_k^{(2)}(j)$ to be smooth functions of j. In this case, equations (30) will take the form:

$$W_kR_k^{(1)}(j)=m_0R_k^{(1)}(j)-2\nu\frac{d}{dj}R_k^{(2)}(j) \tag{32}$$
$$W_kR_k^{(2)}(j)=-m_0R_k^{(2)}(j)+2\nu\frac{d}{dj}R_k^{(1)}(j)$$

or introducing the Pauli matrices:

$$\sigma_1=\begin{pmatrix}0&1\\1&0\end{pmatrix},\quad \sigma_2=\begin{pmatrix}0&-i\\i&0\end{pmatrix},\quad \sigma_3=\begin{pmatrix}1&0\\0&-1\end{pmatrix},\quad R=\begin{pmatrix}R^{(1)}\\R^{(2)}\end{pmatrix} \tag{33}$$

from (32) we get

$$WR=\sigma_3R+2\nu\frac{d}{dx}i\sigma_2R \tag{34}$$

In dimensional form, the 1d Dirac time equation has the form:

$$i\hbar\frac{\partial R}{\partial t}=m_0c^2\sigma_3R+ic\hbar\sigma_2\frac{dR}{dx} \tag{35}$$

where $x = ja$, the function R satisfies the normalization condition. Note that, depending on the choice of matrix elements (24), under the condition that it is Hermitian, there are different forms of writing the one-dimensional Dirac equation.

In Dirac's interpretation, negative energies correspond to an unobservable "Dirac sea" filled with electrons, against the background of which particles with positive energy are described. Unlike Dirac, for a finite value of the lattice constant a, the energy of the particle (28) is limited from above and below and consists of two zones of continuous energies separated by an energy gap, the minimum value of which is equal to $2m_0$.

Here there is a complete analogy with intrinsic semiconductors, in which the lower zone is a completely filled valence band, and the upper one is a free conduction band. The minimum energy required to transfer a particle from the valence band to the conduction band is equal to $2m_0$.

5. Coordinate, Velocity, Momentum operators

As an example, we give expressions for the operators of the coordinate, velocity and momentum of a particle in discrete quantum mechanics.

By introducing the coordinate operator $\hat{x}$:

$$\hat{x} = \sum_n n|n\rangle\langle n|, \tag{36}$$

we find the velocity operator $\hat{V}$ from the quantum mechanical relation for the commutator:

$$i\hat{V} = \left[\hat{x}, \hat{H}\right] = \hat{x}\hat{H} - \hat{H}\hat{x}. \tag{37}$$

Substituting (36) and (16) into (37) we express the velocity operator as:

$$\hat{V} = i\sum_{n,m} v_{n,m}(m-n)|n\rangle\langle m| \,. \tag{38}$$

Thus, the velocity operator is determined by the non-diagonal elements of the matrix $v_{n,m}$ and in the case when $v_{n,m}$ are non-zero only between adjacent sites, that is, in the nearest neighbor approximation, from (38) we obtain:

$$\hat{V} = i\sum_n \big(v_{n,n+1}|n\rangle\langle n+1| - v_{n,n-1}|n\rangle\langle n-1|\big). \tag{39}$$

The momentum operator $\hat{P}$ should be determined from the commutation relations:

$$[\hat{P},\hat{x}] = \hat{P}\hat{x} - \hat{x}\hat{P} = -i\hbar\hat{I} \,, \tag{40}$$

where $\hat{I}$ is the identity matrix, the operator $\hat{x}$ is defined by expression (36). In the finite-dimensional case, however, it is impossible to construct a momentum operator satisfying the commutation relations (40). This is due to the fact that the matrices A and B of finite rank have the property: SpAB=SpBA and, therefore, the spur taken from the left-hand side of equality (40) is equal to zero, and on the right, the spur from the identity matrix is equal to the dimension of the finite-dimensional space. When passing to the continuum limit, however, that is, for matrices of infinite rank, such an operator can be introduced. It is easy to verify that it has the form:

$$\hat{P} = -i\hbar\sum_n \frac{\partial}{\partial x}|n\rangle\langle n| \,. \tag{41}$$

In dimensionless variables, the eigenvalue of such an operator will be the wave number k, while for the velocity operator in a finite-dimensional Hilbert space, the eigenvalue of the velocity operator will be the quantity $|\nu| = 2\nu\sin k$. In dimensional units, this corresponds to $|v| = \ c\sin k$ from which it follows that the speed of light when passing on to a spatial description is the limiting speed.

6. Two-body Problems and Anyons

In both classical and quantum relativistic mechanics, the problem of even two bodies cannot be solved, since in continuum space the relativistic problem of two bodies cannot be reduced to a single-particle problem. This is due to the fact that if we use the special theory of relativity and introduce the concept of time for one of the particles, it becomes unclear how to introduce time for the second particle and write the corresponding dynamic equations. In the case of a discrete space, this is quite easy to do. Choosing the wave function of two particles in the form:

$$|\Psi\rangle = \sum\nolimits_{i,j} \Psi_{i,j} \left|0, \dots, 1_i, 0, \dots 1_j, 0, \dots\right\rangle$$

For the coefficients $\Psi_{i,j}$ we get:

$$v(\Delta\Psi)_{ij} + v_{ij}\Psi_{ij} = \sqrt{-1}\partial\Psi_{ij}/\partial t$$

where v_{ij} are the interactions of particles located at sites i and j, $(\Delta\Psi)_{ij}$ is the discrete Laplace operator:

$$(\Delta\Psi)_{ij} = \Psi_{i-1,j} + \Psi_{i+1,j} + \Psi_{i,j-1} + \Psi_{i,j+1}$$

Accordingly, the probability of finding particles at point i is determined by the expression $P_i(t) = \sum_j \left|\Psi_{ij}(t)\right|^2$

Thus, the two-body problem in a 1d lattice becomes equivalent to the one-body problem in a 2d lattice.

In the 1d case under consideration, there is no concept of a particle spin. The concept of fermions and bosons is preserved in 1d. In the two-body problem, the limit $v_{ii} = \infty$ corresponds to fermions, and the limit $v_{ii} = 0$ corresponds to bosons.

The finite values of v_{ii} correspond to anyons that have not been observed in the world of elementary particles, but have meaning in condensed matter physics by introducing an anyon phase multiplier into the permutation relations:

$$|n, m\rangle = e^{i\theta}|m, n\rangle$$

where $\theta = \pi$ corresponds to Fermi-Dirac statistics, and $\theta = 2\pi$ to Bose-Einstein statistics.

Discussion

The question of the EPR paradox, superluminal tunneling and wave function reduction are in fact questions of the same nature. For their consistent description, the approach under consideration assumes the use of a discrete space. This approach, using the Holstein, Hubbard, Su-Schrieffer-Heeger and other models, has long been used in condensed matter physics.

An experimental test of the discrete nature of space can be cosmological observations. Due to the dependence of the speed of light on the granularity of space, its value for photons of different energies will be different. This follows from the fact that, according to (28), at $m_0 = 0$ the group velocity of a photon $v = c\cos ka$, i.e. it decreases with increasing energy.

In terrestrial conditions, direct confirmation of the possibility of superluminal speed can be obtained in tunnel experiments if a large concentration of particles is created to the left of the tunnel barrier, of which at least one will be recorded to the right of the barrier in a time shorter than the time it takes for light to pass through the region occupied by the barrier.

The approach considered leads to numerous new effects that have apparently never been discussed in the literature. So, for example, due to the finiteness of the magnitude of the possible particle energy determined by (28), it is possible to observe such a phenomenon as Bloch oscillations of elementary particles in superstrong electric fields with a frequency of $w = eEa$, where E is the electric field intensity. The presence of such oscillations leads to the possibility of emitting ultra-low frequency electromagnetic waves. This radiation can be observed in collision experiments of elementary particles, such as protons, the electric field intensity inside of which is millions of times higher than intra-atomic ones.

The motivation for writing this article was the intensive development of such industries as quantum computers and quantum computations. It is generally assumed that any theory is approximate, since an exact theory must be relativistic. However, this does not apply to quantum computers, which operate based on the properties of entangled states. Taking into account relativistic corrections in the theory of quantum computations would make it impossible to carry out such calculations. Relativistic corrections would lead to a rapid accumulation of computational errors due to decoherence associated with the use of SRT. It is also difficult to specify the exact limits of applicability of SRT as well as to determine the value of the fundamental length of a discrete space. Roughly speaking, the limits of applicability of SRT can be defined as follows: if the application of SRT leads to paradoxes, a discrete space and a quantum mechanical description should be used.

One of the current problems of physics is the quantum-mechanical generalization of SRT to gravity, which in the classical case is described by the general theory of relativity. Such a generalization to the case of quantum mechanics, apparently, can be associated with a further rejection of the postulates used, for example, from the translational invariance of discrete space. An experimental confirmation of the discrete nature of the gravitational field would be the observation of electromagnetic radiation from elementary particles in a strong gravitational field. Due to the discreteness of space, this frequency will be equal to the Bloch frequency $w = m_0 G a$, where G is the intensity of the gravitational field, which can reach Planck values near the singularities.

This note can be expanded infinitely by means of sophisticated mathematical formalism and deep philosophical reflections on the nature of space and time. We leave this to those who wish to immerse themselves into the subject matter. The material presented is completely devoid of literature and references to it. This is done because of the countless number of publications on the issues considered, which are easy to find on the Internet. The list of references would be a multi-volume construction, making such an undertaking pointless.