Indeterministic Quantum Gravity

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Abstract

A theory which claims to describe all the universe is advanced. It unifies general relativity, quantum field theory, and indeterministic conception.

Basic entities are: classical metric tensor $g$, cosmic reference frame (including cosmic time $t$), operator $T$ of energy-momentum tensor, Hamiltonian $H_t$, and state vector $\Psi$. Dynamical equations are: the Einstein equation $G[g] = (\Psi, T\Psi)$ ($G$ is the Einstein tensor), the Heisenberg equation $dT/dt = i[H_t, T]$, and the condition $H_t\Psi_t = \varepsilon_t\Psi_t$ arising from the cosmic energy determinacy principle advanced in the theory. The last equation describes quantum jump dynamics.

Quantum jumps lead to the instantaneous transferring of action and information, which, however, neither violates the causality principle, nor contradicts quantum field theory and general relativity.

The cosmic energy determinacy principle implies the eternal universe, i.e., the cyclic one without beginning and ending, the minimal energy in every cycle being finite.
Les plus riches cités, les plus grands paysages,
Jamais ne contenaient l’attrait mystérieux
De ceux que le hasard fait avec les nuages.
Et toujours le désir nous rendait soucieux!

Charles Baudelaire

Introduction

Current physics is based on two fundamental theories and one fundamental conception and is confronted with two fundamental problems. The theories are quantum field theory (QFT) and general relativity (GR), the conception is quantum indeterminism, the problems are quantum gravity and indeterministic quantum theory. But as long as the problem of a unified theory is raised, the global problem may be formulated as that of constructing indeterministic quantum gravity, i.e., a theory which would unify QFT and GR and describe quantum jump dynamics. Such a theory would, naturally, claim to describe all the universe.

The aim of this paper is to construct indeterministic quantum gravity. The usual approach to the problem of constructing a unified physical theory reduces to unifying QFT and GR. Such a unified theory is usually said about as quantum theory of gravitation, or quantum gravity. There is voluminous literature devoted to problems of this approach (see, e.g., [1-10]). But there exists yet another fundamental problem—that of quantum jump dynamics. This is the starting point of the approach advanced in this paper. The reasoning is as follows.

In indeterministic dynamics [11], a quantum system being initially in a pure state \( \omega' = (\Psi', \Psi'') \) passes, in general, into a mixed state \( \omega'' = \sum_{j \in J} w_j \omega_j, \omega_j = (\Psi_j, \Psi'_j) = \delta_{jj'} \). The interpretation of the latter is the following: "In reality", the system is with a probability \( w_j \) in a pure state \( \omega_j \). Quotation marks are put because the corresponding notion is primary. The transition \( \omega' \rightarrow \omega'' \) is usually considered as the result of the breaking of coherence between amplitudes \( \Psi_j \)'s [12-14,11]. Notwithstanding great efforts, this approach has not hit the mark. In this paper the aim will be achieved in quite another way. Now, however, we focus attention on the transition \( \omega'' \rightarrow \omega_j \), which is the reduction of the mixed state to the pure one. Here, a problem arises with the hierarchy of irreduction, i.e., the absence of reduction, or retaining the mixed state [15,16]. (Do not confuse with the von Neumann hierarchy related to the problem of coherence breaking, i.e., the transformation of a pure state into a mixed one.) There is vagueness concerning the stage of time evolution on which the reduction occurs. The problem of irreduction would be solved if indeterministic dynamics were non-linear with respect to states.

A possibility to construct such a dynamics arises by taking into account gravitation in connection with the Einstein equation. The Einstein tensor \( G[g] \) is non-linear with respect to the metric \( g \). Therefore the averaging of the quantum energy-momentum tensor \( T \) with respect to the mixed state \( \omega'' \) is not equivalent to the averaging with respect to the individual pure constituents \( \omega_j \) with the subsequent averaging of the corresponding \( g_j \)'s with the probability distribution \( \{w_j, j \in J\} : g'' \neq \sum_j w_j g_j \). Thus, if one is based on the equation \( G = \omega(T) \) the problem of irreduction hierarchy will be solved. In the usual terminology, such a quantum theory of gravitation is called semiclassical.

The next and crucial point is the following. Denote \( a(t) \) the cosmic scale factor in the Robertson-Walker spacetime. In GR the state of the matter—energy or energy density in the Friedmann model—does not depend on \( da/dt \), which is an adiabatic effect. Correspondingly, we assume that the state vector of matter should be an eigenvector of the Hamiltonian \( H \):
This may be called the principle of cosmic energy determinacy. At branching, i.e., crossing and splitting points of energy levels, this principle gives rise to quantum jumps. Thus quantum jump dynamics arises.

The cosmic time $t$ is determined through the metric $g$, which is the third essential point.

Now indeterministic quantum gravity may be formulated. Basic entities are: the classical metric tensor $g$, the operator $T$ of the energy-momentum tensor, and the state vector $\Psi$. Through $g$, the cosmic time $t$, the corresponding cosmic space, and the Hamiltonian $H_t$ are determined. Dynamical equations are: the Einstein equation $G[g] = (\Psi, T \Psi)$, the Heisenberg equation $dT/dt = i[H_t, T]$, and equations for $\Psi_t$ arising from the cosmic energy determinacy principle.

QFT and GR are limiting cases of the theory.

Quantum jumps lead to the instantaneous transferring of action and information, which, however, neither violates the causality principle, nor contradicts QFT and GR.

The time dependence of the particle energy is known for the Robertson-Walker spacetime. This dependence implies that quantum jumps may be connected with particle transformations. This opens a new avenue of attack on the problem of quantum measurement.

The cosmic energy determinacy principle implies the eternal universe, i.e., the cyclic one without beginning and ending, the minimal energy in every cycle being finite.

1 The problem of unified physical theory

It is conventionally thought that current physics is founded on two fundamental theories: QFT and GR. But QFT per se does not include the conception of quantum indeterminism, so that the latter should be related to the foundations of physics. Thus any unified theory must incorporate the three fundamental entities: QFT, GR, and quantum indeterminism. However, main efforts are directed to unifying either QFT and GR or QFT and quantum indeterminism. Had the efforts been successful, the former direction would have resulted in quantum gravity, the latter in indeterministic quantum theory. There exist, however, no consistent theories of this kind.

1.1 The problem of quantum gravity

Both in GR and in QFT, there are, first of all, the objects of two kinds: 1) a spacetime $(M, g, \nabla)$, i.e., a Lorentz manifold on which the Levi-Civita connection $\nabla$ is defined, where $M$ is a differentiable manifold; 2) a family $F$ of material fields.

In QFT, a special case of the Lorentz manifold figures, namely the Minkowski manifold $(\mathbb{R}^4, \eta)$, where $\eta$ is the Minkowski metric. In GR, material fields are classical (matter and electromagnetic field). In QFT, material fields are quantum (spinor and gauge fields). In both theories, material fields are considered as those on the spacetime manifold $M$. The effect of the material fields on the manifold is taken into account in GR but not in QFT. In both theories, the metric $g$ is a classical (tensor) field. This is natural in GR. In QFT, it is possible to avoid the problem of quantum description of spacetime inasmuch as the effect of the quantum material fields on the spacetime is not taken into account. In gravitation theory, the effect of the material fields on the spacetime $(M, g)$ should be taken into account. In quantum gravity, these fields must be quantum. Thus, there arises the problem of taking into account the effect of quantum material fields on the manifold $(M, g)$, i.e., of describing $(M, g)$ in quantum gravity.

In the usual approach, the problem is posed in such a way: what and how is to be quantized in $(M, g, \nabla)$? Such an approach, at first sight, seems to be natural. Indeed, in GR the effect of matter on the spacetime is defined by the dynamic equation of GR, i.e., the Einstein equation $G = T$, where $G$ is the Einstein tensor, $T$ is the energy-momentum tensor. In QFT the field $T$
is quantum, therefore if the Einstein equation were directly transferred into quantum gravity, the field $G$ should become quantum. But $G = G[g]$ is defined by the metric $g$, so that, one would think, the latter should be quantized. And, what is more, one might try to quantize the manifold $M$ itself. However, as it will be clear from what follows, the situation is by no means such obvious. Be it as it may, this approach has not been crowned with success.

1.2 The problem of indeterministic quantum theory

In QFT, dynamics is deterministic, a dynamic transition being described by a symmetry in the Schrödinger picture and by a Jordan $*$-automorphism in the Heisenberg picture. The GNS-construction reduces both the symmetry and the automorphism to a unitary operator in a Hilbert space. In such a transition, pure states turn into pure ones.

Quantum indeterminism manifests itself in quantum jumps, so that the problem of indeterministic quantum theory is that of indeterministic dynamics, i.e., quantum jump dynamics. A quantum jump is the transition

$$\omega' \rightarrow \omega'' = \sum_{j \in J} w_j \omega_j \rightarrow \omega_j, j \in J,$$

where

$$\omega' = (\Psi', \cdot \Psi'), \omega_j = (\Psi_j, \cdot \Psi_j), (\Psi_j, \Psi_{j'}) = \delta_{jj'}.$$  \hspace{1cm} (1.2.1)

The transition $\omega' \rightarrow \omega''$ is usually considered as the result of the breaking of coherence between the summands in

$$\Psi' = \sum_{j \in J} c_j \Psi_j, c_j = (\Psi_j, \Psi').$$  \hspace{1cm} (1.2.3)

But no clear result has been obtained on this way.

1.3 Indeterministic theory of gravitation

In our papers [15,17], a single theory which unifies QFT, quantum indeterminism, and GR is constructed. But in this theory, indeterministic dynamics is based on the approach of coherence breaking, which seems inadequate.

2 Heuristic considerations and conceptions of the theory

From the previous discussion, it seems that the attempts to unify both QFT with GR (without taking into account indeterminism) and QFT with indeterminism (without gravity) are inadequate. Then the only way that remains is to take into account all the entries—QFT, GR, and indeterminism—from the outset.

2.1 Irreduction hierarchy problem and semiclassical theory of gravitation

We begin with unifying QFT and GR, having taken into account indeterminism.

In quantum indeterminism, the problem of von Neumann hierarchy, or coherence hierarchy, figures. Usually, it is considered in connection with the measurement problem. The essence of the coherence hierarchy problem consists in that it is not known on what stage the coherence of summands of a state amplitude (1.2.3) should be considered to be broken. In the mathematical part
of QFT, i.e., in deterministic dynamics this problem cannot be solved. It is the interpretational part of QFT where it is possible to introduce coherence breaking, i.e., to cut off the hierarchy.

In quantum indeterminism, there exists yet another hierarchy, namely, that of irreduction. The essence of the corresponding problem is that it is not clear on what stage of a dynamic process the reduction, i.e., the transition $\omega^{\prime\prime} \rightarrow \omega_j$ in (1.2.1) should be considered to be realized. Often, it is done on the level of the observer as it was done by von Neumann in the case of coherence hierarchy. But unless one refers to the observer, one may consider that reduction is not realized at all, i.e., the system remains in the mixed state $\omega^{\prime\prime}$ all the time.

But the notion "in reality", or the concept of reality, is so fundamental that it is greatly desirable that this notion appear yet in the mathematical part of the theory. To achieve this, an indeterministic theory in which dynamics would be non-linear with respect to states is required.

In semiclassical theory of gravitation (see, e.g., [1]), material fields are described in a quantum way, and spacetime is described classically. The dynamic equation corresponding to the Einstein equation is

$$G[g] = \omega(T), \quad (2.1.1)$$

where $\omega$ is the state of material fields in the Heisenberg picture. Thus, the metric $g$ is a classical tensor field on the differentiable manifold $M$. The quantum field $T = T[F]$ is expressed in terms of the family $F$ of quantum material fields on the manifold $(M, g, \nabla)$.

The equation (2.1.1) is non-linear with respect to $g$. In the case of the state

$$\omega = \sum_j w_j \omega_j, \quad (2.1.2)$$

the averaging on the right-hand side of the eq. (2.1.1) with respect to $\omega_j$ gives a metric $g_j$, the averaging with respect to $\omega$ gives a metric $g$, and

$$g \neq \sum_j w_j g_j. \quad (2.1.3)$$

Thus, indeterministic dynamics obtained in such a way would be non-linear.

Let us advance some arguments for supporting semiclassical and, by the same token, indeterministic theory of gravitation, the latter being developed on the basis of the former.

In classical mechanics, one usually does not make a distinction between the time dependence of an abstract observable in the Hamilton picture and the change of its mean value. However, in principle the distinction does exist. Accordingly, the classical Einstein equation $G = T$ may be treated in the two ways. But in quantum theory these two ways will not be equivalent: The former results in the operator equation, the latter leads to the equation for mean values. In the latter case, it is possible to retain the classical description of spacetime, which results in the eq. (2.1.1).

2.2 Adiabatic effect in GR and cosmic energy determinacy principle

In GR, in classical cosmology specifically, the state of matter at a time $t$ depends on the state of spacetime at the time $t$ only but not on prehistory. Namely, the energy density depends only on the cosmic scale factor $a(t)$ but not on $a(t'), t' < t$. This is an adiabatic effect (in mechanical, not thermodynamical meaning). What corresponds to this in quantum mechanics is the adiabatic approximation for the time-dependent Schrödinger equation with time-dependent Hamiltonian $H_t$. Thus, we assume that the state vector $\Psi$ of matter should be an eigenvector of the Hamiltonian:

$$H_t \Psi_t = \varepsilon_t \Psi_t. \quad (2.2.1)$$

This fundamental requirement will be called the principle of cosmic energy determinacy. It plays a crucial role in the theory being developed.
2.3 Robertson-Walker spacetime and cosmic time and space in the non-homogeneous universe

The above discussion provides the existence of a preferred universal time $t$. Consider this provision.

In the general case, the manifold $M$ in its own account has no additional structure; specifically the Lorentz manifold is $(M, g)$.

In the Robertson-Walker model, $M$ does have an additional structure: it represents the direct product of two manifolds:

$$M = S \times T, M \ni q = (s, t), s \in S, t \in T. \quad (2.3.1)$$

A 3-dimensional manifold $S$ is a space, a 1-dimensional one $T$ is time. The structure (2.3.1) is analogous to that of the Aristotelian manifold. In both cases, it is possible to speak of an absolute (or cosmic) time $T$ and an absolute space $S$. The manifold $S$ in the Aristotelian case is an affine space, in the Robertson-Walker model it is such only with the flat space. The manifold $T$ in the Aristotelian case is an affine space isomorphic to the real axis, in the Robertson-Walker model $T$ is a real axis interval.

Thus, in the homogeneous universe, there exists the cosmic time. The homogeneous model being a good approximation, we assume the existence of a cosmic time in the non-homogeneous universe, too.

3 Formulation of the theory

Now it is possible to formulate indeterministic quantum gravity as a consistent theory.

3.1 The universe as a physical system

The universe $U$ as a physical system is a pair $(st, m)$, where $st$ is spacetime, $m$ is matter. The spacetime is $(M, g, \nabla)$, the matter is a family $F$ of quantum fields on $M$.

The basic dynamic quantities are: The classical metric tensor $g$, the operator $T$ of the energy-momentum tensor, and the state vector $\Psi$ of the matter.

Dynamic equations are ones for these quantities. One of the equations is (2.1.1), or $G[g] = (\Psi, T\Psi)$. To formulate the other two equations it is necessary to introduce cosmic time and space.

3.2 Cosmic time and space. Hamiltonian

Cosmic time may be introduced by considering eq. (2.3.1) as the trivial fibre bundle and extending this construction for the non-homogeneous universe. But a simpler way is to employ the concept of reference frame [18].

A reference frame $Q$ on a spacetime $(M, g, \nabla)$ is a vector field each of whose integral curves is an observer, i.e., $g(Q, Q) = 1$ and $Q$ is future pointing. Let $\omega$ be the 1-form physically equivalent to $Q$: $\omega = g(Q, \cdot)$. $Q$ is called proper time synchronizable iff $\omega = dt$. The function $t$ on $M$ is called a proper time function for $Q$. This function plays the role of cosmic time. Any level hypersurface $S_t$ of the function $t$ may serve as a cosmic space.

The Hamiltonian is $H_t = \int_{S_t} \mu(ds)T_{00}(s, t)$.

The second dynamic equation is the Heisenberg equation for $T$: $dT/dt = i[H_t, T]$. Some commutation relations for $T$ should be established.
3.3 The time dependence of state vector

We assume the universe to be spatially finite (closed universe). Then the spectrum of $H_t$ is
discrete, the same is the set of branching (crossing and splitting) points of levels of $H_t$.

Let $\Psi_t$ be an eigenvector belonging to a level between two branching points, and let $P_t$ be the
Corresponding projector. We have from the condition (2.2.1)

$$P_t \Psi_t = \Psi_t, \quad (3.3.1)$$

and

$$\Psi_{t+dt} = P_{t+dt} \Psi_t. \quad (3.3.2)$$

We shall see that

$$\| \Psi_{t+dt} \| = 1. \quad (3.3.3)$$

From (3.3.1),(3.3.2) it follows

$$\frac{d\Psi_t}{dt} = \frac{dP_t}{dt} \Psi_t. \quad (3.3.4)$$

From

$$(P_t + \frac{dP_t}{dt} dt)(P_t + \frac{dP_t}{dt} dt) = P_t + \frac{dP_t}{dt} dt \quad (3.3.5)$$

we obtain

$$P_t \frac{dP_t}{dt} + \frac{dP_t}{dt} P_t = \frac{dP_t}{dt}, \quad (3.3.6)$$

whence

$$\langle \Psi_t, \frac{dP_t}{dt} \Psi_t \rangle = 0. \quad (3.3.7)$$

Now

$$\langle \Psi_{t+dt}, \Psi_{t+dt} \rangle = \langle [P_t + \frac{dP_t}{dt} dt] \Psi_t, [P_t + \frac{dP_t}{dt} dt] \Psi_t \rangle = \langle \Psi_t, [P_t + \frac{dP_t}{dt} dt] \Psi_t \rangle = 1. \quad (3.3.8)$$

Thus, the continuous change of $\Psi_t$ is determined by eq. (3.3.4).

Now consider a branching point at $t = t_b$. Let

$$\Psi_{t_b} = \sum_k P_{k_t b} \Psi_{t_b} \quad (3.3.9)$$

where $k$ is the branch number. Then a quantum jump occurs:

$$\Psi_{t_b} \rightarrow \Psi_{k t_b +0} = \frac{P_{k t_b +0} \Psi_{t_b}}{\| P_{k t_b +0} \Psi_{t_b} \|} \quad (3.3.10)$$

with the probability

$$w_k = \langle P_{k t_b +0} \Psi_{t_b}, P_{k t_b +0} \Psi_{t_b} \rangle = \langle \Psi_{t_b}, P_{k t_b +0} \Psi_{t_b} \rangle. \quad (3.3.11)$$

3.4 Dynamic equations

Let us collect the results. The dynamic equations are:

$$G[g] = \langle \Psi, T \Psi \rangle; \quad (3.4.1)$$

$$\frac{dT}{dt} = i[H_t, T], \quad (3.4.2a)$$

commutation relations for $T$; \quad (3.4.2b)
\[
\frac{d\Psi}{dt} = \frac{dP_t}{dt}\Psi, t \neq t_b, \quad (3.4.3a)
\]
\[
\Psi_{t_b} \rightarrow \Psi_{t_b+0k} = \frac{P_{k_{t_b+0}\Psi_{t_b}}}{\|P_{k_{t_b+0}\Psi_{t_b}}\|}, w_k = (\Psi_{t_b}, P_{k_{t_b+0}\Psi_{t_b}}); \quad (3.4.3b)
\]
\[
H_t = \int_{S_t} \mu(ds) T_{00}(s, t); \quad (3.4.4)
\]
\[
g(Q, Q) = 1, g(Q, \cdot) = dt. \quad (3.4.5)
\]

Equation (3.4.1) originates from GR, eqs. (3.4.2) from QFT. Equations (3.4.3) realize the indeterministic conception. Equations (3.4.5) define cosmic time \(t\) and the family \(\{S_t\}\).

Note that eq. (3.4.3a) may be obtained in the same style as eq. (3.4.3b). Such an approach would correspond to the Zeno effect.

### 3.5 Some features of the theory

The picture employed in sec. 3.4 differs from the Heisenberg one in that \(\Psi\) changes in accordance with the cosmic energy determinacy principle.

The “decoherence” in indeterministic quantum gravity has nothing to do with the decoherence problem in quantum mechanics (or QFT). In indeterministic quantum gravity, quantum mechanical decoherence does not exist at all: it would be connected with the Heisenberg dynamics of observables.

At a quantum jump, \(g\) and its first derivatives remain continuous, and second derivatives and \(G\) undergo a jump. Therefore gravity per se is quantum: \(G\) experiences quantum jumps along with \(\Psi\). This proves the name of the theory: indeterministic quantum gravity.

The operator \(T\) of the energy-momentum tensor may be connected with the family \(F\) of quantum fields, and eqs. (3.4.2) may be connected with the equations for the fields.

Any \(\Psi\) may serve as an eigenvector of \(H_t\): this requirement is fulfilled by choosing a Hamiltonian. This gives a condition for \(g_t\) as the function of \(s \in S_t\). In the local inertial frame approximation with the Hamiltonian \(H_{\text{inert}}\), \(\Psi\), in general, is not an eigenvector of \(H_{\text{inert}}\).

### 3.6 QFT and GR approximations

QFT and GR are obvious approximations of indeterministic quantum gravity.

Neglecting gravity, we obtain from eq. (3.4.1)
\[
g = \eta \quad (3.6.1)
\]
— the Minkowski metric. Now there is no privileged reference frame. In any inertial reference frame, \(H\) is time independent, so that eq. (3.4.3a) leads to
\[
\Psi = \text{const}, \quad (3.6.2)
\]
eq (3.4.2) reads
\[
\frac{dT}{dt} = i[H, T]. \quad (3.6.3)
\]
Thus we obtain the Heisenberg picture for matter in the Minkowski spacetime. There are no quantum jumps: the dynamics of QFT is deterministic. Thus, without gravity there is no indeterminism.

Neglecting quantum properties of matter, we obtain from eq. (3.4.1) the classical Einstein equation, which corresponds to GR. It is deterministic theory.

Thus indeterminism results only from the combination of quantum and gravitational properties of the universe.
4 The effect of instantaneous transference

Quantum jumps described by eq. (3.4.3b) imply the effect of instantaneous transference. As an example, a situation of type occurring in the Einstein-Podolsky-Rosen problem may serve. Let the wave function of an electron be split into two parts widely separated, and let the reduction of the wave function occur due to an interaction involving one of the parts only. Then the reduction of the second part occurs simultaneously with that of the first part. Needless to say the simultaneity refers to the cosmic time $t$.

Since the change of $\Psi_t$ (3.4.3b) results in changing the metric $g$, a possibility for transferring signals instantaneously arises. A transmitter acts on the first part of the wave function, and a receiver is a system near the second part which does not interact with the electron and is sensitive to the change of $g$.

It cannot be too highly stressed that the effect of instantaneous transference by no means contradicts QFT, GR, and the causality principle. As for QFT and GR, the effect is beyond their scope, being especially indeterministic one. As to the causality principle, the simultaneity refers to the cosmic reference frame only. What is more, the effect assigns a direct physical meaning to the concept of the cosmic time.

Note that to have a possibility to transmit an instantaneous signal, one has to previously transfer a material excitation, whose speed is not greater than that of light.

5 Some possible ways to develop the theory

The conceptual structure of indeterministic quantum gravity expounded in sec. 3.4 is fairly simple. But as to concrete problems, the mathematical equations of the theory are extremely involved. Therefore, it is important to direct ways to develop the theory. The most important problem concerns physical reasons for level branching.

5.1 Particle transformations and level branching

Consider a transformation of particles in the Robertson-Walker spacetime. The energy of a free particle in the cosmic reference frame is

$$\varepsilon = \left( E^2 + \frac{b^2}{a^2} \right)^{1/2}, a = a(t), b = \text{const}, \tag{5.1.1}$$

where $E$ is the rest energy. Let the state vector of a system of particles be

$$\psi = c_1\psi_1 + c_2\psi_2, \tag{5.1.2}$$

where $\psi_1$ and $\psi_2$ relate to different collections of particles. Let energy levels corresponding to $\psi_1$ and $\psi_2$ coincide for some $t$. With change of $t$, the level for $\psi$ branches.

Thus the particle transformation results in the level branching and, by the same token, in a quantum jump.

5.2 Exponential decay

Deterministic time evolution for a quantum process is determined by eqs. (3.4.2a),(3.4.3a) or, in the QFT approximation, eqs. (3.6.3),(3.6.2). Usually, the process is described in terms of the Schrödinger picture. Let $c(t)$ be the amplitude of the initial state;

$$|c(t)|^2 = e^{-t/\tau} \tag{5.2.1}$$
holds. The problem is that of quantum jump from the initial state into final one. Let \( t_i, i = 1, 2, \ldots \), be moments of branching points. Then the probability to retain the initial state is

\[
w(t_n + 0) = e^{-t_1/\tau} \cdot e^{-(t_2-t_1)/\tau} \cdots e^{-(t_n-t_{n-1})/\tau} = e^{-t_n/\tau},
\]

which describes the exponential decay. We underline the discreteness of the set of branching points, which eliminates the Zeno effect, i.e., retaining the initial state. (This effect does take place for the continuous evolution described by eq. (3.4.3a).)

6 Quantum measurement

One of the most important manifestations of indeterminism is quantum measurement. The problem of the latter is one of the most difficult ones [12–14,19,11]. Indeterministic quantum gravity opens a new avenue of attack on this problem.

In particular, the results of sec. 5.1 may be employed. For example, the measurement of the position of an electron by the use of a luminescent screen involves creating a photon.

7 The eternal universe

Cosmology is inherent in the formulation of indeterministic quantum gravity: \( \Psi_t \) and \( H_t \) relate to the universe as a whole. On the other hand, this theory may be used for solving the cosmological problem of the genesis of the universe. This problem is avoided in the oscillating model of the universe. But it is generally taken that this model faces one severe theoretical difficulty [20]. In each cycle the entropy is increased by a kind of friction as the universe expands and contracts. The increase of the entropy results in that of the minimal value of the energy. For the present cycle this value is not infinite, so it is hard to see how the universe could have experienced an infinite number of cycles.

Indeterministic quantum gravity allows to overcome the difficulty described. In this theory the minimal value of the energy is an eigenvalue of the Hamiltonian \( H_t \), and any eigenvalue is finite (excluding \( t \) of cosmic singularity).

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