The Universal Arrow of Time is a Key for the Solution of the Basic Physical Paradoxes

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Abstract: The modern classical statistical physics, thermodynamics, quantum mechanics and gravity theory are developed and well-known theories. The described theories are developed and well studied for a long time. Nevertheless, it contains a number of paradoxes. It forces many scientists to doubt internal consistency of these theories. However, the given paradoxes can be resolved within the framework of the existing physics, without introduction of new laws. Further, in this paper we discuss the paradoxes underlying classical statistical physics, thermodynamics, quantum mechanics, and non-quantum and quantum gravities. We suggest the approaches to solution of these paradoxes on basis universal arrow of time. The first one relies on the influence of the external observer (environment), which disrupts the correlations in the system and results in time arrows alignment. The basis of the second one is the limits of self-knowledge of the system in case of the observed system; the external observer and the environment are included in the considered system. We introduce the concepts of observable dynamics, ideal dynamics, and unpredictable dynamics. We contemplate the phenomenon of complex (living) systems from the point of view of these dynamics. Perspectives of practical use of Unpredictable systems for artificial intellect are considered.

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Chapter 1. The Universal Arrow of Time: Classical Mechanics.

Abstract: Solution of paradox for the entropy increase in reversible systems.

Statistical physics cannot explain why the thermodynamic time arrow does exist unless very special and so it postulates unnatural initial conditions. However, we are ready to state that statistical physics is able to explain why the thermodynamic time arrow is

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universal, i.e., why the time arrow is directed in the same direction anywhere. Namely, if some two subsystems initially possess opposite directions of the time arrow, the interaction between them makes the configuration statistically unstable and causes transition to a system with the universal direction of the time arrow. We can give general qualitative arguments in favour of such approach and illustrate them by the detailed analysis of a “toy” model based on the “baker’s map”.

1. Introduction

The origin of the time arrow is one of the largest unsolved riddles in physics [1-5]. It is well-established fact that we may reduce the most of time arrows to a thermodynamic arrow, but the origin of the thermodynamic time arrow remains enigmatic. Namely, existence of the thermodynamic time arrow means that the system is not in a state of the maximum possible entropy. However, it means that the system is not in the most probable state, which we can explain statistically in no way. The fact of the entropy increase with time means that the system was even in a less probable state in the past, which makes the task even more complicated. Certainly, we may describe the entropy increase with time, if we suppose that at the beginning the Universe was in a state with very low entropy. However, in such a case it is not possible to explain why the Universe began its existence from such a very special and unnatural initial condition.

Maccone [6] stated in his recent article that we might solve the enigma of the origin of the time arrow by means of quantum mechanics. He showed that in quantum mechanics all phenomena, which leave traces in an observer’s memory (and thus may be studied by physics) are just those whereat the entropy is increased. (It is worth to note that earlier works of other authors [7-9] used for solving the paradox of the entropy increase and the quantum paradox of the wave package reduction the argument of deletion of the observer’s memory at the decreasing entropy and the appropriate mental experiments examined in [6]). On basis thereof, Maccone concludes that in such a way we can reduce the second law of thermodynamics to mere tautology while automatically solving the problem of the time arrow in physics. However, noted in papers [10-12] are some weak points of the arguments used by Maccone in [6]. While giving a response to one of these objections in his later paper [13], Maccone managed to realize that his approach does not give a complete solution of the problem of the origin of the time arrow, as the quantum mechanism also requires extremely improbable initial conditions which cannot be explained just on basis of his arguments.

Yet we reckon (as Maccone did in [13]) that some ideas given in [6] and [13] allow better understanding of the problem of the time arrow. The purpose of this paper is further development, improvement and widening of some of ideas which were presented in [6, 11, 13] and in a somehow different context, in [8, 9, 14, 15, 16, 30]. In particular, opposite to Maccone’s statements in [6, 13], we state that quantum mechanics is not an essential factor for solving this problem. Consequently, in this paper we will regard only classical statistical physics.
The idea of solving this paradox is this. Even though statistical physics cannot explain why the thermodynamic time arrow exists, it becomes possible to explain at least why the thermodynamic time arrow is universal. That is, we can explain why the arrow points out in the same direction anywhere. Namely, if some two subsystems initially possess opposite directions of the time arrow, the interaction between them makes the configuration statistically instable and causes transition to a system with the universal direction of the time arrow. Of course, it will not allow solving the problem of the origin in the time arrow completely; but, in any way, it will make its solving easier.

We structure his paper as following: in the next section, we shall present our basic ideas in intuitive non-technical form. Section 3 afterwards will be devoted to studying of statistical properties of “Baker’s map” (some basic properties whereof are given in Appendix) which serve as a “toy” model for studying peculiarities of reversible chaotic Hamiltonian systems. As a by-result, in this section we will also clarify the difference between various definitions of the phenomenon of “entropy”. Afterwards, in Section 4, we will examine effects of weak interactions between subsystems, which show evolutionary development, without interaction, in accordance with “Baker’s map”. In particular, we shall explain how weak interactions destroy opposite time arrows of subsystems making them much less probable than in the case without interaction. Finally, in Section 5 we will give the qualitative discussion of our results, including their compatibility with availability of strongly interacting systems wherein the subsystem entropy may decrease with time.

2. Basic ideas

A priori, probability of presence of the thermodynamic time arrow is very low. Yet the idea we engage will consist in thinking within terms of conditional probabilities. If we suppose that the thermodynamic time arrow exists, what can we derive from it by using statistical arguments?

To answer this question, it is better to begin with laws of the microscopic theory. We suppose that dynamics of microscopic degrees of freedom is described by a set of differential equations of the second order (with derivatives with time) which are invariant at the time reversion $t \rightarrow -t$. Thus, the both directions of time possess a priori equal roles. In order to determine the only solution of equations of motion dynamics it is also necessary to select some “initial” time $t_0$ on basis whereof the initial conditions shall be determined. (“Initial” time need not to be obligatorily the earliest time wherein he Universe began to exist. For any $t_0$ wherein initial conditions are determined, equations of motion dynamics shall determine the state of the Universe in the solely way both for $t>t_0$ and for $t<t_0$). It is just a usual specific moment of time which may be taken even in “the future”. Indeed, in this paper we accept the picture of “modular Universe” (e.g., see [4, 17, 18, 19] and references therein) according to which the time is not “flowing”. Instead of it, the Universe is just a “static” object in four spatio-temporal dimensions.

Of course, a priori probability of small entropy at moment $t_0$ is very low. But provided
that the entropy available at moment $t_0$ is small, then what is the probability that the thermodynamic time arrow does exist? Certainly, it is very high.

And now let us ask the major question of this section. Taking into account that at the moment of time $t_0$ the entropy is small, why at this moment $t_0$ the entropy increases in one and the same direction (taken as positive) anywhere? It would seem more probable that the direction of the entropy increase be changed from the point at the moment $t_0$. If so, then why don’t we observe it? In other words, why is the time arrow universal having one and the same direction anywhere for the given moment $t_0$. We will refer to this problem as to the problem of universality of the time arrow.

In this paper we state that this problem may be solved by means of statistical physics. To say it short, we have got the following solution. If we ignore interactions between various subsystems then, provided that the entropy is low at $t_0$, the most probable choice will be, indeed, that the direction of the time arrow will be changed from one point to another. On the other hand, if various subsystems interact between each other, then it is not the most probable choice anymore. Instead, even if the direction of the time arrow is changed from one point to another at moment $t_0$, then the interaction will ensure the natural mechanism which will align all time arrows in one and the same direction.

To illustrate the paradox of the time arrow, mental experiments of Loschmidt (paradox of time inversion) and Poincaré (theorem of returns) are frequently used. The appropriate paradoxes in classical mechanics are solved in the following way. Classical mechanics allows, at least in principle, excluding any effect of the observer’s influence in relation to the system to be observed. Yet, the most of real systems are chaotic. Thus, even a weak perturbation may lead to exponential discrepancy of trajectories. Besides, there is insignificant interaction between the observer and the system to be observed. We may examine, as a simple example, some gas widening from a small volume of space into a large volume. In this process which proceeds with the entropy increase the alteration of macroscopic parameters with time is stable in relation to small external perturbations. On the other hand, should all speeds be inversed the gas will be compacted into the initial small volume, but at absence of any perturbations only. This process with the entropy decrease is obviously unstable, and the small external perturbation inversed it into a process with the entropy increases. Thus, processes with the entropy increase are stable, and those with the entropy decrease are not. The natural consequence of it is that the direction of the time arrow (which is determined by the entropy increase) of both the observer and the system to be observed shall be aligned into one and the same direction due to inevitable insignificant interaction between them. They may return to the initial state both in Loschmidt’s paradox and Poincaré’s paradox only together (as a system in whole). Thus, the observer’s memory occurs to be deleted at the end, as it will return to the initial state too. In process of this return of the time arrow both of the observer and of the system to be observed shall be indicated in the direction opposite to the initial one. Hence we may derive two consequences. Firstly, the entropy increase is observed both in the whole system and in its two parts in relation to the observer’s own time arrow, despite the fact that the entropy is decreased in coordinate time. Secondly, the observer’s
memory is deleted not only at the very end but also already at approximation to the end point because the observer does not remember its “past” (determined in relation to the coordinate time) but remembers its “future”.

Indeed, it may seem very probable that interaction will align all time arrows in one and the same direction. But here the question arises: in which direction from the two possible ones? How can one any one direction be preferable when the both directions are equally probable a priori? Is the common direction selected at random, or may it be effectively predicted? If there are two subsystems with opposite directions of time in $t_0$, then the joint system will choose the direction of the “stronger” subsystem as their common direction. But which subsystem will be “stronger”: either that which possesses the larger amount of degrees of freedom, or it will be selected by another principle?

Actually, the “stronger” time arrow is the one which is co-directed with the coordinate direction of time. This situation is not symmetrical, indeed. For $t<t_0$ (when time arrows are oppositely directed) interaction is missing, while for $t>t_0$ it appears. This asymmetry of interaction will determine the observed asymmetry of time.

Now we can understand why the time arrow is universal. Suppose we have a subsystem which possesses a time arrow directed oppositely to our common time arrow and this subsystem is either observed or not observed by us. If we do not observe it this will not contradict to the fact that our time arrow seems universal to us. If we observe it then it will interact with us, and this interaction leads to the situation when these time arrows cannot be opposite for a long period of time. In any case, the things we observe shall have the same direction of time as ours (possibly, except for a short time interval). This is similar to considerations in [6], with an important difference, though, that our consideration is not based on quantum mechanics.

We will confirm these intuitive ideas by the more qualitative analysis in the remaining sections of our paper.

3. Statistical physics of Baker’s map

Baker’s map (for a more detailed analysis see Appendix A) is mapping any point of a single quadrate onto another point of the same quadrate. We study the set of $N \gg 1$ such points (referred to as “particles”) which is moving under influence of Baker’s map. It is a “toy” model for “gas” which possesses all typical properties of classical Hamiltonian reversible determined chaotic systems. Indeed, Baker’s map is widely used in such purposes due to its simplicity [20, 23, 24, 25].

3.1 Macroscopic entropy and ensemble entropy

In order to define a convenient set of macroparameters we will divide a single quadrate into 4 equal sub-quadrates. Suppose that 4 parameters $N_1, N_2, N_3, N_4$ mean a number of “particles” in appropriate sub-quadrates, and they definitely are macroparameters for our system. (Of course, there are many other methods for defining macroparameters but
general statistical regularities should not depend on this choice). Macroscopic entropy \( S_m \) of this macro state shall be determined by a number of various micro states corresponding to this macro state and be described with the following formula:

\[
S_m = -N \sum_{k=1}^{4} N_k \log \left( \frac{N_k}{N} \right) = - \sum_{k=1}^{N} N_k \log \left( \frac{N_k}{N} \right)
\]  

(1)

This entropy is maximum when distribution of particles is uniform, when \( S_m \) is equal to \( S_{m}^{\text{max}} = N \log 4 \). At the same time, the entropy is minimum when all particles are located in one sub-quadrate, i.e. when \( S_m = 0 \).

Suppose that \((x, y)\) are coordinates of the point on a single quadrate. In physical language it corresponds to the position of the particle in 2D phase space. For \( N \) particles we will examine a statistical ensemble with probability density \( \rho(x_1, y_1; \ldots; x_N, y_N; t) \) on \( 2N \) on \( 2N \)-dimensional phase space. Here \( t \) is a temporal parameter which has discrete values \( t = 0, 1, 2 \ldots \) for Baker’s map. In this case, ensemble entropy shall be defined as

\[
S_e = - \int \rho(x_1, y_1; \ldots; x_N, y_N; t) \log \rho(x_1, y_1; \ldots; x_N, y_N; t) \, dX
\]

(2)

where

\[
dX = dx_1 dy_1 \ldots dx_N dy_N
\]

(3)

\( \rho \) and \( S_e \) are changed in process of evolution determined by Baker’s map and depend on the initial \( \rho \). However, if the initial function of probability density has the following form

\[
\rho(x_1, y_1; \ldots; x_N, y_N) = \rho(x_1, y_1) \ldots \rho(x_N, y_N)
\]

(4)

which corresponds to the non-correlated function of density when the function of probability density remains non-correlated in process of the further evolution.

For example, let’s examine the function \( \rho(x_l, y_l) \) which is uniform within some sub-domain \( \Sigma \) (with area \( A<1 \)) of a single quadrate and in converted into zero outside \( \Sigma \). In other words, suppose that

\[
\rho(x_l, y_l, t) = \begin{cases} 
1/A & \text{for } (x_l, y_l) \text{ inside } \Sigma \\
0 & \text{for } (x_l, y_l) \text{ outside } \Sigma 
\end{cases}
\]

(5)

In this case,

\[
S_e = - \left( \frac{1}{A} \right)^{N} \left( \log \left( \frac{1}{A} \right)^N \right) A^N = N \log A
\]

(6)

As \( A \) is not changed in process of evolution defined by Baker’s map, then \( S_e \) is also constant in process of evolution defined by Baker’s map. This example shows that \( S_e \) is actually constant for a random initial function. To prove it, let’s divide a single 2N-dimensional box into a larger amount of small domains \( \Sigma_a \), the probability for each of them will be equal to \( \rho_a \). In process of evolution, each domain \( \Sigma_a \) will change its form but its 2N-dimensional “area” \( A_a \) shall remain unchanged. Besides, probability \( \rho_a \) on the new domain \( \Sigma_a \) shall also stay unchanged. Consequently, the ensemble entropy \( S_e = - \sum A_a \rho_a \log \rho_a \) shall also remain unchanged. This is the major idea of the discrete version of the proof, although the indiscrete version may be performed in the same way.
3.2 Appropriate and inappropriate macroscopic variables

Macroparameters determined in the previous subdivision possess the following properties:

1. For the most of initial micro states characterized by \( S_m < S_m^{\text{max}} \), \( S_m \) will increase due to the effect of Baker’s map.

2. For the most of initial micro states characterized by \( S_m = S_m^{\text{max}} \), \( S_m \) will stay constant due to the effect of Baker’s map.

3. The two above mentioned properties will stay in force when Baker’s map is supplemented by small noise.

Let’s refer to the macroparameters possessing these properties as to *appropriate* macroparameters.

It is not the thing that any rational choice of macroparameters is appropriate, though. We may illustrate it with the following example. We will divide a single quadrate into \( 2^M \) equal vertical strips (\( M \gg 1 \)). We define a new aggregate of macroparameters as numbers of particles in each of these strips. Similar to formula (1), the appropriate macroscopic entropy shall be

\[
S_m = - \sum_{k=1}^{2^M} N_k \log \left( \frac{N_k}{N} \right),
\]

(7)

where \( N_k \) is a number of particles in strip \( k \). The following initial condition will be chosen: the gas is uniformly distributed in odd vertical strips, whereas even strips are empty. Then, for this initial condition \( S_m < S_m^{\text{max}} \) is observed. In such a case, for a long time of evolution of the system performed in accordance with Baker’s map, \( S_m \) is not increasing for any initial micro state corresponding to this initial macro state. During this evolution, a number of filled strips will decrease and their width will increase until only one wide filled vertical strip remains. It is only after it occurs when \( S_m \) will begin to increase. Please note that evolution in direction to the only strip may be easily destructed by any small perturbation.

Thus, we see that vertical strips lead to inappropriate macroparameters. On the contrary, horizontal strips lead to appropriate macroparameters. (However, macroparameters used in (1) are in any case more appropriate, as they lead to much rapid growth of \( S_m \).) This asymmetry between vertical and horizontal strips is a consequence of characteristic asymmetry of Baker’s map itself in relation to vertical and horizontal coordinates. This asymmetry is similar to that between canonic coordinates and pulses in Hamiltonian classical mechanics for many actual systems. Namely, if we take actual systems, for them Hamiltonian functions will contain only local interaction between particles where locality implies closeness in terms of coordinates but not of pulse.

Finally, please note that evolution of macroparameters \( N_k(t) \), \( k = 1, 2, 3, 4 \) may be found by averaging by ensemble in the following way:

\[
N_k(t) = \int N_k(x_1, y_1; \ldots; x_N, y_N; t) \rho(x_1, y_1; \ldots; x_N, y_N; t) \, dX.
\]

(8)
3.3 Coarsening

As it was already mentioned, ensemble entropy (contrary to macroscopic entropy) is always a constant, during the evolution determined by Baker’s map. Although, it is wishful to have a modified definition of ensemble entropy wherein the entropy would increase similar to the macroscopic entropy. Such modification is ensured by coarsening which may be possible due to introduction of the coarsened phase function of probability density

$$\rho_{\text{coar}}(x_1, y_1; \ldots; x_N, y_N) = \int \Delta(x_1 - x'_1, y_1 - y'_1; \ldots; x_N - x'_N, y_N - y'_N)$$

$$\times \rho(x'_1, y'_1; \ldots; x'_N, y'_N) \, dX' ,$$

where $\Delta$ differs from zero in some neighborhood of $X' = 0, 0; \ldots; 0$.

Thus, the coarsened ensemble entropy is

$$S_{e}^{\text{coar}} = -\int \rho_{\text{coar}}(x_1, y_1; \ldots; x_N, y_N) \log \rho_{\text{coar}}(x_1, y_1; \ldots; x_N, y_N) \, dX$$

Certainly, the function may be chosen by many ways. Let’s give some examples here.

The first example: Boltzmann’s coarsening defined in the following way:

$$\rho_{\text{coar}}(x_1, y_1; \ldots; x_N, y_N) = \rho(x_1, y_1) \ldots \rho(x_N, y_N) ,$$

where

$$\rho(x_1, y_1) = \int \rho(x_1, y_1; \ldots; x_N, y_N) \, dx_2 dy_2 \ldots dx_N dy_N ,$$

We may define similarly the other $\rho(x_l, y_l)$.

The second example: an isotropic coarsening having the following form:

$$\Delta(x_1 - x'_1, y_1 - y'_1; \ldots; x_N - x'_N, y_N - y'_N) =$$

$$\Delta(x_1 - x'_1) \Delta(y_1 - y'_1) \ldots \Delta(x_N - x'_N) \Delta(y_N - y'_N) .$$

One more example: Prigogine’s coarsening [20]

$$\Delta(x_1 - x'_1, y_1 - y'_1; \ldots; x_N - x'_N, y_N - y'_N) = \Delta(y_1 - y'_1) \ldots \Delta(y_N - y'_N) ,$$

which is an anisotropic coarsening along the shrinking direction $y$.

Finally, let me remind about coarsening based on division of the system into two lesser interacting subsystems. Coarsened ensemble entropy for the complete system is defined as arithmetic sum of uncoarsened ensemble entropies of these systems. Such coarsened entropy will ignore correlations between subsystems.

All these types possess the following property: if the initial micro state is such that macroscopic entropy increases then the coarsened ensemble entropy for this initial state will increase too. In this case, Prigogine’s coarsening will have the following advantages in comparison with Boltzmann’s coarsening and isotropic coarsening:
Firstly, if we take distribution of initial micro states which is such that its macroscopic entropy decreases then the entropy of the appropriate ensemble coarsened by Prigogine’s will not decrease. At the same time, the entropy of ensemble coarsened by Boltzmann’s or by isotropic coarsening will decrease.

Secondly, let’s suppose that we have some given distribution of initial micro states whereat its macroscopic entropy increases. Now let’s examine some “final” state (which will be further referred to as “initial ensemble”) with large macroscopic entropy which is close to maximum. Upon achieving this final state by the system, let’s examine the new inverse state which is derived from it and possesses the evolution inverse in time. (It is achieved by simple symmetric conversion in relation to the diagonal of a single quadrate with swapping x and y coordinates between each other). Then the ensemble entropy obtained after such “conversion” and coarsened by Prigogine’s, will decrease leap-wise (in relation to the coarsened entropy of the “unconverted” initial ensemble from which it was obtained by such “conversion”). At the same time, the ensemble entropy coarsened by Boltzmann’s or by isotropic coarsening will remain almost unchanged.

Thus, Prigogine’s coarsening ensures the most adequate description of the law of increase of ensemble entropy without any additional suppositions. For instance, in order to obtain the same result with Boltzmann’s coarsening, we would need to use some additional supposition named “hypothesis of molecular chaos” which consists of substitution of $\rho(x_1, y_1; x_2, y_2)$ by $\rho(x_1, y_1) \rho(x_2, y_2)$ in the motion equation for $\rho(x, y, t)$.

4. The effects of weak interactions

4.1 Small external perturbations

We may achieve growth of the ensemble entropy even without coarsening, by introducing some small external perturbation into Baker’s map. The perturbation should be rather small in order not to destroy growth of macroscopic entropy, but at the same time, it should be sufficiently strong in order to prevent inverse processes and Poincare’s returns. For the most of such perturbations, qualitative peculiarities of the evolution will not significantly depend on the detailed form of the perturbation.

We may introduce external perturbation by two methods. One method consists of introducing small external casual noise. Macroscopic processes with increase of macroscopic entropy are stable in relation to such noise. However, the area of the domain of determination of phase density function is not an invariant in relation to the disturbed Baker’s map anymore. Due to this method, the ensemble entropy may be increased.

Another method consists in introducing some weak interaction with the environment (“the observer” may also serve as such). Again, macroscopic processes with increase of macroscopic entropy are stable but the area of the domain of determination of phase density function is not an invariant in relation to the disturbed Baker’s map anymore. Consequently, the ensemble entropy may be increased. However, this system is not isolated anymore. Now it is a part of the larger system divided into two subsystems. Consequently,
as we already explained it in Section 3.3, we may define the coarsened ensemble entropy for the complete system as the sum of uncoarsened entropies of its subsystems aggregate. In the next subsection, we will pay a more thorough attention to weak interactions with the environment.

4.2 Weak interaction and destroying state with subsystems’ opposite time arrows

To move forward, we need to select a certain interaction between two “gases”. In absence of interaction, each of them will evolve in accordance with Baker’s map. We place two single quadrates one above the other and define interaction with the maximum distance $\sigma$ in such a way that all closest pairs of particles (with the distance between particles less than $\sigma$) will swap their places between two consequential steps of Baker’s map. (In more detail, first we find a pair of the closest particles (with the distance between particles less than $\sigma$) and swap their places. Afterwards we find the second pair of the closest particles (with the distance between particles less than $\sigma$, and these particles shall be other than those found earlier) and also swap their places. We repeat this procedure, until got run out of all such particles). These interactions are defined only between particles lying in different subsystems. Such interaction does not touch motion of particles but causes mixing between the two subsystems. Let’s pay our attention to the fact that such mixing will not cause Gibbs’s paradox, as we regard these two single quadrates as two different subsystems. Macroscopic entropy is defined as the sum of macroscopic entropies of these two subsystems.

Now let’s examine the case wherein time arrows of these two subsystems are characterized with the same direction. Processes wherein macroscopic entropies of these two systems increase are stable against interaction. Thus, the most of low-entropy initial states lead to growth of macroscopic entropy of the both subsystems, and of the complete system as well.

Similarly, if we convert the above mentioned process with increase of macroscopic entropy we will obtain the system wherein macroscopic entropy of the both subsystems, as well as that of the complete system, will decrease. In this sense, interaction shall not destroy symmetry between the two directions of time.

Now let’s examine the most interest case wherein entropy increases in the first subsystem and decreases in the second one. The initial state of the first subsystem is characterized with low entropy (e.g., all particles are located in a certain small quadrate near point $(0, 0)$ of the single quadrate). Similarly, the second subsystem is characterized with low entropy too (e.g., all particles are located in a certain small quadrate near point $(1, 1)$ of the single quadrate) in the final state.

In case of absence of interaction the final state of the first subsystem would be a high entropy state corresponding to almost uniform distribution of particles. Similarly, the initial state of the second subsystem would be a high entropy state of the same form.

However, the above mentioned solutions with two opposite time arrows cannot be
solutions anymore as soon as interaction is present. In the most cases the interaction will mix particles between subsystems. A number of solutions with the interaction which are characterized with the same initial-final conditions (described above) is rather small, being in fact much less than the number of such solutions in absence of interaction.

Let me make the latest affirmation more quantitative. After an odd number of swapping between subsystems the particle will be within the other subsystem. Similarly, after an even number of such swapping it will remain in the same subsystem, without changing it. Probabilities of these two events are equal to \( p = \frac{1}{2} \) and don’t depend on other particles (at least approximately). Moreover, we may state that mixing between these two subsystems is insignificant in initial and final states, as entropies of these two subsystems are entirely different. We want to compute probability of small mixing for the final state, provided that the mixing is small in the initial state. To do it determinable, we will take that the mixing is small if a number of particles \( N_t \) transferring from one subsystem into the other is either \( N_t < \frac{N}{4} \) or \( N_t > \frac{3}{4} N \). Thus, the probability is given here by the aggregate binomial distribution \( F \left( N_t; N, \frac{1}{2} \right) \) which is described by

\[
F \left( k; n, p \right) = \sum_{i=0}^{\lfloor k \rfloor} \binom{n}{i} p^i (1-p)^{n-i} \quad (15)
\]

where \( \lfloor k \rfloor \) is the largest integer being less than or equal to \( k \). The function \( F \left( k; n, p \right) \) will satisfy to inequality

\[
F \left( k; n, p \right) < \exp \left( -2 \left( np - k \right)^2 / n \right) \quad (16)
\]

The state with opposite time arrows of the subsystems is not destroyed when \( N_t < \frac{N}{4} \) or \( N_t > \frac{3}{4} N \). The probability thereof is equal to

\[
2F \left( N/4; N, 1/2 \right) < 2\exp \left( -N/8 \right) \quad (17)
\]

It is clear that the probability will decrease exponentially as \( N \) increases. It means that such probability is negligible for a large \( N \). Consequently, one may state almost for sure that processes with opposite time arrows will be destroyed.

In the model described above we need in an almost equal number of particles in these two subsystems, in order to destroy states with opposite time arrows. It is related to the fact that one particle can influence the motion of one close particle only. For more realistic interactions, one particle can influence the motion of a large amount of adjacent particles which means that even a very small number of particles in one system can destroy processes with decrease of entropy for the other system.

4.3 Decorrelation in a system with interaction

Hamiltonian systems are described not only with macro states but also with complicated non-linear correlations between micro states. These correlations are responsible for
reversibility. Interaction between the two subsystems destroys these correlations in subsystems but the whole system remains reversible, i.e., correlations appear in the whole system. Thus, decorrelation in subsystems spreads correlations on the whole system. (This process is a classic analogue of decoherence in quantum mechanics).

Let us set forth these qualitative ideas in a more quantitative form. Linear correlation (Pearson’s correlation) has the behaviour which resembles very much that of non-linear correlations described above. The only difference is that these linear correlations decrease with time. Interaction which we proposed may be approximated by random noise with the amplitude conforming to the distance $\sigma$ of interaction between particles.

So we expect that interaction not only causes alignment of time arrows but also leads to correlations decay which takes place even in a more significant manner than without interaction (Section A.5). During this process the evolution of subsystems becomes irreversible but the whole system remains reversible.

We may quantitatively find the value of this correlations decay by computing Pearson’s correlation for our subsystems described in

$$r(m) = \frac{C(m)}{\sqrt{C(0) \langle C^m(0) \rangle}} ,$$  \hfill (18)

where $\langle C^m(0) \rangle$ is the expected dispersion of a random value $x$ computed after $m$ iterations of mapping. Dispersion $C^m(0)$ may be computed as

$$C^m(0) = \sum_{j=0}^{2^m-1} \int_{j2^{-m}}^{(j+1)2^{-m}} (2^m x - j - \langle x \rangle + S)^2 dx$$  \hfill (19)

where $S$ is a random number defined as $S = \sum_{k=0}^{m-1} 2^k \zeta$. Here $\zeta$ is an independent and uniformly distributed random number with the zero average and dispersion $\sigma^2$ which models the influence of interaction on evolution of the system. Upon short computation, we come to

$$\langle C^m(0) \rangle = C(0) + \langle S^2 \rangle = C(0) + \sum_{k,k'=0}^{m-1} 2^{k+k'} \langle \zeta_k \zeta_{k'} \rangle .$$  \hfill (20)

Using the following property of independent and uniformly distributed random values $\langle \zeta_k \zeta_{k'} \rangle = \delta_{kk'} \sigma^2$ we come to

$$\langle C^m(0) \rangle = C(0) + \frac{2^{2m-1} - 1}{3} \sigma^2$$  \hfill (21)

It is clear that interaction will increase decay of linear correlations at least, as

$$r(m) = \frac{2^{-m}}{\sqrt{1 + 4 (2^{2m-1} - 1) \sigma^2}}$$  \hfill (22)

However, Pearson’s correlation $r(m) = 2^{-m}$ for the whole system will remain the same. As $\langle S^2 \rangle^{1/2}$ shall be much less than the size of the system (a single quadrate), we may conclude that our suppositions leading to (22) are correct only for $\langle S^2 \rangle = [(2^{2m-1} - 1) / 3] \sigma^2 < < 1$ and $\sigma^2 / 2^{-2m} < < 1$.  

4.4 Numerical simulation

Until now, we used only general abstract arguments. In this subsection, we will try to support them by certain numerical modelling.

![Initial configuration of particles at moment $t = 1$.](image1)

**Fig. 1** Initial configuration of particles at moment $t = 1$.

![Evolution of entropy without interaction.](image2)

**Fig. 2** Evolution of entropy without interaction.

We have two subsystems (marked as 1 and 2), each with $N_1 = N_2 = 300$ particles. These two subsystems occupy two single quadrates. To define the coarsened entropy, we divide each single quadrate into $16 \times 16 = 256$ small quadrates. Thus, entropy of each of these subsystems shall be presented as

$$S_i = -N_i \sum_{k=1}^{512} f_{k,i} \log f_{k,i},$$

(23)

where $i = 1, 2$, $f_{k,i} = n_{k,i}/N_i$ and $n_{k,i}$ are numbers of particles in appropriate small
quadrates. Similarly, the complete entropy shall be defined as

\[ S = - (N_1 + N_2) \sum_{k=1}^{512} f_k \log f_k , \]  

(24)

where \( f_k = (n_{k,1} + n_{k,2}) / (N_1 + N_2) \)

Fig. 3 Evolution of entropy with interaction.

For subsystem 1 we choose the initial state with the zero entropy in \( t = 1 \) (see Fig. 1). Absolutely similarly as for system 2 we choose the “final” state the zero entropy in \( t = 6 \). Such initial states ensure that in absence of interactions \( S_1 \) will increase with time, whereas \( S_2 \) will decrease with time for \( t < 6 \).

In order to avoid numerical problems being results of the finite accuracy of computer presentation of rational numbers, (27) is substituted by \( x' = ax - [ax], y' = (y + [ax]) / 2 \), with \( a = 1.999999 \). The results of numerical modelling are given in Fig. 1 and Fig. 2.

To include interaction effects, we define interaction in such a way. (For the sake of computation convenience, it is defined in a slightly different way, as compared to Section 4.2). We take a small range of interaction \( r_y = 0.01 \) in \( y \) direction which, essentially, is a parameter describing weakness of interaction. (Let me remind that \( y \) and \( x \) are analogues of the canonic coordinate and canonic pulse respectively in Hamiltonian phase space). Interaction leads to swapping between the closest pairs, as well as in Section 4.2, but now “the closest” shall be referred to the distance in \( y \) direction, and there isn’t any swapping if the shortest distance is longer than \( r_y \). Moreover, now the interaction is defined in such a way that only \( x \)-coordinates of particles are swapped. By choosing the same initial conditions in \( t = 1 \) as in the case of absence of interdependency (Fig. 1), the results of numerical modelling with interaction can be presented in Fig. 3. We can see that in case of interaction (Fig. 3) \( S_2 \) begins to increase in a more early time than without interaction (Fig. 2).
5. Conclusions

In this paper, we used a “toy” model based on Baker’s map in order to demonstrate peculiarities, which are fair for common systems described by the reversible Hamiltonian mechanics. It is clear that for such systems, one can freely choose either final or initial conditions, but it is not possible to choose freely mixed initial-final conditions. Initial-final conditions are conditions wherein we define canonic parameters for one portion of particles at the initial moment of time and at the final moment of time – for the other portion. There is not any appropriate solution for many mixed initial-final conditions (for Hamiltonian motion equations). Absolutely equally as for our “toy model”, for most of weak interaction Hamiltonians the number of solutions with given coarse-grained initial-final conditions will be much lesser than the number of solutions with coarse-grained initial conditions only or with coarse-grained final conditions only. It explains the fact why we cannot observe in practice subsystems with opposite time arrows, that is, why a time arrow is universal.

In a sense, destroying of states with opposite time arrows is similar to ergodicity. The both properties shall be true in all practical situations but they are not precise laws. They are true for most of real systems but one can always find these or those counterexamples [21, 22]. Besides, the both properties are intuitively obvious but still are very hard for us to prove them strictly. For ergodicity, the appropriate strict result is KAM (Kolmogorov-Arnold-Mozer) theorem, whereas for destroying states with opposite time arrows there is not any strict theorem of such a kind.

Our results allow also resolving of “contradictions” between Prigogin’s “New dynamics” [20] (discussed in Section 3.3 from this paper) and Bricmont’s comment [26]. We may divide dynamics of interacting subsystems into two types of dynamics:

1. Reversible ideal dynamics examined in relation to the coordinate time when entropy may decrease or increase.

2. Irreversible observable dynamics examined in relation to the own observer’s time arrow in relation where to the entropy may only increase, as it was shown above.

Within this terminology, Prigogin’s “New dynamics” [20] is one of forms of observable dynamics, whereas in Bricmont’s paper [26] ideal dynamics is examined. In particular, the observable dynamics does not include Poincaré’s returns and reversibility, which is really an unobservable real observer. This makes it simpler than the ideal dynamics. However, the both types of dynamics are correct in principle.

It is also worth to note that our results are not in conflict with existence of dissipative systems [27] (such as, for instance, certain self-organizing biological systems) wherein the entropy of the subsystem may decrease in course of time, despite increasing of the environment entropy. Entropy of the complete system (including both the dissipative system entropy and the environment entropy) increases which is in accord with the law of increasing entropy. It is typical for such systems that interaction with the environment is strong, whereas we address the results of our paper to weak interactions between subsystems. E.g., intense flow of solar energy is necessary for existing of living organisms.
on Earth. The weak flow of energy from stars is not sufficient for life but it will be sufficient for de-correlation and for alignment of time arrows. We can cite here from paper [6]: “However, the observer is macroscopic by definition, and all remotely interacting systems become correlated very quickly (e.g., Borel managed to remarkably compute that shift of one gram of material over Sirius star for the distance of one meter can influence trajectories of gas particles on Earth in time scale of microseconds order [28]).”

Appendix A. Basic properties of the baker’s map
In this appendix, we will present some basic properties of Baker’s Map. You can find more detailed description, e.g., in [29].

A.1 Definition of Baker’s Map
Let’s examine the binary symbolic consequence.

\[ ...S_{-2}, S_{-1}, S_0; S_1, S_2, S_3,... \]  

being infinite from the both sides. Such consequence shall define two real numbers

\[ x = 0.S_1S_2S_3..., \quad y = 0.S_0S_{-1}S_{-2}... \]  

The consequence may be shifted in reversed way in relation to the semi-colon in both directions. Upon the left shift we will obtain new real numbers

\[ x' = 2x - [2x], \quad y' = \frac{1}{2} (y + [2x]) \]  

where \([x]\) is the largest integer which is less than \(x\), or is equal to it. This mapping of a single quadrate onto itself shall be referred to as Baker’s Map.

Baker’s Map has a simple geometric interpretation given in Fig. 4 where (a) is the initial configuration and (c) is the final configuration upon one iteration of Baker’s map, with the intermediary step presented in (b). Portion (d) is the representation of the final configuration after two iterations.

A.2 Unstable periodic orbits
Periodic symbolic consequences (0) and (1) correspond to fixed points \((x, y) = (0, 0)\) and \((x, y) = (1, 1)\) respectively. Periodic consequence (10) corresponds to the two-period orbit \(\left\{ \left( \frac{4}{7}, \frac{2}{7} \right), \left( \frac{2}{7}, \frac{4}{7} \right) \right\} \). From the periodic consequence ...001;001... we obtain \(\left\{ \left( \frac{1}{7}, \frac{4}{7} \right), \left( \frac{4}{7}, \frac{2}{7} \right), \left( \frac{2}{7}, \frac{4}{7} \right) \right\} \). Similarly, from ...011;011... we obtain \(\left\{ \left( \frac{3}{5}, \frac{4}{5} \right), \left( \frac{4}{5}, \frac{3}{5} \right), \left( \frac{5}{5}, \frac{5}{5} \right) \right\} \).
Any $x$ and $y$ can be approximated randomly well as $0.X_0...X_n$ and $0.Y_0...Y_m$, respectively, provided that $n$ and $m$ are sufficiently large. So, the periodic consequence $(Y_m...Y_0X_0...X_n)$ can be approximated to any point of a single quadrate randomly closely. Thus, the aggregate of all periodic orbits gives a dense aggregate on a single quadrate.

**A.3 Ergodicity, mixing and conserving area**

Due to horizontal stretching all close points diverge exponentially under influence of iterations of Baker’s Map. In these iterations, any casual symbolic consequence will approximate randomly closely to any point of a single quadrate. In general, such ergodic property may be used in order to substitute the average in “time” $\langle A \rangle$ by the average in “ensemble”:

$$\langle A \rangle = \sum_n A(x_n,y_n) = \int A(x,y) \, d\mu(x,y) = \int A(x,y) \, \rho(x,y) \, dx \, dy ,$$

where $d\mu(x,y)$ is an invariant measure, and $\rho(x,y)$ is invariant density for Baker’s Map. For Baker’s Map $\rho(x,y) = 1$.

Under influence of iterations of Baker’s Map, any domain can be mapped into a series of narrow horizontal stripes. In the long run, they uniformly fill the entire quadrate which will correspond to mixing. Absolutely the same inverse iterations shall map the domain into narrow vertical bands which also correspond to mixing.

During these iterations, the domain area will not change. This property is interpreted as the law of conserving the area for Baker’s Map.

**A.4 Exponents of Lyapunov’s power; shrinking and stretching directions**

If $x_0^{(1)}$ and $x_0^{(2)}$ have equal first $k$ binary digits, then for $n<k$,

$$x_n^{(2)}-x_n^{(1)}=2^n (x_0^{(2)}-x_0^{(1)}) = \left(x_0^{(2)}-x_0^{(1)}\right)e^{n\log2} ,$$

where $\Lambda=\log2$ is the first positive exponent of Lyapunov’s power for Baker’s map. Consequently, the distance between two close orbits will increase over the exponent with increasing of $n$, and after $k$ iterations becomes of order 1. This property is referred to as sensitivity to initial conditions. Due to this property, all periodic orbits are unstable.

As the domain area maintains, stretching in horizontal direction discussed above shall imply that a certain direction of shrinking must also exist. Indeed, the evolution in vertical direction $y$ is inverse to the evolution in horizontal direction $x$. If $(x_0^{(1)},y_0^{(1)})$ and $(x_0^{(2)},y_0^{(2)})$ are two points with $x_0^{(1)}=x_0^{(2)}$, then

$$y_n^{(2)}-y_n^{(1)}=2^{-n} \left(y_0^{(2)}-y_0^{(1)}\right) = \left(y_0^{(2)}-y_0^{(1)}\right)e^{n(-\log2)} .$$

Consequently, $\Lambda=\log2$ is the second negative exponent of Lyapunov’s power for Baker’s map.

**A.5 Correlations decay**

As $x$ is unstable direction the evolution in this direction shall lead to correlations decay. The average correlation function $C(m)$ for consequence $x_k$ is usually defined as
\[ C(m) = \lim_{n \to \infty} \frac{1}{n} \sum_{k=1}^{n} (x_k - \langle x \rangle) (x_{k+m} - \langle x \rangle), \]  

(31)

where \( \langle x \rangle = \lim_{n \to \infty} \sum_{k=1}^{n} x_k / n \). Correlations may be computed even easier if the invariant measure \( \mu(x) \) is known; in this case

\[ C(m) = \int (x - \langle x \rangle) (f^m(x) - \langle x \rangle) \, d\mu(x), \]  

(32)

where \( f^m(x) = x_m \) - a function which is mapping \( x \) invariable into its image upon \( m \) iterations of Baker’s Map. Thus, for Baker’s Map \( d\mu(x) = dx \), we can put down:

\[ C(m) = \sum_{j=0}^{2^m-1} \int_{j2^{-m}}^{(j+1)2^{-m}} (x - \langle x \rangle) (2^m x - j - \langle x \rangle) \, dx, \]  

(33)

which leads to

\[ C(m) = \sum_{j=0}^{2^m-1} \left[ \frac{2^m x^3}{3} - 2^m \langle x \rangle + \langle x \rangle \right] \frac{x^2}{2} + \langle x \rangle^2 x - j \left( \frac{x^2}{2} - \langle x \rangle \right) \]  

(34)

For Baker’s Map \( \langle x \rangle = \frac{1}{2} \), and thus, the sum put down above may be apparently computed as

\[ C(m) = 2^{m-1} \frac{12}{12} \]  

(35)

It shows that correlations decay occurs by exponent as \( m \) increases. Pearson’s correlation for the system can be found as follows:

\[ r(m) = C(m) / C(0) = 2^{-m} \]  

(36)

References

Chapter 2. The Universal Arrow of Time: Quantum Mechanics

Abstract: Solution of Schrödinger’s cat paradox, Wigner’s friend paradox, paradox of a kettle which will never begin to boil

This paper is a natural continuation of our previous paper [1] and Chapter 1 of this essay. We illustrated earlier that in classical Hamilton mechanics, for overwhelming majority of real chaotic macroscopic systems, alignment of their thermodynamic time arrows occurs because of their low interaction. This fact and impossibility to observe entropy decrease at introspection explain the second law of thermodynamics. The situation in
quantum mechanics is even a little bit easier: all closed systems of finite volume are periodic or nearly periodic. The proof in quantum mechanics is in many respects similar to the proof in classical Hamilton mechanics – it also uses small interaction between subsystems and impossibility to observe entropy decrease at introspection. However, there are special cases, which we can find in the classical mechanics. In these cases, one microstate corresponds to a set of possible macrostates (more precisely, their quantum superposition). Consideration of this property with use of decoherence theory and taking into account thermodynamic time arrows will introduce new outcomes in quantum mechanics. It allows to resolve basic paradoxes of quantum mechanics:

1. Introduction

First, it is necessary to note that in our paper, unless we stipulate other, a full system is located in a closed finite volume, contains a finite number of particles and is isolated from environment. These are principal requirements of the entropy increasing law, which we consider. We may describe the full system in terms of quantum mechanics laws.

In our previous paper [1], we considered alignment of thermodynamic time arrows in classical Hamilton mechanics leading to proof of the entropy increasing law. Here we intend to consider a quantum case. The reason of alignment of thermodynamic time arrows in quantum mechanics is the same as in the classical mechanics. It is “entangling” and “decoherence” [2-3, 17, 24-27], that is, low interaction between real chaotic macroscopic systems or a real chaotic macroscopic system in unstable state and a quantum microsystem (process of measurement in quantum mechanics).

Use of phenomenon of alignment of thermodynamic time arrows on quantum mechanics for analysis of widely known paradoxes of quantum mechanics allows their full and consistent resolution. All these paradoxes are caused by experimental unobservability for real macroscopic bodies of such purely quantum phenomena predicted by a quantum mechanics as

1. superposition of macrostates for the Copenhagen interpretation, or
2. presence of multiple worlds in case of multi-world interpretation.

Indeed, quantum mechanics has the principal difference from classical one: if in classical mechanics one microstate corresponds to just one macrostate, and then in quantum mechanics one microstate (a pure state characterized by a wave function) can correspond to a set of macrostates. (In other words, this microstate is superposition of microstates co-
responding to various macrostates). Such situation is not possible in classical mechanics! Moreover, such state can not be considered as a simple mixed state, i.e. a classical ensemble of these several macrostates (to be more exact, of macrostates corresponding to them which are included into the superposition) with corresponding probabilities. Evolution of these superpositions and mixed states is different. Presence of interference terms for superposition explains this difference (or quantum correlations of the worlds for multi-world interpretation). Although this difference is very small for macroscopic bodies, yet it exists. What would prevent to observe this difference experimentally? The same reasons that prevents to observe entropy decreasing – it is alignment of thermodynamic time arrows!

Indeed, the more the detailed analysis below shows that experimental manifestations of interference (quantum correlations) are demonstrated in considerable scale only at entropy decrease. This process is not observable in principle if the observer is included into the observable system (introspection). Thus, entropy decrease is very difficultly observable if the observer is not included in the observed macrosystem, because of alignment of thermodynamic time arrows of the observable system and the observer/environment during decoherence. Almost full isolation of the macrosystem from environment / the observer is necessary between observations.

In addition, we cannot observe small manifestations of the interference (quantum correlations) at entropy increase at introspection in principle (at introspection, the full observation will be impossible – we can measure only macroparameters exactly, the full measuring is impossible). They are very difficultly observable for the external observer case because of decoherence with the observer/environment.

2. Qualitative consideration of the problem.

The reason of alignment of thermodynamic time arrows in quantum mechanics, as well as in classical mechanics, is low interaction between real chaotic macroscopic systems. It is a well-studied phenomenon named “decoherence” [2-3, 17, 24-27]. It results not only in widely known “entangling” states of systems but also in alignment of thermodynamic time arrows. (The direction of the entropy increase defines the direction of a thermodynamic time arrow). The reason of alignment of thermodynamic time arrows is absolutely the same as in classical Hamilton mechanics: instability of processes with opposite time arrows with respect to small perturbations. These perturbations exist between the observer/environment and the observed system (decoherence).

Maccone’s paper [4] gave similar arguments in the case of quantum mechanics. However, therein he formulated that the similar logic is applicable only in quantum mechanics. Our previous paper shows incorrectness of this conclusion [1, 5]. Paper [6] formulates the other objection to his judgments. Therein small systems with strong fluctuations are considered. Alignment of thermodynamic time arrows does not exist for such small systems. It must be mentioned that both Maccone’s replay to this objection and the subsequent paper of the authors of the objection [7] do not explain the true reason of the disagree-
ment described. The real solution is very simple. More specifically, the entropy increase law, the concept of thermodynamic time arrows and their alignment are applicable only to non-equilibrium macroscopic objects. Violation of these laws for microscopic systems with strong fluctuations is a widely known fact. Nevertheless, although the objection [6] is trivial physically, yet it is interesting from purely mathematical point of view. It gives good mathematical criterion for macroscopicity of chaotic quantum systems.

The situation in quantum mechanics is even simpler than in classical one: chaotic quantum systems are nearly periodic systems. However, the random law may describe distribution of energies (eigenvalues of a Hamiltonian determining “frequencies” of energy modes) [8]. This fact defines chaotic character of the quantum systems.

One can often see a statement that behaviour of quantum chaotic systems differs very strongly from that of classical ones. It is, however, a bad mistake related to deep misunderstanding of physics of these systems. Really, quantum chaotic systems are nearly periodic, whereas the random law for Poincare’s returns times characterizes classical chaotic systems. Thermodynamic time arrows of the observer and the observable system have the same direction. Therefore, the observer is capable to carry out observation (or introspection) only on finite time intervals when its time arrow exists (i.e. its state is far from thermodynamic equilibrium), and it does not change its direction. On such finite times (that the observer is capable to carry out observation during this time) the behaviour of chaotic quantum systems has the same character as that for classical quantum systems.

Decoherence results in transition of observed systems from a pure state to mixed one, i.e. results in entropy increase. (Actually, one macrostate transforms to the set of microstates). On the other hand, Poincare’s returns yield the inverse result (i.e. “recoherence”) and are related to the entropy decrease. Thus, decoherence and the correspondent alignment of thermodynamic time arrows of the observer and observable systems shall lead to the syncs of moments when the systems pass from pure states to mixed states. Consequently, it makes impossible to observe experimentally the inverse process (i.e. “recoherence”).

Summing up the above mentioned, consideration of alignment of thermodynamic time arrows in quantum mechanics is in many aspects similar to consideration in classical mechanics. However, consideration of this property for analysis of widely known paradoxes of quantum mechanics gives their full and consistent resolution. These are the following paradoxes:

1. explaining the paradox of wave packet reduction at measurements when an observer is included in system (introspection) (paradox of the Schrodinger cat);
2. explaining unobservability of superposition of macroscopic states by an external observer in real experiments (paradox of Wigner’s friend);
3. proving the full equivalence of multi-world and Copenhagen interpretations of quantum mechanics;
4. explaining deviations from the exponential law at decay of particles and pass from one energy level on another (paradox of a kettle which will never begin to boil).
As we described above, in quantum mechanics the solution of the problem of alignment of thermodynamic time arrows is similar to that in classical mechanics. However, there is one important exception. In classical mechanics, one microstate (a point in a phase space) corresponds to just one macrostate. In quantum mechanics, one microstate (wave function) can correspond to the set of possible macrostates (quantum superposition of the wave functions corresponding to this macrostates). This situation appears in the well-known paradox of “Schrodinger cat”.

Multi-world interpretation of quantum mechanics is very popular today. It states that these different macrostates correspond to different worlds. These parallel worlds exist simultaneously and interfere (summing to each other). We suggest it as a solution of “Schrödinger cat” paradox.

Then the following question appears, “Why do we need to suppose simultaneous existence of these worlds?” Instead, we can say, “The system collapses in one of these macrostates with the probability defined by Bohr’s rules. Why do we need these mysterious parallel worlds?” Copenhagen Interpretation is a name for this point of view.

The following objections are usually given:

1. We do not have any mechanisms describing the collapse in Copenhagen Interpretation.
2. We accept that wave functions are something, which really exists.
3. These wave functions and their superposition satisfy to Schrodinger equations.
4. Multi-world interpretation follows automatically from 1 and 2.
5. Decoherence, which is also a consequence of Schrodinger equations, explains why we can see as a result only one of the worlds (with corresponding Bohr’s probabilities).

However, here it is possible to object to it: “Yes, we don’t have any collapse mechanism. Nevertheless, we need not know it. We just postulate such collapse. Moreover, we do not want at all to know this mechanism. Really, we are capable to describe and calculate any physical situation without this knowledge”.

However, such approach encounters the following difficulties:

1. We cannot specify or calculate the exact instant when this collapse takes place. For macrobodies, it is possible to specify just a very narrow, but still a finite interval of time in which this collapse happens.
2. For macrobodies there is a quite clear separation between the worlds (because of decoherence) but it will never be full. There is always some small ”overlapping” between the worlds (the interference terms, quantum correlations of the worlds) even for macrobodies. Decoherence which is described above resolves the problem only partially. It “separates” macroworlds not completely but leaving this small ”overlapping”.
3. There are specific models of collapse (so-called GRW theory [16]). We can verify experimentally them. However, until now, such experiments did not give any proof of existence of such collapse. They give only boundaries on parameters for such models (in the case when they are true) defined by accuracy of the experiment. However, it is possible to object again:
(1) Yes, there is a problem to define exact collapse times. However, exactly the same problem does exist in multi-world interpretation as well: in what instant does the observer see, in what of the possible worlds he has occurred?

(2) The problem of “overlapping” of the worlds also exists in the multi-world interpretation. Indeed, the observer sees only one world in some instant. He can tell nothing about existence or non-existence of other parallel worlds. Therefore, he can conclude all predictions of the future (based on Bohr’s rules) only on knowing of “his” world. However, due to “overlapping” of the worlds (even just a small one) he cannot predict some possible effects. It means that quantum mechanics cannot give even an exact probabilistic prediction.

(3) It is possible to add one more uncertainty that exists in both interpretations. Suppose, for example that a superposition of two macrostates exists: “an alive cat” and “a dead cat”. Why does the world split (or collapse) into these two states? What is wrong with the pair: (“an alive cat” – “a dead cat”), (“an alive cat” + “a dead cat”)? The three problems described above lead to uncertainty of predictions done by means of quantum mechanics. We cannot insert it even within probabilistic frameworks based on Bohr’s rules. This uncertainty is very small for macrobodies but it exists. It exists for all interpretations, yet masking and changing its form. The aim of majority of interpretations is to overcome these problems. Actually, different interpretations only “mask” the uncertainty problem yet not solving it.

(4) All that we told above about GRW theories is true. There is no necessity to use it instead of quantum mechanics. However, it is not correct for Copenhagen Interpretation. The Copenhagen Interpretation resembles GRW very much but one important feature is very much different from GRW. The Copenhagen Interpretation postulates the collapse only for one final observer. It does not demand the collapse from the remaining macroobjects and observers. A point of view of a final observer describes all physical experiments. The final ”observer” is not some person possessing mysterious ”consciousness”. It is some standard macroscopic object. It is far from its state of thermodynamic equilibrium. The final observer is the last in the chain of observers and macrobodies. We choose the direction of his thermodynamic time arrows as a ”positive” direction. It is similarly to our previous paper [1]. This constrain on collapse leads to serious consequence, which does not appear in GRW. Namely, we can verify experimentally the existence of the collapse in GRW, but existence of the collapse in Copenhagen Interpretation we cannot prove or disprove even in principle. Let us demonstrate it. We will consider mental experiments, which allow verifying existence of the collapse predicted in GRW. Further, we will demonstrate that we cannot use these experiments for verification of the collapse in the Copenhagen Interpretation.

(a) Quantum mechanics, as well as classical, predicts Poincare’s returns. Moreover, unlike classical chaotic systems, the returns happen periodically or almost periodically. However, because of the collapse in GRW such returns are impossible and we cannot observe them experimentally, i.e. this fact can be used for
experimental verification.

(b) Quantum mechanics is reversible. At a reversion of evolution, the system must return to the initial state. However, the collapse results in irreversibility. We can verify this fact also experimentally.

(c) We can observe experimentally the small effects related to the small quantum correlations that exist even after decoherence. In GRW this small effects disappear.

Suppose that we want to verify the collapse of the final observer in the Copenhagen Interpretation. Hence, we must include the observer into the observable system, i.e. there is introspection here. We will demonstrate that it is impossible to verify (or contravene) existence of the collapse in Copenhagen Interpretation by the methods described above:

1. Suppose that the observer waits for the return predicted by quantum mechanics. However, the observer is included into the system; i.e., at Poincare’s return, he will return to his initial state together with the entire system. Hence, his memory about his past will be erased. Therefore, the observer will not be possible to compare the initial and finite state. It makes the verification of the existence (or non-existence) of the observer’s collapse experimentally impossible.

2. The same reasons as those in item (a.) make impossible the experimental verification of the returns caused by the reversion of system evolution.

3. For observation of the small effects (quantum correlation macrostates), the measuring split-hair accuracy is necessary. However, as the observer is included into the observed system (introspection), it is not possible to make full measurement of such system. (Figuratively speaking, the observer uses some ”ink” to describe the full system state. However, the ”ink” is also a part of the full system during intersection. So the ”ink” must describe also itself!) We can describe such system by macroparameters only. It makes impossible experimental observation and calculation of the small effects of the quantum correlations.

Actually, the first two items (a., b.) are related to a following fact which took place also in classical mechanics [1]. Decoherence (decomposition on macrostates) leads to the entropy increase (one macrostate is replaced by a full set of possible macrostates). On the other hand, observation of the return (i.e. recoherence) is related to the entropy decrease. The observer is capable to carry out introspection experimentally only on finite time intervals when it has a time arrow (i.e. a state far from the thermodynamic equilibrium), and it does not change its direction. Thus, inability to distinguish experimentally the Copenhagen and Multi-world Interpretations is closely related to the entropy increase law and the thermodynamic arrow of time.

Everything from the abovementioned makes impossible to verify experimentally the difference between the Copenhagen and Multi-world Interpretation, so we can regard them as equivalent. Such statements about indistinguishability of these interpretations meet in the literature. However, in cases when this fact is not just stated but someone tries to prove it, it is usually referred to impossibility to make such verification only practically for macrobodies (FAPP - for all practical purposes). The understanding of its
principal impossibility is lacking. This incorrect understanding is a basis for erroneous deduction about “exclusiveness” of Multi-world Interpretation. We will demonstrate the clearest example [9]:

”MWI proponents might argue that, in fact, the burden of experimental proving lies on MWI opponents, because it is they who claim that there is the new physics beyond the well tested Schrödinger equation.”

”Despite the definition ”interpretation”, the MWI is a variant of quantum theory that is different from others. Experimentally, the difference is relative to collapse theories. It seems that there is no experiment distinguishing the MWI from other no-collapse theories such as Bohmian mechanics or other variants of MWI. The collapse leads to effects that are, in principle, observable; these effects do not exist if MWI is the correct theory. To observe the collapse, we would need a superb technology, which would allow ”undoing” a quantum experiment, including a reversal of the detection process by macroscopic devices. See Lockwood 1989 (p. 223), Vaidman 1998 (p. 257), and other proposals in Deutsch 1986. These proposals are all for mental experiments that cannot be performed with current or any foreseen future technology. Indeed, interference of different worlds has to be observed in these experiments. Worlds are different when at least one macroscopic object is in macroscopically distinguishable states. Thus, what is needed is an interference experiment with a macroscopic body. Today there are interference experiments with larger and larger objects (e.g., fullerene molecules C60), but these objects are still not large enough to be considered ”macroscopic”. Such experiments can only refine the constraints on the boundary where the collapse might take place. A decisive experiment should involve the interference of states which differ in a macroscopic number of degrees of freedom: an impossible task for today’s technology”.

The given proof of principal experimental unverifiability of collapse in Copenhagen Interpretation, as far as we know, can be found only in this and the previous papers [10-13]. It is possible to term it as the ”Gödel” theorem of impossibility for quantum mechanics. Both its statement and its method of its proof really remind “the Gödel theorem of incompleteness”.

We concentrate on this problem so much here for the following reasons. Firstly, the impossibility to distinguish experimentally the Copenhagen and Multi-world Interpretations is closely related to the entropy increase law and the thermodynamic arrow of time. Secondly, it is too many people sincerely but erroneously believe that Multi-world Interpretation (or other less fashionable Interpretations) completely solves all problems of quantum mechanics. Uncertainty, which we described already above, is one of such problems of quantum mechanics. It means that quantum mechanics using Bohr’s rules is characterized with small uncertainty connected to small quantum correlation of the observer. How can we find them actually? We can conclude these results from the fact that the specified uncertainty exist in ideal dynamics over an abstract coordinate time. This uncertainty is absent in observable dynamics over the observer’s time arrow and is not observed experimentally in principle.

(1) Introspection: The same reasons already described above which do not allow verify-
ing the collapse experimentally will not allow experimental discovery of the uncer-
tainty specified in item 1 (the exact instant of the collapse) and item 2 (quantum
correlations). Therefore, it is senseless to discuss it.

(2) External observation:
   (a) If this observation does not perturb the observable system then the collapse of
the system and, hence, uncertainties [specified in item 1 (the exact instant of
the collapse) and item 2 (quantum correlations)] do not arise. Therefore, we can
verify can quantum mechanics experimentally in precise way. Such unpertru-
bative observation is possible for macrobodies only theoretically. The necessary
condition is a known initial state (pure or mixed) (Appendix A).
   (b) The observed system is open. It means that there is a low interaction be-
tween the observable system and the observer/environment. This low interac-
tion masks uncertainty (specified in points 1 and 2) and makes impossible its
experimental observation.

Here it is necessary to return to the uncertainty described in item 3 above. The ma-
jority of real observations correspond to two cases: the introspection cases (when the full
description is impossible in principle) or the open system (perturbed with uncontrollable
small external noise from the observer/environment). How is it possible to describe such
open or incomplete systems? We can make it by input of macroparameters of the system.
The real observable dynamics of such parameters is possible for a wide class of systems.
It does not include “the parallel worlds” unobservable in realities, entropy reduction,
quantum superposition of macrostates and other exotic, possible only in ideal
dynamics. Observable dynamics is considered with respect to the thermodynamic time arrow of
the real macroscopic non-equilibrium observer, weakly interacting with observable system
and an environment (decoherence). We consider ideal dynamics with respect to abstract
coordinate time. The other papers [14-15, 17-18] successfully solved the problem of the
pass from ideal to real dynamics. Selection of macrovariables is ambiguous, but also is not
arbitrary. We should be chose macrovariables so that at entropy increase random small
external noise did not influence considerable their dynamics. Such macrovariables exist
and pointer states [3, 17] are a name for them. Presence of the selected states is a result
of interaction locality in the real world. It means that close particles interact stronger
than far particles. If we defined the force of interaction, for example, by closeness of
momentums the principal states would be absolutely different. Therefore, the property
of a locality is untrue over distances comparable with wavelength. Therefore, radio waves
have field pointer states, strongly differing from particles pointer states. The situation
described here is completely equivalent to paper [1]. This paper considers ”appropriate”
macrostates for classical mechanics were.

What can be an example of observable dynamics for quantum systems? These are
the described above GRW theories. To understand it, we will return to the Copenhagen
Interpretation. We can choose different non-equilibrium macrobodies as ”the final ob-
server” in the Copenhagen Interpretation. Theoretically, such different observers will see
the collapse differently. “Paradox of Wigner’s friend” is a name for this appearance. We
will call this appearance of ambiguity of the collapse in the Copenhagen Interpretation as “Quantum solipsism”. We chose this name by analogy to the similar philosophical doctrine. This problem can be resolved similarly to the paper [1]. The entropies of all weakly interacting macrobodies increase or decrease synchronously, because of alignment of thermodynamic time arrows. The collapse corresponds to entropy increase (one macrostate replaces on a set of possible macrostates). Hence, low interaction (decoherence) between macrobodies yields not only alignment of thermodynamic time arrows but also synchronize of all moments of “collapse” for different observers. It makes “Quantum solipsism” for macrobodies although theoretically possible but it would be extremely difficult to realize it in practice. Thus, this resolution of “Quantum solipsism” by the collapses differs from Copenhagen Interpretation. There we cannot prevent the observer’s collapse even theoretically. Thus, the GRW theories described above are the description of the real observable dynamics of macrobodies (FAPP dynamics) for quantum mechanics. It throws out effects not observed in reality. Non-synchronism in the macrobodies collapses moments and the entropy decrease that ideal dynamics predicts can be examples.

“The paradox of a kettle which will never begin to boil” can serve as a good illustration of the abovementioned connection of observed and ideal types of dynamics. In quantum mechanics, it is related to a deviation from the exponential law of particles decay (or a pass from one energy level on another). The exponential character of such law is very important – the relative rate of decay does not depend on an instant. It means that the decaying particle has no ”age”. In quantum mechanics, however, in small lengths of time the law of ideal dynamics of decay strongly differs from the exponential law. Therefore, when the number of measurements of a decaying particle state for finite time interval increases the particle in limit of infinite number of measurements does not decays at all!

Let us observe a macrosystem consisting of large amount of decaying particles. Here it is necessary to note that decay of a particle happens under laws of ideal dynamics only between measurements. Measurements strongly influence dynamics of the system, as we described above. To transfer to the observable dynamics featured above, we should decrease perturbing influence of observation strongly. We can reach it by increasing the interval between observations. It must be comparable with a mean lifetime of unperturbed particles. For such large intervals of time, we get real observable dynamics of decay. We can feature it by an exponential curve, and the mean lifetime does not depend on a concrete interval between measurements. Thus, the exponential decay is a law of observable but not of ideal dynamics of particles. (The same reason explains absence of Poincare’s returns for this system).

3. The quantitative consideration of the problem

3.1 Definition of the basic concepts

(1) In classical mechanics a microstate is a point in a phase space. In quantum mechanics it corresponds to a wave function $\psi$ (a pure state), and trajectories are evolution
of a wave function in time. In classical mechanics a macrostate corresponds to a function of density distribution in a phase space. In quantum mechanics it corresponds to a density matrix $\rho$. The density matrix form depends on the chosen basis of orthonormal wave functions. If $\rho \neq \rho$ then it is in mixed state.

(2) The equation of motion for the density matrix $\rho$ will have the following form:

$$i \frac{\partial \rho_N}{\partial t} = L \rho_N,$$

where $L$ is the linear operator:

$$L \rho = H \rho - \rho H = [H, \rho]$$

and $H$ is the energy operator of the system, $N$ is a number of particles.

(3) If $A$ is the operator of a certain observable, then the average value of the observable can be found as follows:

$$\langle A \rangle = \text{tr} A \rho$$

(4) If the observation is introspection the full observation is impossible. In case of external observation because of low interaction with the observer and instabilities of an observable chaotic system the full exposition also is senseless. Therefore, introducing some finite set $M$ of macrovariables is necessary:

$$A_{set} = \{A_1, A_2, \ldots, A_M\},$$

where $M \ll N$.

These macrovariables are known with finite small errors:

$$\Delta A_i \ll |A_i| \quad 1 \leq i \leq M$$

This set of macrovariables corresponds to a macrostate with a density matrix $\rho_{set}$. All microstates answering to requirements

$$\{|\langle A_1 \rangle - A_1| \leq \Delta A_1, |\langle A_2 \rangle - A_2| \leq \Delta A_2, \ldots, |\langle A_M \rangle - A_M| \leq \Delta A_M \}$$

are assumed to have equal probabilities.

Corresponding to thermodynamic equilibrium is a macrostate $\rho_E$. It corresponds to a set of microstates satisfying to the following requirement:

$$|\langle E \rangle - E| \leq \Delta E \quad (\Delta E \ll |E|),$$

where $E$ is the full system energy.

All these microstates are assumed to have equal probabilities.

(5) In quantum mechanics ensemble entropy is defined via density matrix $[15]$:

$$S = -k \text{ tr} (\rho \ln \rho),$$

where $\text{ tr}$ stands for matrix trace.
Entropy defined in such a way does not change in the course of reversible evolution:

\[ \frac{\partial S}{\partial t} = 0 \]

(6) \textit{Macroscopic entropy} is defined as follows:

(a) For current \( \rho \) we find all corresponding sets of macrovariables

\[
\left\{ A^{(1)}_1, A^{(1)}_2, ..., A^{(1)}_M \right\} \quad \Delta A^{(1)}_i < < A^{(1)}_i, \quad 1 \leq i \leq M
\]

\[
\vdots
\]

\[
\left\{ A^{(L)}_1, A^{(L)}_2, ..., A^{(L)}_M \right\} \quad \Delta A^{(L)}_i < < A^{(L)}_i, \quad 1 \leq i \leq M
\]

(b) We find a matrix \( \rho_{\text{set}} \) for which all microstates corresponding to the specified set of macroparameters have equal probabilities

(c) Macroscopic entropy \( S = -k \text{ tr} (\rho_{\text{set}} \ln \rho_{\text{set}}) \). Unlike ensemble entropy, macroscopic entropy (macroentropy) is not constant and can both increase and decrease in time. For given energy \( E \pm \Delta E \) it reaches its maximum for thermodynamic equilibrium. The direction of the macroentropy increase defines the direction of a \textit{thermodynamic arrow of time} for the system.

(7) Similarly to the classical case, the interaction locality results in the fact that not all macrostates are appropriate. They should be chosen so that small noise would not influence essentially evolution of the system for the entropy increase process. Such states are well investigated in quantum mechanics and named \textit{pointer states} \cite{3, 17}. Quantum superposition of such states is unstable with respect to small noise. So such superposition is not, accordingly, a pointer state. For macrosystems close to the equilibrium pointer states are usually corresponding to Hamiltonian eigenfunctions.

(8) \textit{Coarsened} value of \( \rho \) (\( \rho_{\text{coar}} \)) should be used to obtain changing entropy similarly to changing macroscopic entropy. We will enumerate ways to achieve it:

(a) We define a set of pointer states and we project a density matrix \( \rho \) on this set. I.e. (a) we note a density matrix \( \rho \) in representation of these pointer states (b) we throw out non-diagonal terms of \( \rho \) and obtain \( \rho_{\text{coar}} \). So entropy:

\[
S = -k \text{ tr} (\rho_{\text{coar}} \ln \rho_{\text{coar}})
\]

(b) We divide the system into some interacting subsystems (for example: the observer, the observable system and the environment). Then we define the full entropy as the sum of the entropies of these subsystems:

\[
S = S_{\text{ob}} + S_{\text{ob.sys}} + S_{\text{env}}
\]
3.2 Effect of a weak coupling

3.2.1 Small external perturbation

We can put our macrosystem of finite volume inside of an infinite volume system ("environment", "reservoir") with some temperature. (This reservoir can be also a vacuum with zero temperature.) We will suppose that this reservoir is in thermodynamic equilibrium, has the same temperature as a temperature of the finite system in equilibrium and weakly interacts with our finite system. Then it is possible to use the quantum version of "new dynamics" developed by Prigogine [14] for such infinite systems. Dynamics of our finite system with a reservoir will be the same as its observable dynamics without a reservoir with respect to its thermodynamic time arrow. Such description has sense only during finite time. It is time when its thermodynamic time arrow exists (i.e. the system is not in equilibrium) and does not change its direction.

3.2.2 Alignment of thermodynamic time arrows at interaction of macrosystems (the observer and the observable system)

It ought to be noted that here our job is much easier than in the case of classical mechanics. This is because the quantitative theory of small interaction between quantum systems (decoherence, entangling) is a well-developed field [2-3, 17, 24-27]. We will not repeat these conclusions here but just give short results only:

(a) Suppose that we have two macrosystems for some instant. One or both of them are in their quantum superposition of pointer states. The theory of decoherence [2-3, 17, 24-27] states that small interaction between macrosystems (decoherence time is much less than relaxation time to equilibrium) transforms such system into the mixed state very fast in which the quantum superposition disappears. Such process of vanishing quantum superposition of pointer states corresponds to the entropy increase. It follows from Poincare’s theorem that the system (in coordinate time) should return to its initial state. There should be an inverse process of recoherence. However, it will happen in both systems synchronously. It means that any system can see only decoherence and entropy increase with respect to its thermodynamic time arrow. It means that both processes decoherence and time arrows will be synchronous in interacting subsystems. It is especially worthy of note that we consider here a case of macroscopic systems. For small systems where large fluctuations of parameters are possible, we cannot observe similar alignment of thermodynamic time arrows and the instances of “collapses” for subsystems [6-7].

(b) Now, suppose that all macroscopic subsystems are in their pointer states. In the decoherence theory it is shown that in presence of small noise between its macroscopic subsystems the behaviour of a quantum system is completely equivalent and is indistinguishable from behaviour of the correspondent classical system [2-3, 17, 24-27]. Thus, the analysis of alignment of thermodynamic time arrows is completely equivalent to the analysis made in paper [1].

(c) It is worth to specify what the meaning of “classical system” is in this case.
It means that in the theory there do not exist specific mathematical features of quantum theory. They are, for example, such features as not commuting observables, quantum superposition of pointer states. At that, these "classical theories" can be very exotic, include Planck’s constant and we cannot reduce them to laws of the known mechanics of macrobodies or waves.

Superconductivity, superfluidity, radiation of absolute black body, and superposition of currents in Friedman’s experiment [19] are often named "quantum effects". They are really quantum in the sense that their equations of motion include Planck’s constant. However, they are perfectly featured over macroscale by a mathematical apparatus of usual classical theories: either the theory of classical field (as pointer states), or the theory of classical particles (as pointer states). From this point of view, they are not quantum but classical. In quantum theory, featured objects both are particles and probability waves at the same time.

It is worth to note that in the classical limit, at room temperatures, quantum mechanics of heavy-weighted particles gives the theory of classical particles as pointer states (electron beams, for example). On the other hand, light-weighted particles give the classical field as pointer states (radio waves). In addition, these theories do not include Planck’s constant.

However, at high temperatures when radiation achieves high frequencies, we can feature light quanta by the theory of classical particles as pointer states. They give, for example, a spectrum of absolute black body on high frequencies. Though this spectrum includes Planck’s constant its dynamics of pointer states (particles) will be classical. For deriving this spectrum, the quantum mechanics formalism is not necessary (Planck derived this spectrum knowing nothing about the mathematical apparatus of quantum physics).

Vice versa, at low temperatures for particles classical fields are pointer states (superfluidity or superconductivity phenomena). For example, classical wave of “order parameter” features superconductivity. Though the equations, which feature this field, include Planck’s constant, yet the equations correspond to mathematical apparatus of the classical field theory. These waves can be summed (superposed) with each other similarly to quantum waves. However, the square of their amplitude does not define probability density. It defines density of Cooper pair. Such wave cannot collapse at measurement, as probability quantum waves can [20].

For quantum-mechanical states of bosons at low temperatures, pointer states are classical fields, and at high temperatures, they are classical particles. We need to understand the word "classical" as a mathematical apparatus of the observable dynamics featuring their behaviour, but not presence or absence of Planck’s constant in their equations of motion.

What happens in the intermediate states between classical fields and classical particles? It is, for example, light in an optical wave guide \( L \gg \lambda \gg \lambda_{ultraviolet} \), \( L_{opt} \) - the characteristic size of the macrosystem (the optical wave guide) (Appendix B), \( \lambda \) - light-wave length, \( \lambda_{ultraviolet} \) - ultra-violet boundary of light. When using macroscales and
macrovariables, and taking into account small noise from the observer, both descriptions ("classical waves" and "classical beam of particles") are identical. They are equivalent and can be used as pointer states. The equivalent situation arises for a case of superconductor where the roles of particles or waves play elemental "excitations" in gas of Cooper pairs.

Let’s carry out a simple calculation to illustrate the said above.

Let \( E \) be energy of particle; \( k \) - Boltzmann constant, \( T \)-temperature, \( p \) - momentum, \( \Delta p \) - momentum uncertainty, \( \lambda \) - particle wave length, \( \omega \)-frequency, \( \Delta x \) - a coordinate uncertainty; \( \hbar \) - Planck constant. We will consider the "gas" of such particles which is in a cavity, filled with some material with distance between atoms \( a \). \( a \ll L \), \( L \) the characteristic size of the cavity. In vacuum \( a\sim\left(\frac{L^3}{N}\right)^{1/3} \), \( N \)-number of particles in the cavity. \( c \)- velocity of light (let suppose for simplicity that refraction index in the cavity is close to 1).

1. Firstly, let us consider light in weight particles which at room temperature have the speed close to speed of light \( c \).

   \[ E\sim pc; \quad E\sim kT; \quad p\sim \Delta p; \quad \lambda\sim \Delta x; \quad \Delta p\Delta x \sim \hbar; \quad \omega=E/\hbar \]

   Hence,

   \[ \hbar \sim \Delta p\Delta x \sim p\lambda \sim \frac{kT\lambda}{c} \]

   From this equalities we get

   \[ \lambda \sim \hbar c/kT \]

   Condition of classical field approach with frequency \( \omega\sim c/\lambda \) is following:

   \[ L<\lambda \text{ or } L\sim \lambda \].

   Hence \( L<\hbar c/kT \) or \( L\sim \hbar c/kT \)

   Condition of approach of classical relativistic particles with \( E\sim \hbar c/\lambda \) and \( p=E/c \) is following:

   \[ L \gg \lambda \].

   Hence, \( L \gg \hbar c/kT \).

2. Secondly, let us consider heavy particles bosons which at room temperature have the speed \( v \ll c \):

   \[ p\sim (Em)^{1/2} \quad ; \quad E\sim kT; \quad p\sim \Delta p; \quad \lambda\sim \Delta x; \quad \Delta p\Delta x \sim \hbar; \quad \omega=E/\hbar \]

   Hence,

   \[ \hbar \sim \Delta p\Delta x \sim p\lambda \sim (kTm)^{1/2} \Rightarrow \lambda \sim \hbar/(kTm)^{1/2} \]

   Condition of classical field approach with frequency \( \omega=p^2/(m\hbar) \) is following:
\[
L < \lambda \text{ or } L \sim \lambda.
\]
Hence \( L < \hbar / (kTm)^{1/2} \) or \( L \sim \hbar / (kTm)^{1/2} \).

Condition of approach of classical particles with energy \( E = p^2 / (2m) \) and momentum \( p = mv \) is following: \( L \gg \lambda \). Hence, \( L \gg \hbar / (kTm)^{1/2} \).

(3) Let us consider now heavy particles fermions which at room temperature have the speed \( v \ll c \)

\[
p \sim (Em)^{1/2}; \ E \sim kT; \ p \sim \Delta p; \ \Delta p \Delta x \sim \hbar
\]

\( \Delta x \leq \lambda \) and \( \lambda \leq a \) is a requirement of Pauli’s principle for fermions. They cannot appear in the same state, so they are distributed in ”boxes” with size \( a \).

Hence, \( \hbar \sim \Delta p \Delta x \leq p \lambda \sim (kTm)^{1/2} \lambda \)

From this inequality we get

\[
a \geq \lambda \geq \hbar / (kTm)^{1/2}
\]

\( T \geq T_F = \hbar^2 / (a^2 km) \)- Fermi’s temperature when fermion gas transfers in the basic state and expression \( E \sim kT \) becomes untrue.

At \( T < T_F \) we have the following:

\[
E \sim E_F = kT_F; \ \lambda \sim \hbar / (E_F m)^{1/2} \sim a
\]

Requirement of classical field approach:

\( L < \lambda \) or \( L \sim \lambda \). But it is impossible because \( L \gg a \geq \lambda \)

At \( T \geq T_F \) approach of classical particles in quality pointer states with energy \( E = p^2 / 2m \) and momentum \( p = mv \) is correct.

At \( T \leq T_F \) approach of classical particles in quality pointer states, prisoners in boxes with size \( a \), with energy \( E \sim E_F \) and momentum \( p \sim (E_F m)^{1/2} \) is correct.

At \( T \sim T_F \) we observe dynamics of “excitations” in the degenerated Fermi gas which is featured by particles or waves as pointer states for these “excitations”.

To create the paradox of “Schrodinger cat” in experiment, the quantum superposition of the pointer states is necessary, instead of superposition of classical waves. Therefore, superposition of classical waves of “order parameter” or light waves is not related in any way to this paradox and does not illustrate it.

So, for example, experiments of Friedman [19] state a superposition of opposite currents. But the superposition is itself a pointer state for this case. This pointer state is classical, not quantum superposition of pointer states, as it is usually erroneously declared. Really, the state of bosons system (Cooper pairs) is featured at such low temperature by a classical wave as it was demonstrated above. These waves of ”order parameter” are pointer states. They differ from pointer states of a high-temperature current of classical particles having a well-defined direction of motion. The superposition observed in Friedman’s experiment is not capable to collapse to quantum-mechanical sense: its square features not probability but density of Cooper pairs [20]. It is not more surprising and not more ”quantum” than usual superposition of electromagnetic modes in the closed
resonator where spectrum of modes is discrete too. The only difference is that "order 
parameter" wave equations for pointer states include . It is the only reason to use concept 
of "quantum" for this case.

3.3 Resolution of Loshmidt and Poincare paradoxes in framework of 
quantum mechanics

The state of a quantum chaotic system in a closed cavity with finite volume is featured 
by a set of energy modes $u_k (r_1, \ldots, r_N)$ with spectrum $E_k$ distributed under the random 
law [8].

Let’s write the expression for wave functions of a non-interacting pair of such systems:

$$\psi^{(1)}(r_1, \ldots, r_N, t) = \sum_k u_k(r_1, \ldots, r_N)e^{-\frac{iE_k^{(1)}}{\hbar}t}$$

$$\psi^{(2)}(r_1, \ldots, r_L, t) = \sum_l v_l(r_1, \ldots, r_L)e^{-\frac{iE_l^{(2)}}{\hbar}t}$$

The united equation is following:

$$\psi^{(1)}(r_1, \ldots, r_N, r_1, \ldots, r_L, t) = \psi^{(1)}(r_1, \ldots, r_N, t)\psi^{(2)}(r_1, \ldots, r_L, t) =$$

$$\sum_k \sum_l u_k(r_1, \ldots, r_N)v_l(r_1, \ldots, r_L)e^{-\frac{i(E_k^{(1)}+E_l^{(2)})}{\hbar}t}$$

At presence of small interactions between the systems

$$\psi^{(1)}(r_1, \ldots, r_N, r_1, \ldots, r_L, t) =$$

$$\sum_k \sum_l f_{kl}(r_1, \ldots, r_N, r_1, \ldots, r_L)e^{-\frac{i\Omega_{kl}}{\hbar}t}$$

, where $E_{kl}=E_k^{(1)}+E_l^{(2)}+\Omega_{kl}$, $\Omega_{kl}$ -generally a set of random variables, $f_{kl}, u_k, v_l$ are 
eigenfunctions of corresponding Hamiltonians.

The obtained solutions are almost-periodic functions. The obtained period of return 
defines Poincare’s period. The period of Poincare’s return of full system is generally 
larger than periods of the both subsystems.

For resolution of Poincare and Loshmidt paradoxes (returns in these paradoxes con-
tradict to entropy increase law), we will consider three cases now.

(1) Introspection: At introspection, the time the arrow is always directed over entropy 
growth, so the observer is capable to see only entropy growth with respect to this 
time arrow. Besides, return to the initial state erases the memory about the past. It 
does not allow the observer to detect entropy reduction. Thus, reduction of entropy 
and returns happen only with respect to coordinate time. However, any experiment 
is possible with only with respect to time arrow of the observer. With respect to
coordinate time, we cannot experimentally observe the entropy reduction and returns
[1, 10-13].

(2) External observation with small interaction between macrosystems: Small interaction
results in alignment of the thermodynamic time arrows of the observer and observed
systems. Accordingly, all arguments that are relevant for introspection again become
relevant for this case.

(3) For a very hardly realizable experiment with unperturbative observation (Appendix
A), macroentropy reduction can really be observed. However, it is worth to note
that in the real world ”entropy costs” on the experimental organization of such
unperturbative observations will exceed considerably this entropy decrease. Indeed,
the observable system needs to be isolated very strongly from environment noise.
In classical systems, the period of Poincare’s return is a random variable strongly
depending on an initial state. In quantum chaotic systems, the period is well defined
and does not depend considerably on the initial state. However, this real difference in
behaviour of quantum and classical systems is not observed experimentally even in ab-
sence of any explicit constraint on experiment time. Indeed, any real physical experiment
has a duration that is much smaller than Poincare’s period of macrobodies. Physical ex-
periments are possible only during the time while the thermodynamic time arrow exists
(i.e. the system is not in a state of thermodynamic equilibrium) and does not change the
direction.

3.4 Decoherence for process of measurement

3.4.1 Reduction of system at measurement

This part is based on [22, 23]

Let’s consider a situation when a measuring device was at the beginning in state \(|\alpha_0\rangle\),
and the object was in superposition of states \(|\psi\rangle = \sum c_i |\psi_i\rangle\), where \(|\psi_i\rangle\) are experiment
eigenstates. The initial statistical operator is given by expression

\[
\rho_0 = |\psi\rangle \langle \alpha_0 | \langle \alpha_0 | \langle \psi |
\] (37)

The partial track of this operator which is equal to statistical operator of the system,
including only the object, looks like \(tr_A(\rho_0) = \sum_n \langle \varphi_n | \rho_0 | \varphi_n \rangle\)

where \(|\varphi_n\rangle\) - any complete set of device eigenstates. Thus,

\[
tr_A(\rho_0) = \sum_n |\psi\rangle \langle \varphi_n | \alpha_0 \rangle \langle \alpha_0 | \varphi_n \rangle \langle \psi | = |\psi\rangle \langle \psi |
\] , (38)

Where the relation \(\sum \langle \varphi_n | \varphi_n \rangle = 1\) and normalization condition for \(|\alpha_0\rangle\) are used.
We have statistical operator correspondent to object state \(|\psi\rangle\). After measuring there
is a correlation between device and object states, so the state of full system including
device and object is featured by a state vector

\[
|\psi\rangle = \sum c_i e^{i\theta_i} |\psi_i\rangle |\alpha_i\rangle
\] (39)
And the statistical operator is given by expression

\[ \rho = |\psi\rangle \langle \psi| = \sum c_i^* c_j e^{i(\theta_i - \theta_j)} |\psi_i\rangle \langle \alpha_i| \langle \alpha_j| \langle \psi_j|. \tag{40} \]

The partial track of this operator is equal to

\[ \text{tr}_A (\rho) = \sum_n \langle \varphi_n | \rho | \varphi_n \rangle = \sum_{(ij)} c_i^* c_j e^{i(\theta_i - \theta_j)} |\psi_i\rangle \{ \sum_n \langle \varphi_n | \alpha_i \rangle \langle \alpha_j| \varphi_n \rangle \} \langle \psi_j| = \sum_{(ij)} c_i^* c_j \delta_{ij} |\psi_i\rangle \langle \psi_j|. \tag{41} \]

(Since various states |\alpha_i\rangle of the device are orthogonal each other); thus,

\[ \text{tr}_A (\rho) = \sum_i |c_i|^2 |\psi_i\rangle \langle \psi_i|. \tag{42} \]

We have obtained statistical operator including only the object, featuring probabilities |c_i|^2 for object states |\psi_i\rangle. So, we come to formulation of the following theorem.

**Theorem 1** (about measuring). If two systems S and A interact in such a manner that to each state |\psi_l\rangle systems S there corresponds a certain state |\alpha_l\rangle of systems A the statistical operator \text{tr}_A (\rho) over full systems (S and A) reproduces wave packet reduction for measuring, yielded over system S, which before measuring was in a state |\psi\rangle = \sum_i c_i |\psi_i\rangle.

Suppose that some subsystem is in mixed state but the full system including this subsystem is in pure state. Such mixed state is named as improper mixed state.

### 3.4.2 The theorem about decoherence at interaction with the macroscopic device

This part is based on [21, 22]

Let’s consider now that the device is a macroscopic system. It means that each distinguishable configuration of the device (for example, position of its arrow) is not a pure quantum state. It states nothing about a state of each separate arrow molecule. Thus, in the above-stated reasoning the initial state of the device |\alpha_0\rangle should be described by some statistical distribution on microscopic quantum states |\alpha_{0,s}\rangle; the initial statistical operator is not given by expression (37), and is equal

\[ \rho_0 = \sum_s p_s |\psi\rangle \langle \alpha_{0,s}| \langle \alpha_{0,s}| \langle \psi|. \tag{43} \]
Each state of the device $|\alpha_{0,s}\rangle$ will interact with each object eigenstate $|\psi_i\rangle$. So, it will be transformed to some other state $|\alpha_{i,s}\rangle$. It is one of the quantum states of set with macroscopic description correspondent to arrow in position $i$; more precisely we have the formula

$$e^{i\frac{\hbar}{\tau} (|\psi\rangle\langle\alpha_{0,s}|)} = e^{i\theta_{i,s}} (|\psi\rangle\langle\alpha_{i,s}|)$$ (44)

Let’s pay attention at appearance of phase factor depending on index $s$. Differences of energies for quantum states $|\alpha_{0,s}\rangle$ should have such values that phases $\theta_{i,s}$ (mod $2\pi$) after time $\tau$ would be randomly distributed between 0 and $2\pi$.

From formulas (43) and (44) follows that at $|\psi\rangle = \sum_i c_i |\psi_i\rangle$ the statistical operator after measuring will be given by following expression:

$$\rho = \sum_{(s,i,j)} p_s c_i j^s e^{i(\theta_{i,s} - \theta_{j,s})} |\psi_i\rangle\langle\alpha_{i,s}| \langle\alpha_{j,s}| \langle\psi_j|$$ (45)

As from (45) the same result (42) can be concluding. So we see that the statistical operator (45) reproduces an operation of reduction applied to given object. It also practically reproduces an operation of reduction applied to device only (”practically” in the sense that it is a question about ”macroscopic” observable variable). Such observable variable does not distinguish the different quantum states of the device corresponding to the same macroscopic description, i.e. matrix elements of this observable variable correspondent to states $|\psi_i\rangle |\alpha_{i,s}\rangle$ and $|\psi_j\rangle |\alpha_{j,s}\rangle$ do not depend on $i$ and $s$. Average value of such macroscopic observable variable $A$ is equal to

$$tr (\rho A) = \sum_{(s,i,j)} p_s c_i j^s \sum a_{i,s} \sum a_{j,s} e^{i(\theta_{i,s} - \theta_{j,s})} |\psi_i\rangle\langle\alpha_{i,s}| \langle\alpha_{j,s}| \langle\psi_j|$$ (46)

As phases $\theta_{i,s}$ are distributed randomly, the sum over $s$ are zero at $i \neq j$; hence,

$$tr (\rho A) = \sum_i |c_i|^2 a_{i,i} = tr (\rho' A)$$ (47)

Where

$$\rho' = \sum |c_i|^2 p_s |\psi_i\rangle\langle\alpha_{i,s}| \langle\alpha_{j,s}| \langle\psi_j|$$ (48)

We obtain statistical operator which reproduces operation of reduction on the device. If the device arrow is observed in position $i$, the device state for some $s$ will be $|\alpha_{i,s}\rangle$. The probability to find state $|\alpha_{i,s}\rangle$ is equal to probability of that before measuring its state was $|\alpha_{i,s}\rangle$. Thus, we come to the following theorem.

**Theorem 2. About decoherence of the macroscopic device.** Suppose that the quantum system interacts with the macroscopic device in such a manner that there is a chaotic distribution of states phases of the device. Suppose that $\rho$ is a statistical operator of the device after the measuring, calculated with the help of Schrodinger equations, and $\rho'$ is the statistical operator obtained as a result of reduction application to operator $\rho$. 

Then it is impossible to yield such experiment with the macroscopic device which would register difference between $\rho$ and $\rho'$.

It is the so-called Daneri-Loinger-Prosperi theorem [21].

For a wide class of devices it is proved that the chaotic character in distribution of phases formulated in the theorem 2 really takes place if the device is macroscopic and chaotic with unstable initial state. Indeed, randomness of phase appears from randomness of energies (eigenvalues of Hamiltonian) in quantum chaotic systems [8].

It is worth to note that though Eq. (48) is relevant with a split-hair accuracy it is only assumption with respect to (45). There from it is often concluded that the given above proof is FAPP. It means that it is only difficult to measure quantum correlations practically. Actually they continue to exist. Hence, in principle they can be measured. It is, however, absolutely untrue. Really, from Poincare’s theorem about returns follows that the system will not remain in the mixed state (48), and should return to the initial state (43). It is the result of the very small corrections (quantum correlation) which are not included to (48). Nevertheless, the system featured here $|\alpha_{i,s}\rangle$ corresponds to the introspection case, and consequently, it is not capable to observe experimentally these returns in principle (as it was shown above in resolution of Poincare and Losshmidt paradoxes). Hence, effects of these small corrections exist only on paper in the coordinate time of ideal dynamics, but it cannot be observed experimentally with respect to thermodynamic time arrow of observable dynamics of the macroscopic device. So, we can conclude that Daneri-Loinger-Prosperi theorem actually results in a complete resolution (not only FAPP!) of the reduction paradox in principle. It proves impossibility to distinguish experimentally the complete and incomplete reduction.

The logic produced here strongly reminds Maccone’s paper [4]. It is not surprising. Indeed, the pass from (43) to (48) corresponds to increasing of microstates number and entropy growth. And the pass from (48) in (43) corresponds to the entropy decrease. Accordingly, our statement about experimental unobservability to remainder quantum correlation is equivalent to the statement about unobservability of the entropy decrease. And it is proved by the similar methods, as in [4]. The objection [6] was made against this paper. Unfortunately, Maccone could not give the reasonable replay [28] to this objection. Here we will try to do it ourselves.

Let’s define here necessary conditions.

Suppose $A$ is our device, and $C$ is the measured quantum system.

The first value, the mutual entropy $S(A:C)$ is the coarsened entropy of ensemble (received by separation on two subsystems) excluding the ensemble entropy. As the second excluding term is constant, so $S(A:C)$ describes well the behavior of macroentropy in time:

$$S(A:C) = S(\rho_A) + S(\rho_C) - S(\rho_{AC})$$

where $S = -tr(\rho \ln \rho)$.

The second value $I(A:C)$ is the classical mutual information. It defines which maximum information about measured system ($F_j$) we can receive from indication of
instrument \((E_i)\). The more correlation exists between systems, the more information about measured system we can receive:

\[
I(A:C) = \max_{E_i} \otimes F_j H(E_i; F_j),
\]

where

\[
H(E_i; F_j) = \sum_{ij} p_{ij} \log p_{ij} - \sum_i p_i \log p_i - \sum_j q_j \log q_j,
\]

\(p_i = \sum_i P_{ij}\) and \(q_j = \sum_j P_{ij}\) - given POVMs (Positive Operator Valued Measure) \(E_i\) and \(F_j\) for A and C, respectively.

Maccone [4] proves an inequality

\[
S(A:C) \geq I(A:C)
\]

(49)

He concludes from it that entropy decrease results in reduction of the information (memory) about the system \(A+C\) and \(C\).

But (49) contains an inequality. Correspondingly in [6] an example of the quantum system of three qubits is supplied. For this system the mutual entropy decrease is accompanied by mutual information increases. It does not contradict to (49) because mutual entropy is only up boundary for mutual information there.

Let’s look what happens in our case of the macroscopic device and the measured quantum system

Before measurement (43)

\[
S(A:C) = - \sum_s p_s \log p_s + 0 + \sum_s p_s \log p_s = 0
\]

\(E_i\)-corresponds to the set \(|\alpha_{0,s}\rangle, F_j-|\psi_s\rangle\)

\[
I(A:C) = - \sum_s p_s \log p_s + 0 + \sum_s p_s \log p_s = 0 = S(A:C)
\]

In the end of measurement from (48)

\[
S(A:C) = - \sum_s |c_i|^2 \log |c_i|^2 - \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s + \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s = - \sum_s |c_i|^2 \log |c_i|^2
\]

\(E_i\)-corresponds to the set \(|\alpha_{i,s}\rangle, F_j-|\psi_j\rangle\)

\[
I(A:C) = - \sum_s |c_i|^2 \log |c_i|^2 - \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s + \sum_{s,i} |c_i|^2 p_s \log |c_i|^2 p_s =
\]

\[- \sum_s |c_i|^2 \log |c_i|^2 = S(A:C)
\]

Thus, our case corresponds to

\[
S(A:C) = I(A:C)
\]

(50)

in (49). No problems exist for our case. It is not surprising – the equality case in (49) corresponds to macroscopic chaotic system. The system supplied by the objection [6] is not macroscopic. It demonstrates the widely known fact that such thermodynamic concepts as the thermodynamic time arrows, the entropy increase and the measurement
device concern to macroscopic chaotic systems. Both the paper [6] and the subsequent paper [7] describe not thermodynamic time arrows but, mainly, strongly fluctuating small systems. No thermodynamics is possible for such small systems as three cubits. The useful outcome of these papers is equality (50). It can be used as a measure for macroscopicity of chaotic quantum systems. On the other hand, the difference between mutual information and mutual entropy can be a criterion of fluctuations value.

The paper of David Jennings, Terry Rudolph “Entanglement and the Thermodynamic Arrow of Time” is very interesting. However, the Thermodynamic Arrow of Time is not applicable for microsystems. It is a nice paper about quantum fluctuation, but not a paper about Thermodynamic Arrow of Time. In the Abstract of the paper, “Entanglement and the Thermodynamic Arrow of Time” the authors write, “We examine in detail the case of three qubits, and also propose some simple experimental demonstrations possible with small numbers of qubits.” However, no thermodynamics is possible for such a microsystem. D. Jennings and T. Rudolph (like Maccone) do not understand that category “thermodynamic arrow of time” is correct only for large macrosystems. Using these categories for small fluctuating systems has no physical sense. They also (like Maccone) use incorrect definition of macroscopic thermodynamic entropy. We also give (instead of Maccone) the correct reply to “Comment on “Quantum Solution to the Arrow-of-Time Dilemma”. The correct reply is that no contradictions (found in this Comment) appear for macroscopic systems. Only for a microscopic system, such contradictions exist. However, the concepts “the Thermodynamic Arrow of Time” and “the entropy growth law” is not relevant for such systems. We illustrate this fact by consideration of a quantum chaotic macrosystem and demonstrate that no contradiction (found by David Jennings, Terry Rudolph for a microscopic system) exists for this correct thermodynamical case. It must be mentioned that big size of a system (quantum or classic) is also not an enough condition for a system to be macroscopic. The macroscopic system (considered in Thermodynamics) must also be chaotic (quantum or classic) and has small chaotic interaction with its environment/observer resulting in decoherence (for quantum mechanics) or decorrelation (for classical mechanics). It should be also mentioned that thermodynamic-like terminology is widely and effectively used in quantum mechanics, quantum computers field, and information theory. The big number of the examples we can find in the references of Jennings and Rudolph’s paper. The other nice example is Shannon’s entropy in information theory. However, usually an author (using such a thermodynamic-like terminology) does not consider such a paper as analysis of classical Thermodynamics. Contrarily Jennings and Rudolph “disprove” the second law of Thermodynamics on the basis of the irrelevant microscopic system (in their Comment) and give (also in this Comment) the announcement of their next paper “Entanglement and the Thermodynamic Arrow of Time” as a correct consideration and a disproof of the second law.
4. Conclusion

In this paper, we present the analysis of thermodynamic time arrow in quantum mechanics. It is in many aspects similar to the classical case. The important difference of quantum systems from classical ones is that one microstate in quantum mechanics can correspond not to one macrostate but to a set of macrostates. It is referred to as quantum superposition of macrostates. For this case, considering thermodynamic time arrow by means of the decoherence theory gives resolution of the quantum paradoxes. These paradoxes relate to a wave packet reduction (collapse).

Appendix A. Unperturbative observation in quantum and classical mechanics

It is often possible to meet a statement that in classical mechanics, in principle, it is always possible to organize unperturbative observation. On the other hand, in quantum mechanics interaction of the observer with the observable system at measurement is inevitable. We will show that both these statements are generally untrue.

Let us first define the nonperturbative observation [10-11, 30-31] in QM. Suppose we have some QM system in a known initial state. This initial state can be either a result of some preparation (for example, an atom comes to the ground electronic state in vacuum after long time) or a result of a measurement experiment (QM system after measurement can have a well-defined state corresponding to the eigenfunction of the measured variable). We can predict further evolution of the initial wave function. Therefore, in principle we can make further measurements choosing measured variables in such a way that one of the eigenfunctions of the current measured variable is a current wave function of the observed system. Such measuring process can allow us the continuous observation without any perturbation of the observed quantum system. This nonperturbative observation can be easily generalized for the case of a known mixed initial state. Really, in this case the measured variable at each instant should correspond to such set of eigenfunctions that the density matrix in representation of this set at the same instant would be diagonal.

For example, let us consider some quantum computer. It has some well-defined initial state. An observer that known this initial state can in principle make the nonperturbative observation of any intermediate state of the quantum computer.

It is especially worth to note that such unperturbative observation is possible only under condition of a known initial state. However, an observer that does not know the initial state cannot make such observation because he cannot predict the intermediate state of the quantum computer.

Let us consider now classical mechanics. Suppose that a grain of sand lies on a cone vertex. The grain of sand has infinitesimally small radius. The system is in the Earth field of gravity. Then attempt to observe system even with infinitesimal perturbation will lead to misbalance with the indefinite future through a terminating interval of time. Certainly, the reduced example is exotic – it corresponds to a singular potential and an infinitesimal object. Nevertheless, similar strongly labile systems are good classical analogues of quantum systems. Among them, it is possible to search for analogies of
quantum systems and quantum paradoxes. Let us introduce a requirement that classical measuring renders very small but not zero perturbation on measured system. Therefore, it is possible to lower requirements to a singularity of these systems.

Very often examples of "purely quantum paradoxes" can be met which do not ostensibly have analogy in classical mechanics. One of them is Elitzur-Vaidman paradox \[29\] with a bomb, which can be found without its explosion:

Suppose that the wave function of one light quantum branches on two channels. In the end, these channels of the waves again unite, and there is an interference of the two waves of probability. A bomb inserted into the one from the two channels will destroy the process of interference. Then it allows us to discover the bomb even for a case when the light quantum would not detonate it, having transited on other channel. (The light quantum is considered capable to detonate the bomb)

Classical analogy of this situation is the following experiment of classical mechanics:

In one of the channels where there is no bomb we throw in a macroscopic beam of many particles. In other channel where, maybe, there is the bomb, we will throw in simultaneously only one infinitesimally light particle. Such particle is not capable to detonate the bomb but it may be thrown back out of it. If the bomb is not present the particle will transit the channel. On the exit of this channel for the bomb, we will arrange the cone featured above with the grain of sand with infinitesimal radius on the cone vortex. If our infinitesimally light particle would throw down the grain of sand from the vertex, it means that the bomb is not present. If the grain of sand would remains on the vertex after exit of particles beam from the second channel it means that the bomb is present.

In the given example, infinitesimally light particle is an analogue of an "imponderable" wave function of the light quantum. However, the light quantum is sensitive to behaviour of this "imponderable" wave function. Equally, the grain of sand with infinitesimal radius on the cone vertex is sensitive with respect to infinitesimally light particle.

Summing up, it is possible to say that the difference between quantum and classical systems is not as fundamental as it is usually considered.

Application B. Expansion on modes at arbitrary boundary conditions

Encountered quite often is a problem of description of radiation in a closed cavity filled by some substance. Usually it appears by decomposition of radiation on modes. These modes are a set of eigenfunctions of the wave equation for some cavity and for some boundary conditions. For example, it is a square cavity with periodical boundary conditions. Then the received radiation decomposition is substituted to the wave equation for radiation. There the modes of the series are differentiated termwise. Thus, such radiation feature as \(\omega(\vec{k})\) is received. Here \(\omega\) is frequency of a mode; \(\vec{k}\) is a mode wave vector; \(|k| = 2\pi/\lambda\); \(\lambda\) is a mode wave length.

But here there is a purely mathematical problem. Suppose that the modes have been discovered for some shape of the cavity and for some boundary conditions. For termwise differentiability uniform convergence in all points of space is required. It is automatically true for any radiation with the same shape of a concavity and boundary conditions.
conditions as modes. But for any other case it is not true. Modes are the full orthogonal set and any radiation may be presented as superposition of such modes. But generally the series converges nonuniformly (the series converges badly near cavity boundaries) and cannot be termwise differentiable. The problem of possible necessity using different modes for different boundary conditions is discussed in Peierls's book \[32\]. However, a case is considered there when some complete orthonormal set of modes exists for given boundary conditions. But the situation is possible that for such boundary condition no set of such modes is possible. Or the boundary conditions are not known, and only energy requirements on boundary are known. How can the problem be solved for such cases?

The point is that all perturbations in radiation are expanding with a velocity which is not exceeding the speed of light in cavity \(v=c\). It means that any perturbation of initial conditions of radiation expands from a point \(x\) to a point \(x_1\) only over finite time \((x-x_1)/c\). It means that perturbations from walls will reach the center of the cavity in time \(t=L/c\) where \(L\) is a characteristic size of the cavity. Non-uniform convergence appears only near the cavity walls. So inside the cavity far from walls the exact radiation field is almost precisely equal to the modes series during time \(L/c\). Therefore, this field has uniform convergence and can be termwise differentiable during time \(L/c\).

To estimate correctly frequency of a mode \(\omega(\vec{k})\) it is necessary that its amplitude does not change essentially from walls perturbation over time \(t \gg T\). \(T=2\pi/\omega(\vec{k})\) is time period of the mode. There from we receive the requirement of cavity macroscopicity:

\[
\frac{2\pi}{\omega} \ll \frac{L}{c}
\]

or

\[L \gg 2\pi \left(\frac{c}{\omega}\right)\]

\(\omega\) - correspondent to maximum of frequencies \(\omega(\vec{k})\).

Let suppose that this condition is fulfilled.

It means that termwise differentiation of modes far from concavity walls can be made over timescales \(t<2\pi/\omega=L/c\)

On timescales \(t>L/c\) the outcome cannot be correct. Here the energy conservation law and the entropy increase law are usually used. By means of these laws slow evolution of amplitudes \(A(t, \vec{r})\) and phases \(\phi(t, \vec{r})\) of modes can be received:

\[
E(t, \vec{r}) = \sum_i A_i(t, \vec{r}) \sin \left(\omega(\vec{k}_i) t + \vec{k}_i \vec{r} + \phi(t, \vec{r})\right)
\]

For vacuum:

\[
\omega(\vec{k}) = c |\vec{k}|
\]

\[L \gg \lambda\]
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Chapter 3. The Universal Arrow of Time: Nonquantum gravitation theory

Abstract: Solution of “informational paradox” for black holes and “paradox with the grandfather” for time travel “wormholes”

The paper is dealing with the analysis of general relativity theory (theory of gravitation) from the point of view of thermodynamic time arrow. Within this framework, “informational paradox” for black holes and “paradox with the grandfather” for time travel “wormholes” are resolved.

1. Introduction

In this paper we consider a thermodynamic time arrow [1-2] (defined by a direction of the entropy increase) within the limits of the non-quantum relativistic gravitation theory. In the classical Hamilton mechanics, any initial and final states are possible. Besides, there is one-to-one correspondence between them. The situation is different with relativistic theory of gravitation. There are topological singularities of space, which make possible a situation when for finite time different initial states give an identical final state. It is a collapse of black holes. On the other hand, having considered inverse process in time - white holes, we receive a situation when a single initial state can give a set of different final states for a finite time. There are also situations of other sort when non-arbitrary initial states are possible. It is a case of ”wormholes” through which it is possible to travel to the past. Thus, there is necessity of self-consistency between the past and the
future making impossible some initial states. Black Holes lead to informational paradox, and "wormholes" lead to “paradox with the grandfather”. Analysis of these situations from a point of view of thermodynamical time arrow and resolution of the defined above paradoxes are a topic of this paper.

2. Black Hole

In modern cosmological models, there are some phenomena additional to those featured in classical mechanics. In Einstein’s relativity theory, as well as in classical mechanics, motion is reversible. However, there is also an important difference from classical mechanics. It is ambiguity of a solution of an initial value problem: deriving a final state of a system from the complete set of initial and boundary conditions can give multiple solutions or no solution. In general relativity theory, unlike classical mechanics, two various states for finite time can give infinitesimally close states. It happens at formation of a black hole because of a collapse. Hence, formation of the black hole goes with its entropy increase.

Let us consider an inverse process featuring a white hole. In this process, infinitesimally close initial states for finite time can give different terminating states. Time reversion leads to appearing of a white hole and results in entropy decrease. The white hole cannot exist in a reality because of the same reasons on which processes with entropy decrease are impossible in classical mechanics.

However, its instability is much stronger than instability in classical mechanics. It has finite value in respect to infinitesimally small perturbations. Consequently, there are alignment of thermodynamic time arrows between the white hole and the observer/environment. The white hole transforms to a black hole for the observer. It means that the observer/environment even infinitesimally weakly interacting with the white hole can affect considerably its evolution for finite time. Thus, the gravitational interaction of the observer/environment with the white hole is always different from zero.

There is a well-known informational paradox here: the collapse leads to losses of the information in the Black Hole. It, in turn, results in incompleteness of our knowledge of a state of system and, hence, to unpredictability of dynamics of system, including Black Hole. The information, which in classical mechanics always conserves in a black hole, disappears forever. Is it really so? Alternatively, probably, it is stored in some form inside of a black hole? Usually only two answers to this problem are considered: either the information really vanishes completely; or the information is stored inside and can be extracted by some way. However, most likely, the third answer is true. Because of inevitable influence of the observer/environment, it is impossible to distinguish these two situations experimentally in principle! In addition, if it is impossible to verify something experimentally, it cannot be a topic for the science.

Actually, suppose that the information is stored in a black hole. Is it possible to resolve informational paradox and to extract this information from it? Perhaps, we can reverse a collapsed black hole, to convert it into a white hole and to extract the disappeared
information? It would seem impossible. Recently an interesting paper appeared which seems allowing to make it, although indirectly [4]. It is proved that a black hole is completely equivalent to an entry to a channel coupling two Universes, and an entry of this channel is similar to the black hole, while an exit is similar to the white hole. This white hole can be considered, in some sense, as a reversed black hole. However, to verify that the information does not disappear we should come into the second Universe. To do it, we need to suppose that there is some “wormhole” which connects these two Universes. Let assume that the observer can pass it and observe the white hole. However, even if it happens, we know that the white hole is extremely unstable with respect to any observation. Attempts to observe it will result in its transformation into a black hole. It will close any possibility to verify that the information is stored. Hence, both solutions of informational paradox are really equivalent and observationally are not distinguishable.

This property of irreversible information losses results in the fact that the entropy increase law turns to be an exact law of the nature within framework of the gravitational theory. Really, here appears such a new fundamental value as entropy of a black hole. It distinguishes gravitational theory from classical mechanics where the entropy increase law has only approximate character (FAPP, for all practical purposes).

The accelerated expansion of the Universe results in the same effect of irreversible information losses: there are unobservable fields, whence we are not reached even by light. Hence, these fields are unobservable, and the information stored in them is lost. Once again, it results in unpredictability of relativistic dynamics.

3. Time wormhole

Let us consider from the point of view of the entropy such a paradoxical object of general relativity theory as time “wormhole” [5]. At first, we will consider the most popular variant offered by Morris and Thorne [6]. Suppose we have a space wormhole with the extremities lying nearby. By a very simple procedure (we will place one of the extremities on a spaceship and move it with a speed close to the speed of light, and then we will return this extremity on the former place) this space wormhole can be conversed into a time wormhole (wormhole traversing space into one traversing time). It can be used as a time machine. Such wormhole demands the special exotic matter necessary for conserving its equilibrium. However, there were models of a time machine, which allow dispensing absolutely without the exotic substance [7, 9]. Alternatively, using an electromagnetic field, allow dispensing by its small amount [8]. Use of such a time machine can lead to the well-known “paradox of the grandfather” when the grandson, being returned in the past, kills his grandfather. How can this paradox be resolved?

From the physical point of view, the paradox of the grandfather means that not all initial states, which exist before time machine formation, are realizable. Introducing the additional feedback between the future and the past, a time wormhole makes them impossible. Hence, we either should explain non-reliability of such initial states, or suppose that time “wormhole” is unstable, like a white hole, and easily changes.
Curiously enough, but the both explanations are true. However, for macroscopic wormholes the first explanation has priority. Really, it would be desirable very much to have a macroscopic topology of the space to be stable. Constrains on initial states appears from entropy increase law and the corresponding alignment of thermodynamic time arrows related to instability of states with opposite directions of these time arrows [1-2]. However, macroscopic laws of thermodynamics are probabilistic. For a very small number of cases they are not correct (large-scale fluctuations). Both for these situations and for microscopic wormholes where the concept of a thermodynamic time arrows and thermodynamics laws are not applicable, the second explanation will have priority. It is related to extreme instability of the topology, which is defined by the time machine [9]. We discussed above such type of extreme instability for white holes. For macroscopic wormholes, the solution can be discovered by means of the entropy increase law. It is ensured by instability of processes with the entropy decrease with respect to the Universe.

This instability results in alignment of thermodynamic time arrows.

Indeed, a space wormhole does not lead to a paradox. The objects immersed by its one extremity will go out of the other extremity during later time. Thus, the objects from a more normalized low-entropy past occur in a less normalized high-entropy future. During the motion through the wormhole, the entropy of the travelling objects also increases: they transfer from a more normalized state into a less normalized one. Thus, the time arrows of the object travelling inside of the wormhole, and the time arrow of the world around the wormhole would have the same directions. It is also true for travelling through the time wormhole from the past to the future.

However, for travelling from the future to the past of the time arrow directions of the traveller into the wormhole and the world around the wormhole will already be opposite [10, 11-13]. Really, the object travels from the less normalized future to the more normalized past but its entropy increases, instead of decreasing! Hence, thermodynamic time arrows of the Universe and of the traveller will have opposite directions. Such process at which entropies of the traveller decreases concerning the Universe are unstable [1-2]. Hence, “memory about the past” of the traveller will be destroyed (and, may be, he will be destroyed completely), what will not allow him “to kill the grandfather”.

Which mechanism at travelling in the wormhole ensures alignment of thermodynamic time arrows of the traveller and the Universe? Both extremities of a “wormhole” are large bodies having some finite temperature. Both extremities under the second thermodynamics laws inevitably should radiate light, which partially penetrates into the wormhole. Already at the moment of formation of a “time machine” (transformation of the space wormhole into the time one), a closed light ray appears between its extremities. Every time when the ray spins a circle, it gets more and more biased to a violet part of the spectrum. Passing a circle after circle, rays are lost their focal point; therefore, energy does not get amplified and does not become infinite. The violet bias means that the history of a particle of light is finite and defined by its coordinate time, despite the infinite number of circles [14]. This and other rays of light in the wormhole fluctuate. They also have a direction of its thermodynamic time arrow coinciding with a thermodynamic time
arrow of the Universe. Thanks to the inevitable interaction with this radiation, a very unstable state of the traveller is destroyed. The state of the traveller is unstable because his thermodynamic time arrow is opposite to the Universe thermodynamic time arrows. The resulting destruction is enough to prevent the paradox of the grandfather.

“Free will” would allow us to initiate freely only irreversible processes with the entropy increase, but not with its decrease. Thus, we cannot send an object from the future to the past. Process of alignment of thermodynamic time arrows and the correspondent entropy increase law forbids the **initial conditions** necessary for travelling of the macroscopic object to the past and resulting in the “paradox of the grandfather”.

In paper [10], it is strictly mathematically proved that the thermodynamic time arrow cannot have identical orientation with the coordinate time arrow during all travel over a closed timelike curve. Process of alignment of thermodynamic time arrows (related to instability of processes with entropy decrease) is this very **physical mechanism**, which actually ensures performance of the entropy increase law.

Macroscopic laws of thermodynamics are probabilistic. For a very small number of cases they do not work (large-scale fluctuations). Both for these situations and for microscopic systems where thermodynamics laws are not applicable, the other explanation of the grandfather paradox will have priority. In this case, the time wormhole, like a white hole, appears unstable even with respect to infinitesimally weak perturbations from gravitation of travelling object. It can result in its fracture and prevention of the paradoxes, as is proved strictly in [9]. What are outcomes of reorganization of the space-time topology after fracture of the time wormhole? The author of [9] writes:

“As we argue ... non-uniqueness does not let the time travel paradoxes into general relativity — whatever happens in a causal region, a space-time always can evolve so that to avoid any paradoxes (at the sacrifice of the time machine at a pinch). The resulting space-times sometimes ... curiously remind one of the many-world pictures”.

Let us formulate the conclusion: for macroscopic processes, instability of processes with the entropy decrease and correspondent alignment of thermodynamic time arrows makes existence of initial conditions that allow travel to the past to be almost impossible. Thereby it prevents both wormholes fracture and travelling of macroscopic bodies in the past leading to the “paradox of the grandfather”.

For very improbable situations of macroscopic wormholes and for microscopic wormholes the wormhole fracture must occur. This fracture is a result of a remarkable property of general relativity theory – extreme instability: infinitesimal external action (for example, gravitation from traveller) can produce wormhole fracture for finite time!

4. Conclusions

Let us summarize the said above. A process of observation should be inevitably taken into account when examining any physical process. We must transform from ideal dynamics over coordinate time arrow to observable dynamics with respect to thermodynamic time arrow of observer. It allows us to exclude all unobservable in the reality phenomena
leading to paradoxes. Thus, it is necessary to consider the following things. The observer inevitably is a non-equilibrium macroscopic chaotic body with the thermodynamic time arrow defined by his entropy increase direction. He yields all measurements with respect to this thermodynamic time arrow. Dynamics of bodies with respect to this thermodynamic time arrow is referred to as observable dynamics. It differs from ideal dynamics, with respect to the coordinate time arrow. All bodies are featured in observable dynamics in macroparameters, unlike in the ideal dynamics where microparameters are used. The coordinate does not exist at thermodynamic equilibrium. It can change the direction and does not coincide with the coordinate time arrow of the ideal dynamics. There is always a small interaction between the observer and observable system. It leads to alignment of thermodynamic time arrows of the observer and the observable systems.

We can see a mysterious situation. The same reasons, which have allowed us to resolve paradoxes of wave packet reduction in quantum mechanics, paradoxes of Loshmidt and Poincare in classical mechanics allow to resolve the informational paradox of black holes and the paradox of the grandfather for time wormholes. It is remarkable universality!

References


Chapter 4. The Universal Arrow of Time: Quantum gravitation theory

Abstract: Solution of “informational paradox” for black holes, “paradox with the grandfather” for time travel “wormholes”, black stars paradox, Penrose’s project of new quantum gravitation theory paradoxes, anthropic principle paradox.

The paper is dealing with the analysis of quantum gravitation theory from the point of view of thermodynamic time arrow. Within this framework “informational paradox” for black holes and “paradox with the grandfather” for time travel “wormholes”, black stars, Penrose’s project of new quantum gravitation theory, anthropic principle are considered.

1. Introduction

The paper includes the analysis of quantum gravitation theory from the point of view of the thermodynamic time arrow [1-3]. Within this framework, “informational paradox” for black holes and “paradox with the grandfather” for time travel “wormholes”, black stars [4] and anthropic principle [5] are considered. It is shown that wishes of Penrose [6-7] for the future theory of quantum gravitation need not creation of a new theory but can be realized within framework of already existing theories by means of the thermodynamic approach.

2. Black holes

In general relativity theory, unlike in classical mechanics, two different states for finite time can give infinitesimally close states. It happens during formation of a black hole because of its collapse. It results in the well-known informational paradox [8]: the collapse leads to losses of the information in the black hole. It results in incompleteness of our knowledge of the system state. Hence, it can leads to unpredictability of the system dynamics. The information, which in classical and quantum mechanics is always conserved, disappears in a black hole. Is it really so? Usually only two answers to this problem are considered: either the information really vanishes completely, or the information is conserved inside the black hole and can be extracted. We will see that in quantum gravitation, we have the same answer, as in general relativity theory – both answers are possible and true because the difference is not observed experimentally.

For the semi-classical theory of gravitation where gravitation is featured by relativistic relativity theory and fields are featured by quantum field theory, resolution of the paradox is made with the help of Hawkingradiation.
In quantum field theory, the physical vacuum is filled by permanently appearing and disappearing “virtual particles”. Close to the event horizon (but nevertheless outside it) of a black hole, pairs of particle-antiparticle can be born directly from vacuum. A situation is possible when an antiparticle total energy appears to be subzero, and a particle total energy appears to be positive. Falling to the black hole, the antiparticle reduces its total energy and mass while the particle is capable to fly away to infinity. For a remote observer it looks like Hawking radiation of the black hole.

Since this radiation is incoherent, all information accumulated inside of it disappears after evaporation of the black hole. It is an answer of the semi-classical theory. It would seem that this result contradicts to reversibility and unitarily of quantum mechanics where the information cannot be lost. We would expect the same result from quantum gravitation theory. However, is it really so?

We do not have now a finished theory of quantum gravitation. However, for a special case of the 5-dimensional anti-de-Sitter space this paradox is considered by many scientists to be resolved. The information is supposed to be conserved, because a hypothesis about AdS/CFT dualities, i.e. hypotheses that quantum gravitation in the 5-dimensional anti-de-Sitter space (that is with the negative cosmological term) is equivalent mathematically to a conformal field theory on a 4-surface of this world [9]. It was checked in some special cases but not proved yet in a general case.

Suppose that if this hypothesis is really true, it automatically solves the problem of information. The matter is that the conformal field theory is structurally unitary. If it is really dual to quantum gravitation then the corresponding quantum gravitation theory is unitary too. Therefore, the information in this case is not lost.

Let us note that it not so. Taking into account the influence of the observer makes information losses inevitable. The process of black hole formation and its subsequent evaporation happens overall surface of the anti-de-Sitter world (described by the conformal quantum theory) which includes the observer as well. The observer inevitably gravitationally interacts with the black hole and its radiation. Unlike to the conventional quantum mechanics, all-pervading gravitational interaction exists in quantum gravitation. So, influence of the observer already cannot be made negligibly small under any requirements. Interaction with the observer makes the system not unitary, similarly to the semi-classical case.

It would seem that we could solve the problem by including the observer in the description of the system. However, the observer cannot precisely know the initial state and analyze the system when he is its part! Therefore, he cannot experimentally verify the difference between unitary and not unitary evolution. It is necessary to have complete knowledge of the system state for such verification. However, it is impossible at introspection.

In the anti-de-Sitter world Universe, expansion is inevitably replaced by a collapse. However, the same effect information losses are available also for the accelerated expansion of the Universe - there appear unobservable parts of Universe, whence we are not reached even by light. Hence, these parts are unobservable, and the information containing in
them is lost. It again results in unpredictability.

Thus, the experimental verification of the informational paradox becomes impossible in principle again! In case of quantum gravitation information, conservation happens only on paper in the ideal dynamics. In the real observable dynamics the difference is not observed experimentally in principle. It is possible to consider both answers to the problem to be correct. The two cases of conservation or non-conservation of information are not distinguishable experimentally.

Principal difference between the conventional quantum theory and quantum gravitation theory occurs because of inevitable gravitational interaction. In usual quantum theory interaction between an observer and an observed system can be made zero in principle at known initial conditions of the observed system. In quantum gravitational systems, the small gravitational interaction with the observer is irremovable in principle: it creates principally inherent decoherence and converts evolution of any observable system into non-unitary. Only the non-observable ideal evolution on paper can be made formally unitary. However, it is also possible not to make it unitary – here we have freedom to choose. If we wish to feature real observable dynamics, we can put the dynamics to be non-unitary. For macrobodies, such observable dynamics is quasi-classical theory. It is experimentally indistinguishable for the real macroscopic observer from unitary quantum gravitation dynamics of large black holes.

3. Time wormhole

Let us consider from the point of view of the entropy such a paradoxical object of general relativity theory as time “wormhole” [10]. At first, we will consider the most popular variant offered by Morris and Thorne [11]. Suppose we have a space wormhole with the extremities lying nearby. By a very simple procedure (we will place one of the extremities on a spaceship and move it with a speed close to the speed of light, and then we will return this extremity on the former place) this space wormhole can be conversed into a time wormhole (wormhole traversing space into one traversing time). It can be used as a time machine. Such wormhole demands the special exotic matter necessary for conserving its equilibrium. However, there were models of a time machine, which allow dispensing absolutely without the exotic substance [12, 17]. Or, using an electromagnetic field, allow dispensing by its small amount [13]. Use of such a time machine can lead to the well-known “paradox of the grandfather” when the grandson, being returned in the past, kills his grandfather. How can this paradox be resolved?

Let us consider that the answer to this problem is given by the semi-classical theory of gravitation. Suppose that the macroscopic topology of the space related to the time machine is unchanged. At the moment of the time machine formation (transformation of the space wormhole into time one) between its extremities, there is a closed light ray. Its energy does not reach infinity, despite the infinite number of passes, because of a defocusing of the light [16]. Another situation, however, arises in the semi-classical theory with a radiation field of “vacuum fluctuations” [14]. Passing the infinite number
of times through the wormhole and being summed with each other, these fluctuations reach the infinite energy, which will destroy any traveller.

However, the situation in quantum gravitation is different. Quantum fluctuations contain large energies when they arise on short distances. Therefore, it is possible to find so small distance on which energy of fluctuation will be large enough for formation of a tiny black hole, and the horizon of this tiny black hole will have the same size as this small distance. The space-time is not capable to remain homogeneous on such short distances. This mechanism ensures natural “blocking” of singular fluctuations formation, restricting them in their sizes: “maximum energy in minimal sizes” [16].

Detailed calculations of quantum gravitation show [15] that this “blocking” to formation of singular fluctuations provides a very small but not a zero probability of unobstructed transiting through a time “wormhole” for macroscopic object. How can the “paradox of the grandfather” be prevented in this situation? Here it is convenient for us to use the language of the multi-world interpretation of quantum mechanics. To prevent this paradox, the traveller should penetrate into the parallel world where it can easily “kill the grandfather” without breaking a causality principle. Such a parallel world will interfere quantum-mechanically with the worlds of the “not killed grandfather” where the observer was unsuccessful to transit the time wormhole. However, the probability amplitude of such the world will be extremely small. Can the observer in the world where “the grandfather is not killed” discover the alternative world at least in principle, using quantum correlations between the worlds? Similarly to “paradox of the Schrödinger cat, he cannot do it because of the same reasons as in the conventional quantum mechanics [2]. Observation of large effects of quantum correlations is impossible because of “observer’s memory erasing” [1-2]. Penetration to the parallel world of quantum mechanics is experimentally indistinguishable from the time wormhole fracture and penetration to the parallel world of general relativity theory [3, 17]. It means that from the point of view of the external real macroscopic observer a situation when the traveller has perished in the wormhole or has penetrated in “another world” is observationally indistinguishable. It is equivalent to a situation when the traveller falls into a black hole. We do not know whether he is crushed in the singularity or penetrated into “the other world” through the white hole [18]. (Although this difference is observed and essential for the traveller. However, he will carry away all these observations with himself into “the other world”.) We see that as well as in a case of “informational paradox”, the difference between quantum and semi-classical theories for macroscopic objects experimentally is not observed for the macroscopic observer, which is not travelling in the time wormhole.

4. Black stars

Recently an interesting theory of “black stars” appeared [4]. Usually a collapse of a black hole is considered as a fast process. However, we do not know well states of the matter under high pressures. We know that intermediate stages such as white dwarfs or neutron stars are possible before a black hole collapse. These intermediate stages make
a collapse not avalanche-like but gradual. Probably, additional intermediate stages will appear on the way to a collapse, for example, quark stars. These intermediate stages make this process to be gradual without a fast collapse at all. For classical gravitation, it is incidental. The star becomes a black hole for gradual process too. However, for semi-classical gravitation it is important. It can be shown that for such case at slow squeezing quantum fluctuations at a surface will prevent a star material to collapse to a singularity and to become a black hole. Outside, this object would be similar to a black hole but inside it would be different, conserving all information without singularity. It will allow a traveller to penetrate through its surface and to come back. It is worth to note that there is a considerable objection against such picture.

How stable is such construction of a star with respect to the external perturbation imported by the traveller? Also how stable is the traveller during such travel? The traveller is a macroscopic body. After penetration to a black star, he will increase its mass stepwise at finite value. It can results in its collapse to a black hole. Suppose that the process again goes “gradually” without collapse. Then the traveller “would be dissolved” into the star and cannot come back as well. Thus, it seems that the difference between a black star and a black hole cannot be observed experimentally. Therefore, it means that the difference between these objects exists only on paper, i.e. in ideal dynamics.

5. **Penrose’s project of new quantum gravity theory**

In his remarkable books [6-7] Penrose gives a remarkable prediction of the future theory of quantum gravitation. In this theory:

1) Unlike to usual quantum mechanics, wave packet reduction is a fundamental property of the theory.

2) This reduction is inseparably linked with the phenomenon of gravitation.

3) The reduction leads not only to probabilistic laws but can lead to some more complex uncertain behaviour that can not be predicted even by a probability law.

4) Unlike to remarkable coherent quantum systems, classical chaotic non-equilibrium systems are exposed to criticism. They are supposed to be not relevant for modelling of real complex systems. The unpredictable systems described above must be only pure quantum system.

It is worth to note that we need not a new theory for receiving all these properties. Let us take into account an inevitable gravitational interaction of the macroscopic real observer and his thermodynamic time arrow. It results in all described above outcomes within framework of already existing theories of quantum gravitation. Besides, classical chaotic non-equilibrium systems possess all properties of quantum ones. For any “purely quantum effect” it is always possible to discover such classical analogue (Appendix A [2]). Namely:

1) We saw above that an inevitable gravitational interaction of a macroscopic real observer with an unstable observable system inevitably makes evolution of the observable
system non-unitary. The difference between the unitary and non-unitary theory exists only on paper and is not observed experimentally in quantum gravitation theory.

2) Because of the reasons stated above the gravitation interaction results in the inevitable reduction and correspondent non-unitarity in framework of the current quantum gravitation theory. Moreover, for macroscopic objects the semiclassical theory is already possessing desirable fundamental property of non-unitary. It is experimentally equivalent to the quantum gravitation theory.

3) Behaviour of many macroscopic bodies, in spite of non-unitarity, can be described completely by a set of macroparameters and laws of their evolution. There are, however, unpredictable systems whose behaviour cannot be described completely even by probability laws.

For example, let us consider quantum computers. Suppose that some person started such a quantum computer and knows its initial state. Its behaviour is completely predicted by such person. However, for the second person who is not present at start, its behaviour is uncertain and unpredictable. Moreover, an attempt of the second person to observe some intermediate state of the quantum computer would result in destroying its normal operation.

In case of quantum gravitation, even the person who started quantum computer cannot predict its behaviour. Indeed, the inevitable gravitational interaction between the person and the quantum computer will make such prediction impossible. Thus, “the unpredictability which is distinct from a probability law” becomes a fundamental property of any quantum gravitation theory.

4) Unstable classical systems in many aspects remind on the properties of the quantum system (Appendix A [2]). Moreover, mathematical models of classical analogues of quantum computers exist [19]. Some paradoxical properties of the life objects reminding quantum computers can be modelled by classical unstable systems [20].

Summing up, we can see that all wishes of Penrose are realizable within the framework of the existing paradigm and there is no need in any new fundamental theory. Moreover, all properties of macroobjects are usually described by macroparameters to exclude influence of the macroscopic observer. That inevitably results in unobservability of too small intervals of time and space. Therefore, it is possible to construct their observable dynamics on basis of “discrete model of space-time”. However, such dynamics would not be a new theory. For any macroscopic observer the dynamics would be experimentally indistinguishable from the current quantum theory of gravitation.

6. Anthropic principle in quantum gravity theory

The number of possible vacuum states in quantum gravitation theory is equal to a very large value. For a selection of suitable vacuums, anthropic principle is usually used [5]. It means that evolution of the system should result in appearing an observer, which is capable to observe the Universe. However, such formulation is of too philosophical nature. It is difficult to use it in practice. We can formulate here more accurate physical
principles, which are equivalent to the anthropic principle:

The initial state of the Universe should result in formation of its substance in the form of a set of many macroscopic non-equilibrium objects weakly interacting with each other. These objects should have entropy and temperature. They should have thermodynamic time arrows. Small local interaction between objects should result in alignment of thermodynamic time arrows. Though these objects consist of many particles and are described by a huge set of microparameters, evolution of these objects can be described by a set of macroparameters, except for rare instable state.

However, these unstable states play an important role, forming a basis for origin of an observer in the Universe. There should be unstable global correlations between parts of the Universe and non-equilibrium macrosystems with local interior correlations, which are the origin of the observer.

We can conclude here: to get the situation described above, the initial state of the Universe should be highly ordered and posses the low entropy.

I.e., in short, evolution should result in the world that can be described in the thermodynamic form [1-3, 21-23]. Only such the world can be the origin of an observer who is capable to study this world.

7. Conclusions

We see that the informational paradox and the paradox of the grandfather are resolved in the quantum gravitational theory very similarly to those in the non-quantum general relativity theory. It is realized by consideration of weak interaction of systems with the real non-equilibrium macroscopic observer. Moreover, this approach (similarly to usual quantum theory) allows resolving the wave packet reduction problem. However, this reduction in quantum gravitation becomes a fundamental property of the theory, unlike in the case of conventional quantum mechanics. Such approach allows considering other complicated questions of quantum gravitation – anthropic principle, black stars.

References


Chapter 5. The Universal Arrow of Time: Unpredictable dynamics

Abstract: Solution of the paradox about contradiction between reductionism and principal (not defined by complexity) emergence on basis Gödel-like theorem; Solution of the paradox about the existence of the systems with entropy decrease.

We see that exact equations of quantum and classical mechanics describe ideal dynamics, which is reversible and leads to Poincare’s returns. Real equations of physics describing observable dynamics, for example, master equations of statistical mechanics,
hydrodynamic equations of viscous fluid, Boltzmann equation in thermodynamics, and the entropy increase law in the isolated systems are irreversible and exclude Poincare’s returns to the initial state. Besides, these equations describe systems in terms of macroparameters or phase distribution functions of microparameters. There are two reasons of such differences between ideal and observable dynamics. Firstly, there is uncontrollable noise from the external observer. Secondly, when the observer is included into described system (introspection) the complete self-description of a state of such full system is impossible. Besides, introspection is possible during finite time when the thermodynamic time arrow of the observer exists and does not change the direction. Not in all cases ideal dynamics broken by external noise (or being incomplete at introspection) can be changed to predictable observable dynamics. For many systems introduction of macroparameters that allow exhaustive describing of dynamics of the system is impossible. Their dynamics becomes unpredictable in principle, sometimes even unpredictable by the probabilistic way. We will refer to dynamics describing such system as unpredictable dynamics. As follows from the definition of such systems, it is impossible to introduce a complete set of macroparameters for unpredictable dynamics. (Such set of macroparameters for observable dynamics allowed predicting their behaviour by a complete way.) Dynamics of unpredictable systems is not described and not predicted by scientific methods. Thus, the science itself puts boundaries for its applicability. However, such systems can intuitively “understand itself” and “predict” the behaviour “of its own” or even “communicate with each other” at intuitive level.

1. Introduction

Let us give definitions of observed and ideal dynamics [1-4], and explain necessity of introduction of observable dynamics. We will refer to exact laws of quantum or classical mechanics as to ideal dynamics. Why have we named them ideal? Because for the most of real systems the entropy increase law or wave packet reduction in the quantum case are observed. These properties contradict with laws of ideal dynamics. Ideal dynamics is reversible and includes Poincare’s returns. It is not observed in irreversible observable dynamics. Where does this inconsistency between these kinds of dynamics come from?

The real observer is always a macroscopic system far from thermodynamic equilibrium. It possesses a thermodynamic time arrow of its own, which exists for a finite time (until the equilibrium is reached) and can change its direction. Besides, there is a small interaction of the observer with the observable system, which results in alignment of thermodynamic time arrows and, in case of quantum mechanics, in wave packet reduction.

The observer describes the observable system in terms of macroparameters and corresponding thermodynamic time arrow. It also results in the difference of observable dynamics and ideal dynamics. The ideal dynamics is formulated with respect to the abstract coordinate time in terms of microparameters.

Violations of ideal dynamics are related to either openness of measured systems (i.e. it can be explained by influence of environment/observer) or impossibility of self-measuring
at introspection (for the full closed physical systems including both the environment and
the observer). What is it possible to do for such cases? The real system is either open or
incomplete, i.e. we cannot use physics for prediction of the system evolution? Not at all!

Many of such systems can be described by equations of exact or probabilistic dynam-
ics, despite openness or incompleteness of description. We name it observable dynamics.
The most of equations in physics – master equations of statistical mechanics, hydrody-
namic equation of viscous fluid, Boltzmann equation in thermodynamics, and the entropy
increase law – are equations of observable dynamics.

To possess the property specified above observable dynamics should meet certain
requirements. It cannot operate with the full set of microvariables. In observable dy-
namics, we use much smaller number of macrovariables, which are some functions of
microvariables. It makes the dynamics much more stable with respect to errors of initial
conditions and external noise. Really, a microstate change does not result inevitably in
a macrostate change, as one macrostate is correspondent to a huge set of microstates.
For example, in case of gas such macrovariables are density, pressure, temperature and
entropy. Microvariables are velocities and coordinates of all its molecules.

How can we get observable dynamics from ideal dynamics? It can be got by either
insertion to equations of the ideal equations of small external noise, or insertion of errors
to an initial state. Errors/noise should be large enough to break effects unobservable in
reality. It is reversibility of motion or Poincare’s returns. On the other hand, they should
be small enough not to influence observable processes with entropy increase.

For the complete physical system including the observer, observable system and a
surrounding medium, Observable Dynamics is not falsifiable in Popper’s sense [36] (under
condition of fidelity of Ideal Dynamics). I.e. the difference between Ideal and Observable
Dynamics in this case cannot be observed in experiment.

However, there are cases when it is not possible to find any observable dynamics. The
system are unpredictable, because of either openness or description incompleteness. It is
a case of unpredictable dynamics [21, 29-33] considered here.

2. Unpredictable dynamics

Let us introduce the concept of synergetic models [10]. We will name so simple physical
or mathematical systems. Such systems illustrate in a simple form some real or supposed
properties of unpredictable and complex (living) systems.

Unpredictable systems, because of its unpredictability, are extremely unstable with
respect to external observation or thermal noise. To prevent their chaotization, they
should have some protection from external influence.

Therefore, we are mainly interested in synergetic models of systems that are capable
to protect itself from external noise (from decoherence in quantum mechanics). They con-
serve internal correlations (quantum or classical), resulting in reversibility or Poincare’s
returns. They also can conserve correlations with the surrounding world.
There are three methods for such protection:

(1) The passive method - creation of some "walls" or shells impenetrable for noise. It is also possible to keep such systems at very low temperatures. Many models of quantum computers may serve as an example.

(2) The active method, inverse to passive - complex dissipative or living systems, they conserve disequilibrium by the help of active interaction and interchanging of energy and substance with environment (metabolism). It is thought that the future models of quantum computers should correspond to this field.

(3) When correlations cover the whole Universe. The external source of noise is absent here. Origin of correlations over Universe is that Universe was in low entropy initial states. Universe appeared from Big Bang. We will name these correlations as global correlations. Sometimes it is figuratively named “holographic model of Universe”.

The following facts ought to be noted:

(1) Many complex systems during evolution pass dynamic bifurcation points when there are several alternative ways of future evolution. The selection of one of them depends on the slightest fluctuations of the system state in the bifurcation point [5-6]. In these points, even weak correlations can have huge influence on future. These correlations define one from alternative ways of future evolution specified above. Presence of such correlations restricts predictive force of the Science, but it does not restrict at all our personal intuition. Since we are an integral part of our Universe, we are capable at some subjective level to “feel” these correlations inaccessible for scientific observation. No contradiction with current physics exists here.

(2) In the described unobservable systems the entropy decrease is often observed or they are supported at a very low-entropy state. It does not contradict to the second thermodynamics law of the entropy decrease. Really, for creation of both passive and the active protection huge negoentropy from environment is necessary. Therefore, the total entropy of system and an environment only increase. The entropy increase law remains correct for a full system (observable system + an environment + the observer) though it is untrue for the observable system. Entropy decrease in the full system can happen, for example Poincare’s returns. However, they are unobservable [1-4]. Therefore, we can skip them.

(3) Existence of many unpredictable systems is accompanied by the entropy decrease (It does not contradict to the entropy increase according to the second law of thermodynamics as it is explained above in the third item). Thus, existence of such systems corresponds to the generalized principle of Le-Shatelie - Brown: the system hinders with any modification of the state caused by both external action, and internal processes, or, otherwise, any modification of a state of the system caused both by external and internal reasons, generates in the system the processes guided on reducing this modification. In this case, the entropy growth generates appearance of systems cause the entropy decrease.

(4) Often maximum entropy production principle (MaxEPP) demonstrates correct results [38]. According to this principle, the non-equilibrium system to aspire to a state
at which entropy growth in system would be maximal. Despite the apparent inconsistency, MaxEPP does not contradict to Prigogine’s minimum entropy production principle (MinEPP) for linear non-equilibrium systems [38]. These are absolutely different variation principles. However, for both cases, the extreme of the same function (the entropy production) is looked for, but various restrictions and various parameters of a variation are thus used. It is not necessary to oppose these principles, as they are applicable to various stages of evolution of non-equilibrium system. MaxEPP means that dissipative unpredictable systems (including living systems), being in the closed system with finite volume, accelerate appearance of thermodynamic equilibrium for this system. It means that they also reduce Poincare’s return time, i.e. promote faster return to the low-entropy state. It again corresponds to the generalized principle of Le-Shatelie - Brown: the entropy growth generates appearance of systems cause the entropy decrease. From all the above-stated it is possible to give a very interesting conclusion: global "purpose" of dissipative systems (including living systems) is (a) minimization of their own entropy (b) stimulation of the global full system to faster Poincare’s return to the initial low-entropy state.

(5) Global correlations generally “spread” over a closed system with the finite volume and result only in Poincare’s unobservable return [1-4]. However, in the presence of objects conserving local correlations, global correlations can become apparent in correlation between such objects with each other and around the world. Thus, presence of conserved local correlations allows making global correlations to be observable, preventing their full “spreading” over the system.

(6) The correct definition of thermodynamic macroscopic entropy is a very difficult problem for complex physical systems without local equilibrium [39].

(7) Very important facts ought to be noted. Unstable correlations exist not only in quantum but also in classical mechanics. Hence, such models should not have only quantum character. They can be also classical! Very often, it is wrongly stated that only the quantum mechanics have such properties [11-12]. However, it is not so [7-9]. Introduction of small, but finite interaction by “hands” during classical measurement and small errors of an initial state erases the difference between properties of quantum and classical mechanics (in the presence of unstable correlations of microstates).

3. Synergetic models of local correlations

Let us consider examples of synergetic models of unpredictable systems using the passive or active methods for protection from noise.

(1) There are exceptional cases for which there is no alignment of thermodynamic time arrows [13].

(2) Phase transition or bifurcation points. In such points (some instance for evolution or some value for external parameter), a macroscopic system described by observable dynamics can be transformed not to single but to several macroscopic states.
That is, observable dynamics loses the unambiguity in these points. There are huge macroscopic fluctuations in these points, and used macroparameters does not result in predictability of the system. Evolution becomes unpredictable, i.e. there is unpredictable dynamics.

(3) Let’s take a quantum microscopic or mesoscopic system described by ideal dynamics and isolated from decoherence. Its dynamics depends on uncontrollable microscopic quantum correlations. These correlations are very unstable and can disappear because of decoherence (entangling with environment/observer). For example, let us consider a quantum system. Suppose that some person knows its initial and final states only. Its behaviour is completely predicted by such person. In the time interval between the start and finish, the system is isolated from the environment/observer. In that case, these microscopic correlations do not disappear and influence dynamics. However, for the second person who is not present at start, its behaviour is uncertain and unpredictable. Moreover, an attempt of the second person to observe some intermediate state of the quantum computer would result in destroying its normal operation. I.e. from the point of view of such observer, this is unpredictable dynamics. Well-known examples of such systems are quantum computers and quantum cryptographic transmitting systems. Quantum computers are unpredictable for any observer who does not know its state in the beginning of calculations. Any attempt of such observer to measure the intermediate state of a quantum computer during calculation destroys calculation process in unpredictable way. Its other important property is high parallelism of calculation. It is a consequence of QM laws of linearity. Initial state can be chosen as the sum of many possible initial states of “quantum bits of the information”. Because of QM laws of linearity, all components of this sum can evolve in independent way. This parallelism allows solving very quickly many important problems, which usual computers cannot solve in real time. It gives rise to large hopefulness about future practical use of quantum computers. Quantum cryptographic transmitting systems use property of the unpredictability and unobservability of “messages” that cannot be read during transmitting by any external observer. Really, these “messages” are usual quantum systems featured by quantum laws and quantum correlations. An external observer, which has no information about its initial states and tries, make measuring (reading) of a “message” in course of transmission inevitably destroy this transmission. Thus, message interception appears principally impossible under laws of physics.

(4) It should be emphasized that, contrary to the widespread opinion, both quantum computers and quantum cryptography have classical analogues. Really, in classical systems, unlike in quantum systems, measuring can be made precisely in principle without any distortion of the measured state. However, in classical chaotic systems too there are uncontrollable and unstable microscopic additional correlations resulting in reversibility and Poincare’s returns. Introducing some small finite perturbation or initial state errors “by hands” destroys these correlations and erases this principal difference between classical and quantum system behaviour.
small external noise from environment always exists in any real system. By isolation
of chaotic classical systems from this external noise, we obtain classical analogues of
isolated quantum devices with quantum correlations. There exist synergetic models
of the classical computers, which ensure, like quantum computers, huge parallelism
of calculations [7]. Analogues of quantum computers are molecular computers [9].
The huge number of molecules ensures parallelism of evaluations. The unstable mi-
croscopic additional correlations (resulting in reversibility and returns) ensure dy-
namics of intermediate states to be unpredictable for the external observer, which is
not informed about the computer initial state. He would destroy computer calcula-
tion during attempt to measure some intermediate state. Similar arguments can be
used for classical cryptographic transmitting systems using these classical unstable
microscopic additional correlations for information transition. “Message” is some
classical system that is chaotic in intermediate states. Therefore, any attempt to
intercept it inevitably destroys it similarly to QM case.

(5) Conservation of unstable microscopic correlations can be ensured not only by pas-
sive isolation from an environment and the observer but also by active dynamic
mechanism of perturbations cancelling. It happens in so-called physical stationary
systems in which steady state is supported by continuous stream of energy or
substance through system. An example is a micromaser [16] - a small and well
conducting cavity with electromagnetic radiation inside. The size of a cavity is so
small that radiation is necessary to consider with the help of QM. Radiation damps
because of interaction with conducting cavity walls. This system is well featured
by density matrix in base energy eigenfunction. Such a set is the best choose for
observable dynamics. Microscopic correlations correspond to non-diagonal elements
of the density matrix. Non-diagonal elements converge to zero much faster than
diagonal ones during radiation damping. In other words, decoherence time is much
less than relaxation time. However, a beam of excited particles, passing through a
micromaser, leads to the strong damping deceleration of density matrix non-diagonal
elements (microcorrelations). It also leads to non-zero radiation in steady state. In
addition, in the theory of quantum computers methods of the active protection are
developed. These methods protect quantum correlations from decoherence. They
are capable to conserve correlations as long as desired, by iterating cycles of active
quantum error correction. Repetition code in quantum information is not possible
due to the no-cloning theorem. Peter Shor was first to discover the method of for-
mulating a quantum error correcting code by storing the information of one qubit
onto a highly-entangled state of nine qubits [17].

(6) In physics, a macrostate is usually considered as some passive function of a mi-
crostate. However, it is possible to consider a case when the system observes (mea-
sures) both its macrostate and an environment macrostate. The result of the obser-
vation (measurement) is recorded into the microscopic “memory”. By such a way,
the feedback appears between macrostates and microstates. An example of very
complex stationary systems is living systems. Their states are very far from thermo-
dynamic equilibrium and extremely complex. These systems are highly ordered but their order is strongly different from order of a lifeless periodical crystal. Low entropy disequilibrium of live beings is supported by entropy growth in environment. It is metabolism - the continuous stream of substance and energy through a live organism. On the other hand, not only metabolism supports disequilibrium, this disequilibrium is itself a catalytic agent of metabolic process, i.e. creates and supports it at a necessary level. As the state of live systems is strongly non-equilibrium, it can support existing unstable microcorrelations, preventing to decoherence. These correlations can be both between parts of a live system and between different live systems (or live systems with lifeless systems). If it happens dynamics of the live system can be referred to as unpredictable dynamics. Huge successes of the molecular biology allow describing very well dynamics of live systems. However, there is no proof that we are capable to feature completely all very complex processes in the live system. It is difficult enough to analyze real living systems within framework of concepts of ideal, observed and unpredictable dynamics because of their huge complexity. However, it is possible to construct simple mathematical models. It is, for example, non-equilibrium stationary systems with metabolism. It would allow us to understand a possible role of all of three types of dynamics for such systems. These models can be both quantum [11-12, 18-20, 35] and classical [7-9].

(7) The cases described above do not characterize all multiplicity of unpredictable types of dynamics. Exact conditions at which ideal dynamics transfers in observable and unpredictable dynamics present a problem, which is not solved completely for mathematics and physics yet. The role of these three types of dynamics for complex stationary systems is an unsolved problem too (being related to the previous problem). The solution of these problems will allow understanding physical principles of life more deeply.

2 Entropy of the Sun grows in such a way, for example. It is an energy source for life on the Earth.
4. Synergetic models of global correlations expanded over the whole Universe

With the help of synergetic “toy” models, it is possible to understand synchronicity\(^3\) (simultaneity) of processes causally not connected [37], and also to illustrate a phenomenon of global correlations.

Global correlations of the Universe and the definition of life as the totality of systems maintaining correlation in contrast to the external noise is a reasonable explanation of the mysterious silence of Cosmos, i.e. the absence of signals from other intelligent worlds. All parts of the universe having the unique center of origin (Big Bang) are correlated, and life maintains these correlations, which are at the base of its existence. Therefore, the emergence of life in different parts of the Universe is correlated, so that all the civilizations have roughly the same level of development, and there are not just any supercivilizations capable of somehow reaching the Earth.

4.1 Blow up systems

Examples are non-stationary systems with "blow up" [6, 22-25] considered by Kurdumov’s school. In these processes a function on plane is defined. Its dynamics is described by the non-linear equation, similar to the equation of burning:

\[
\frac{\partial \rho}{\partial t} = f(\rho) + \frac{\partial}{\partial r} \left( H(\rho) \frac{\partial \rho}{\partial r} \right),
\]

where \(\rho\) - density, \(N = \int \rho dr\), \(r\) - space coordinate, \(t\) - time coordinate, \(f(\rho), H(\rho)\) - non-linear connections:

\(f(\rho) \to \rho^\beta, \ H(\rho) \to \rho^\sigma\).

\(^3\) The study was conducted by Russian specialists under guidance of Valeri Isakov, a mathematician who specializes in paranormal phenomena. They were not able to obtain data from domestic flights, so the researchers used Western statistics. As it turned out over the past 20 years, flights which ended in disaster were refused by passengers by 18% more in number than in case of normally ended flights. “We are just mathematics who revealed a clear statistical anomaly. But mystically-minded people may well associate it with the existence of some higher power” - quoted Isakov, "Komsomolskaya Pravda".

http://mysouth.su/2011/06/scientists-have-proved-the-existence-of-guardian-angels/
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"That was Staunton’s theory, and the computer bore him out. In cases where planes or trains crash, the vehicles are running at 61 percent capacity, as regards passenger loads. In cases where they don’t, the vehicles are running at 76 per cent capacity. That’s a difference of 15 percent over a large computer run, and that sort of across-the-board deviation is significant. Staunton points out that, statistically speaking, a 3 percent deviation would be food for thought, and he’s right. It’s an anomaly the size of Texas. Staunton’s deduction was that people know which planes and trains are going to crash...that they are unconsciously predicting the future.”

Stephen King, “The Stand” (1990)
These equations have a set of dynamic solutions named solutions with “blow up”. It was proved localization of processes in the form of structures (at \( \beta > \sigma + 1 \)) with discrete spectrum. The structures can be simple (with individual maximums of different intensity). They also can be complex (united simple structures) with different space forms and several maximums of different intensity. It is shown that the non-linear dissipative medium potentially contains a spectrum of such various structures-attractors. Let \((r, \varphi)\) be polar coordinates.

\[
\rho(r, \varphi) = g(t) \Theta_i(\xi, \varphi), \quad \xi = \frac{r}{\psi(t)}, \quad 1 < i < N
\]

\[
g(t) = \left(1 - \frac{t}{\tau}\right)^{-\frac{1}{\beta-1}}, \quad \psi(t) = \left(1 - \frac{t}{\tau}\right)^{\frac{\beta-\sigma-1}{\beta-1}}
\]

Number of eigenfunctions:

\[
N = \frac{\beta-1}{\beta-\sigma-1}
\]

For these solutions a value of function can converge to infinity for finite time \( \tau \). It is interesting that the function reaches infinity in all maximums in the same instant, i.e. is synchronous. In process of converging to time \( \tau \) the solution “shrinks”, the maximums “blow up” (Fig. 5) and moves to a common center. Approximately at the moment of \( 0.9\tau \) the system becomes unstable, and fluctuations of the initial condition can destroy the solution. For high correlated initial condition it is possible to reduce these fluctuations to as small values as desired.

**Fig. 5** From [34]. It is one of structures-attractors of the equation of burning in the form of the solution with “blow up”.

By means of such models we can illustrate the population growth (or level of engineering development of civilizations) in megacities of our planet [25]. Points of maximum of function \( \rho \) are megacities, and population density is a value of the function \( \rho \).
It is possible to spread this model to the whole Universe. Then the points of maximum are civilizations, and population density of civilizations (or level of engineering development of civilizations) is a value of the function \( \rho \). For this purpose we will make the model more complicated. Suppose that at the moment when process starts to go out on a growing asymptotic solution there is very fast expansion ("inflation") of the plane in which process with "blow up" runs. Nevertheless, processes of converging to infinity remain synchronous and are featured by the equation of the same type (only with the changed scale), in spite of the fact that maximums are distant at large intervals.

This complicated model is capable to explain the qualitative synchronism of processes in very far parts of our Universe as a result of "inflation" after Big Bang. The high degree of global correlations reduces the fluctuations leading to destruction of the solution structure. These global correlations are modelling coherence of parts of our Universe.

Processes with "blow up" appear with necessary completeness and complexity only for some narrow set of coefficients of the equation (I). \( N \gg 1, \beta > \sigma + 1, \beta \approx \sigma + 1 \) is a necessary condition for appearance of a structure with large number of maximums and their slow coming to the common center. It allows drawing an analogy with “anthropic principle” [26]. The anthropic principle states that the fundamental constants of the Universe have such values that a result of Universe's evolution is our Universe with anthropic “beings” capable to observe the Universe.

One more fact is worth mentioning: if we want that the ordered state in the model would not be destroyed at \( t = 0.9 \tau \), and would continue to exist as long as possible then exact adjustment is required not only for model parameters, but also for an initial state. It is necessary that fluctuations arising from the initial state would not destroy orderliness as long as possible. And the presence of this rare exclusive state can be also explained by the anthropic principle.

4.2 “Cellular” model of Universe

It is also interesting to illustrate the complex processes by means of "cellular" model. Discrete Hopfield’s model [27-28] can be used as a good basis. This model can be interpreted as a neural network with a feedback or as a spin lattice (a spin glass) with unequal interactions between spins. Such systems are used for recognition of a pattern.

This system can be featured as a square two-dimensional lattice of meshes \( N \times N \) which can be either black or white \( (S_i = \pm 1) \). Coefficients of linear interaction between meshes \( J_{ji} \) are unequal for different pairs of meshes. They can be chosen so that in the process of discrete evolution the overwhelming majority of initial states would transfer in one of possible final states. This set of final states (attractors) can be chosen and defined “by hands”.

\[
S_i(t+1) = \text{sign} \left[ \sum_{j=1}^{N} J_{ij} S_j(t) \right], \quad 1 \leq i \leq N
\]

\[
J_{ij} = J_{ji}, \quad J_{kk} = 0, \quad 1 \leq i, j, k \leq N
\]
Attractors correspond to energy $E$ minimum:

$$E = -\frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} J_{ij} S_i S_j$$

Let choose lattice attractors to be letters A or B.

There are such two initial unstable states, which differ by one mesh only (a critical element). Thus, one of them has a state as A attractor, and another as B attractor. Such unstable initial states clearly illustrate a property of the global instability of a complex system. This instability is inherent in a system as a whole, not in its some part. Only some external observer can change the value of the critical element and vary the system evolution. Internal dynamics of the system cannot do it. Global correlation between meshes of an unstable initial state defines completely a final attractor (A or B) of the lattice.

It is possible to complicate the model. Let suppose that each mesh in the lattice featured above is such a sub-lattice. We will define evolution of such composite lattice going to two stages.

At the first stage, large meshes do not interact. Interaction exists only in sub-lattices. This interaction is the same as for the one-stage model featured above. Coefficients of the linear interaction between meshes are chosen so that attractors, as well as its was observed before, are letters A or B. Initial states of all sub-lattices can be chosen as unstable and containing the critical element. We will perceive the final state A of sub-lattices as a black mesh for a large lattice, and the state B of sub-lattices – as a white mesh.

The second stage of evolution is defined as evolution of this large lattice over the same way as in the one-stage model featured above. The initial state of the large lattice is defined by the first stage. This initial state, appearing at the first stage, is also unstable and contains the critical element. For final state of the large lattice to each black mesh, we will appropriate state A of the sub-lattices, and for each white mesh we will appropriate state B of the sub-lattices.

The initial state of the composite lattice can be chosen always so that an attractor of the two-stage process will be A. For every mesh included to A, the sub-lattice state also corresponds to A. Let us name this state of the composite lattice as “-”. Then this final attractor can be explained by:

a) global correlations of the unstable initial state

b) specific selection of all coefficients of interaction between meshes.

Let us make the model even more complicated. Similarly to the aforesaid, we will make this lattice not two-level but three-level, and the process will be three-stage instead of two-stage. A final state will be “--A”.

Let us suppose that prior beginning of the aforementioned three-stage process our composite lattice was occupying a very small field of physical space. However, because of expansion ("inflation") it was dilated to a huge size. Then the aforementioned three-stage process was begun. Thus, it is possible to explain presence of the unstable correlation of the initial state of the composite lattice leading to a total state “--A”. Indeed, before
“inflation” all meshes were closed by each other. Therefore, the unstable initial correlation can be easily formed under such conditions.

This three-level composite lattice can be compared to our Universe. Its smallest sub-lattices “A” can be compared to “intelligent organisms”. Lack of their interaction with the environment at the first stage (before formation of the final state “A”) is equivalent to the active or passive protection of internal correlations from external noise. Lattices of the second level in state “A-A” correspond to “civilizations” organized by “intelligent organisms” (“A”) at the second stage. At the third stage, “supercivilization” (“A-A-A”) is formed by “civilizations” (“A-A”).

Then global correlations of the unstable initial state of the composite lattice can serve as analogues of the possible global correlations of the unstable initial state of our Universe existed before its inflation. Coefficients of interaction of the meshes correspond to the fundamental constants of our Universe. The initial process of the lattice expansion (before its three-stage evolutions) corresponds to Big Bang. The specific selection of interaction coefficients between the meshes leading to the asymptotic state “–A”, and the initial correlations can be explained by “anthropic principle”. Here we remind that the anthropic principle states that the fundamental constants of the Universe have such values that the result of Universe’s evolution is our Universe with anthropic “beings” capable to observe the Universe.

5. Conclusions

The phenomenon existence of unpredictable complex (including living) systems is considered in the paper.

It is shown, that though existence of such systems, apparently, contradicts to the entropy increasing law, and actually does not lead to the real contradiction with it. Indeed, for existence of such systems in the real world the very specific boundary conditions are necessary. The entropy increase for making of such requirements in real external world much more exceeds the entropy decrease observed inside such systems.

The possibility of the proof of the Gödel-like theorem for such systems is shown. It means that reductionism (reducibility of the complex system’s behavior to fundamental physics laws) does not contradict to existence of the principal emergency. The principal emergency is the existence of principal unpredictability of complex system’s behavior based on fundamental physics laws. This emergency is not result of a system complexity only.

It is shown, that this unpredictability is closely connected to existence of the complex correlations both inside these composite systems, and with around world. Simple mathematical models, illustrating the principal possibility of such correlations are constructed.
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Chapter 6. The Universal Arrow of Time: Future of artificial intelligence - Art, not Science or Practical Application of Unpredictable Systems

Abstract: Solution of Unpredictability paradox – Unpredictable does not mean Uncontrolled

Perspective of the future of artificial intellect (AI) is considered. It is shown that AI development in the future will be closer rather to art than to science. Complex dissipative systems whose behavior cannot be understood completely in principle will be the basis of AI. Nevertheless, it will not be a barrier for their practical use.

1. Introduction

Nowadays technologies relating to design of systems of artificial intellect (AI) are actively developed in the world. In this paper, we would like to consider not tactical but strategic problems of this process. Interesting papers on this topic are few now, but they exist [1]. It is because most of serious experts are occupied with solving tactical problems and often does not think about farther prospects. However, the situation at the beginning of cybernetics origin was not like that. In those days, these problems were actively considered. Therefore, we will construct our paper as a review of problems of cybernetics as they were seen to participants of the symposium in 1961 [2]. We will try to give the review of these prospects from the point of view of the up-to-date physical and cybernetic science and its latest achievements.

2. Analysis of problems

The principal strategic direction in 1961 has been set by lecture of Stafford Beer “On the way to a cybernetic factory” (Fig 6). He sees a control system as some black box with a large quantity of internal states. Depending on internal states of the black box, different functions are carried out linking its input and output. Among all these functions, some optimal function exists. This function realizes its operation by optimal way according to some measure of optimality. The feedback will be organized between an output of the factory and internal state of the black box ensuring optimality of search of the internal state.

Here the following three difficulties arise:

(1) It is clear that the number of internal states of such black box should be huge to ensure realization of all possible functions. For this purpose, the author suggests to use some block of the substance, possessing huge number of internal states at atomic level. It is something, for example, like the colloid system of Gordon Pask. This system realizes reversion of matrixes of the astronomical order.

(2) Space of search of such box is huge and the search over all possible internal states is not real for reasonable time. Therefore, the strategy, which would allow discovering
not the most optimum solutions but at least just “good”, is necessary. At present such strategy is named as “geneticalgorithm” [3] supplied with the random generator. In addition, the method of heuristics is widely used. [4] It is a set of empirical recipes for the search of optimum between the internal states. They are either found from the previous experience or defined by the external expert.

(3) Criteria of optimality cannot be formulated accurately for all cases. Therefore, we may take for the “purpose” of such box its physical “survival”. Then it will search for such criteria itself, or some external expert would estimate its operations.

In the specified solutions of problems there is one very basic difficulty. Let our black box has n binary inputs and one binary output. Then number of all possible internal states of box is $2^n$. How large is this number? The answer is given by D.G. Willis in “Set of realized functions for the complex systems”. The physical calculation made here shows that all molecules of the Earth is enough only for creation of the black box with maximum $n = 155$. It does not make sense to reproduce his calculation here. The modern physics gives an exact method of calculation for the upper bound of memory through entropy of a black hole of corresponding mass [25]. (But it is problematic to extract this information because of informational paradox.) The estimation for memory, however, will not be more optimistic. It is clear that such number of the inputs is not sufficient for controlling over the complex systems. Consequently, the number of possible functions realized by box should be regarded as some subset of all possible functions. How can we choose this subset?

Now the methods based on neural networks [26] or fuzzy logic [27] are actively developed. They allow easy realizing many “intuitive” algorithms which are used by people. Besides, there are well developed methods of training or self-training for them. However, it is shown for both methods that any possible function is realized by these methods. On the one hand it is good, as proves their universality. On the other hand it is bad, as this redundancy do not allow us to lower space of search of the black box when using these
methods.

In his lecture Willis offers a solution which is actual even now. He suggests using a subset of all functions of \( n \) variables (Fig. 7). This subset can be realized by a combination of \( p \) functions with \( k \) variables where

\[
p \ll 2^n
\]

\[
k \ll n
\]

This class is small enough, so it can be realized.

![Fig. 7](image)

**Fig. 7** Exact expansion of switching functions on functions with a smaller number of variables.
(a) \( n = 6, \ p = 3, \ k = 3 \) (b) \( n = 8, \ p = 5, \ k = 3 \)

This solution is acceptable for a wide class of problems. For example, the neural network was used for recognition of the handwritten digit highlighted on the screen \cite{28}. The screen was divided into meshes (pixels). The mesh could be black or white. Thus, meshes were divided into groups of neighbouring meshes (\( k \) cells). Each group arrived on input of the network with one output. These outputs were grouped also in \( k \) the nearest groups which moved on inputs of the network etc. As a result, there were only 10 exits, which yielded outcome of classification. The specified network uses restrictions relating to “locality” of our world.

However, it is possible to introduce other similar criterions restricting space of search by less hard way. For example, we can use only the requirement (1) and not use the requirement (2). Instead of (2) we restrict type of used functions, i.e. we create some “library” of the useful functions.

For example, for existing field of the pattern recognition such set of functions already exists. It is software packages of functions for images processing. Example of such package is Matlab \cite{29}. By combining these functions, it is possible to create a large number of the useful features for recognition. To select useful superposition of functions, it is possible to use a random search of the genetic algorithm. However, it can be made also by using human intuition: a person can combine these functions so that they would reproduce
some intuitively felt feature of an object. The person himself cannot mathematically specify this feature without such search. These are human-machine systems of search.

It is worth to note that both creation of such “libraries” and human-machine search are not algorithmizable processes. They are based on human intuition. For this reason, we think that the artificial intellect is closer to Art than to Science.

Let us consider problems, which arise when this approach is used:

(1) Those restrictions (“libraries”) which we set on internal states of the black box are human formed. It makes this process labour-consuming and restricted by human intuition.

(2) Human-machine search is more effective than the genetic algorithm but suffers from the two above-mentioned problems.

Let us consider the following lecture, which is, apparently, the most prophetical and gives a trajectory to a solution of these problems: George W. Zopf “Relation and context”.

His main thought is that for construction of an effective model for artificial intellect we should not use some mathematical scientific abstraction like a black box. To construct such model we need to use properties of similar systems in the surrounding world. These are living adaptive systems. What their properties allow them to overcome restrictions and problems specified above?

Their most important property is that such systems are not, like a black box, some external objects in relation to the surrounding world. They are inseparably linked within it. (For example, Zopf pays attention to the fact that the features used for recognition of the object, or even the “code” of neurons of a brain (consciousness) are context-dependent. It means that they depend not only on internal state of the object or the brain, but also on their external environment.) It explains efficiency of restrictions on realized internal states of adaptive systems. They do not need to invent some “library” of search functions - it is already given to them in many aspects from their birth. These systems have happened from the surrounding world and are relating to it already at their birth by a set of hidden connections. Therefore, their “library” of search functions is quite effective and optimal. The same is true for algorithms of adaptation – unlike “genetic algorithms”; they are already optimally arranged with respect to the surrounding world. It allows preventing search and verification of large number of unsuccessful variants. Moreover, somebody from the outside does not set “purposes” of adaptive systems. In many aspects, they are already arranged with respect to their search algorithms and surrounding world restrictions.

We often perceive events in the world surrounding us as a set of independent, casual appearances. Actually, this world reminds a very complicated mechanism penetrated by a set of very complex connections. (“Accidents don’t happen accidentally.”) We cannot observe all completeness of these connections.

At first, as we are only a small part of this world, our internal states are not sufficient for mapping all its complexity. Secondly, we inevitably interact with the surrounding world and we influence it during observation. The modern physics states that this interaction cannot be made to naught in principle [5-12]. Therefore, to model and to consider
this influence exactly, we need to observe not only the external world but we need to observe ourselves too! Such introspection cannot be made completely in principle at any our degree of internal complexity. Introduction of physical macrovariables only reduces acuteness of the problems but does not resolve it.

Nevertheless, as it was already mentioned above, we are a part of the surrounding world and are related to it by the set of connections. Therefore, we are capable on such effective behavior. It creates illusion that we are capable effectively to foresee and to calculate everything. This property of adaptive living systems may possibly be referred to as superintuition\(^4\) [13]. It considerably exceeds adaptive properties of any black box developed by purely scientific methods.

Hence, we should build our future systems of AI also based on some similar “physical” adaptive systems possessing superintuition. We will give here the list of properties of such systems [9-10, 17-18].

1. The random generator of such systems (making selection of internal state) should not generate just random numbers. Such numbers should be in the strong connection (correlation) both with the surrounding world and with internal state of AI system, ensuring superintuition.

2. The internal state of the system should be complex. It should be not equilibrium but stationary; i.e. it should correspond to the dynamic balance. It is like a water wall in a waterfall. The internal state should be either for classical mechanics systems correlated, unstable (or even chaotic) or for quantum mechanics systems quantum coherent. Such systems are capable to conserve the complex correlations either inside of themselves or between themselves and the surround world.

3. The internal state of the system should be closed from external observation. It is achieved, at first, by high internal complexity of the system. Secondly, the system should change strongly the internal state and behavior at an attempt of external observation. This property is intrinsic for both unstable classical systems (close to chaos), and quantum coherent systems.

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\(^4\) The study was conducted by Russian specialists under guidance of Valeri Isakov, a mathematician who specializes in paranormal phenomena. They were not able to obtain data from domestic flights, so the researchers used Western statistics. As it turned out over the past 20 years, flights which ended in disaster were refused by passengers by 18% more in number than in case of normally ended flights. "We are just mathematics who revealed a clear statistical anomaly. But mystically-minded people may well associate it with the existence of some higher power"— quoted Isakov, "Komsomolskaya Pravda".

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"That was Staunton’s theory, and the computer bore him out. In cases where planes or trains crash, the vehicles are running at 61 percent capacity, as regards passenger loads. In cases where they don’t, the vehicles are running at 76 per cent capacity. That’s a difference of 15 percent over a large computer run, and that sort of across-the-board deviation is significant. Staunton points out that, statistically speaking, a 3 percent deviation would be food for thought, and he’s right. It’s an anomaly the size of Texas. Staunton’s deduction was that people know which planes and trains are going to crash...that they are unconsciously predicting the future.”

Stephen King, "The Stand" (1990)
(4) The system should be strongly protected from an external thermal noise (decoherence).

(5) The system should support the classical unstable or quantum coherent state and be protected from the external thermal noise not so much passively as actively. I.e. it should not be some hard armour or low temperatures. Rather it should be some active metabolic process. The system should be in a stationary dynamic balance, instead of thermodynamic equilibrium. So the vertical wall of water in a waterfall is supported by its constant inflow from the outside.

(6) The main purpose of such system should be its “survival”. To use similar systems, we need not to know in details their internal states and algorithms of operation which they will establish at interaction with the surrounding world. Moreover, trying to make it we will strongly risk breaking their normal operation. The only thing we should be concerned in is that the purposes, which they pursue for “survival”, are coinciding with the solution of problems, which are necessary for us.

We see that physics becomes necessary for creation of such cybernetic AI systems. Are there prototypes of such systems nowadays? Many features of the abovementioned systems are inherent to quantum computers [19-20, 24] or to their classical analogues, namely classical unstable computers [14] and molecular computers [16]. Besides, there is a lot of literature where synergetic systems modelling specified above property of living systems are constructed “on paper”. In quantum field it is [21-23, 30-32], and for classical unstable systems [15].

Here two problems arise:

(1) Which of the above-mentioned objects will be appropriate in the best way for creation of AI systems?

(2) What purposes necessary for “survival” of these systems do we need to put? Indeed, these purposes must be coinciding with solution of our problems.

The solution of these two problems is not an algorithmizable creative process. It makes again artificial intellect to be closer to Art than to Science. Really, usually we cannot even know how such systems are arranged inside. We can define their restrictions only. It is necessary to direct these systems to solve problems useful for us. We often are not capable even to understand and to formulate accurately our own purposes and problems. Without all this knowledge, the Science is powerless. So creation of such systems more likely will be related to writing music or drawing pictures. The Science will give only “brushes” and “canvas” to us.

Are AI systems capable to solve the two abovementioned problems instead of us? For the first problem, such chances exist, but the second one cannot be solved without us in principle. Indeed, nobody can know better than us that we want. However, both these problems are interconnected. Therefore, people always will have to do intellectual job. It is true also for the case that our “intelligent assistants” will be very powerful.
3. Conclusion

Perspective of the future of artificial intellect (AI) is considered here. It is shown that AI development in the future will be closer rather to art than to science. Complex dissipative systems whose behavior cannot be understood completely in principle will be a basis of AI. Nevertheless, it will not be a barrier for their practical use. However, a human person inevitably will conserve his important role. It is impossible to completely to exclude him from the process.

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