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CRITICAL REVIEW OF FUNDAMENTAL CONCEPTS IN PHYSICS

Part 2 – The Observer Factor

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Abstract

The mathematical principles of quantum mechanics are defined in the extended probability space for complex-valued probability amplitude functions. The process of this extension was going on in parallel with the formation of the principles of quantum mechanics and in the absence of the corresponding experience of such extensions. Therefore, some provisions arising from the physical and mathematical principles of this mechanics were not completely transparent and understandable to all physicists. For this reason, some physicists made incorrect statements based mainly on incorrect interpretations of these principles. However, this did not greatly hinder the advancement of the correct ideas of quantum mechanics. Since the 90s, an intensive resuscitation of old incorrect provisions of quantum mechanics and the interpretations corresponding to them began, and on their basis - the creation of new ones. Because these misconceptions concern the foundations of quantum mechanics and have become myths over the past three decades, they are already making it much more difficult to move forward in the right direction. We have assigned the title of the main myth to the "quantum computer" and use it as a trigger for a critical analysis of incorrect statements and interpretations. In this part of the text we discuss the "observer factor" because this issue plays an important role in the correct understanding of all the principles of quantum mechanics and its misunderstanding plays an important role in the formation of the details of the above-mentioned myth. In this part of the text, both the "observer factor" and the history of the appearance of this factor in physical discussions of quantum theory are analyzed. A detailed analysis of this issue will facilitate the process of understanding the erroneous details of the "quantum computer" myth.

Keywords: *quantum computer; observer factor; quantum entanglement; quantum superposition; quantum computing; "Thing in itself" and "Thing for us"*

Introduction

Starting from the 1990's, the development of digital technologies has been accompanied by an exponential growth in information flows, making it difficult to separate reliable from unreliable information. This circumstance contributed to creating the myth of the "quantum computer." As the pioneers of this myth indicate (see, for example, (Nielsen et al, 2011)), the idea is based on the following three "quantum phenomena":

First phenomenon – "quantum discreteness". According to the "followers of the idea" – discrete numerical values of physical characteristics of "quantum objects" of the micro-world can be used to create digital information bits;

Second phenomenon – "quantum superposition". According to the principle of "quantum superposition," when a quantum object is not being observed, at any moment in time it exists in many different physical states simultaneously, and each of these states can potentially be used to create a classical bit. Based on this phenomenon, from one quantum object – when we are not observing it – it would be possible to simultaneously create multiple (potentially infinite) classical digital bits. An information bit created based on this phenomenon was called a quantum bit, or "Q-bit."

Third phenomenon – "quantum correlation," i.e., "quantum entanglement". Followers of the idea rely on a well-known misconception – that two interacting objects, even after the end of their interaction – when they become free – still continue to exist in a unified quantum state. This leads to the emergence of the following "physical phenomenon": information about the quantum state of one object, which is formed during the act of "observation"* on this object, is instantaneously transmitted to another object, whose quantum state instantaneously restructures itself so that the conservation laws – acting in the joint system of these objects before observation – are not violated during "observation." According to the "proponents of the idea," this "physical phenomenon" can be used as a basis for creating a mechanism for instantaneous "quantum computations."

We will examine the above-mentioned phenomena from the perspective of quantum mechanics principles and indicate how they contradict these principles. The review will be presented in six parts: In this section - i.e. in the second part of the full text, the phenomenon corresponding to the "observer factor" will be discussed; in the third part of the full text, the phenomenon of "Quantum discreteness" will be discussed; in the fourth part of the full text, "Classical origins of quantum superposition" will be discussed; in the fifth part of the full text - "Quantum superposition"; in the sixth part of the full text - the problem of elastic scattering of particles in non-relativistic quantum mechanics, "Mott formula" will be discussed; in the seventh part - "Quantum entanglement" will be discussed.

We will briefly indicate the list of statements examined in the first part:

1. Do micro-world objects have trajectories? Answer - Yes, they do have trajectories;
2. Does the act of "observation" uncontrollably change the physical state of a micro-object? Answer – yes, it does change it!;
3. Are the laws operating in the micro-world before the act of "observation" deterministic in nature or not? Answer – both classical mechanics and quantum mechanics are built on the assertion that the laws of both the macro-world and micro-world are deterministic!;
4. Do the quantitative relationships corresponding to micro-world laws change uncontrollably as a result of the act of "observation"? Answer - yes, they do change!;
5. According to the statements indicated above, will the results of "observation" – conducted by an "observer" with macro dimensions over micro-world processes – necessarily have a random character? Answer - yes, they will necessarily have a random character!;
6. We can describe micro-world processes only by statistical methods corresponding to the "law of large numbers" and mathematical principles corresponding to probability theory.

*By the term "observation" we mean both ordinary human observation and measurement of some physical characteristic of the object being observed.

Chapter I: Brief History of the Question

The "observer factor" became a relevant topic after the publication in 1935 of a work by three authors – Einstein, Podolsky, and Rosen – "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" (see - Einstein et al, 1935). This article is often cited as the primary source from which the phenomenon of "quantum entanglement" appeared in discussions. However, it should be noted that this publication mentions neither this phenomenon nor the corresponding term. The authors discussed an already formed idea that if in a fixed physical circumstance one can precisely indicate the coordinate of a micro-object, then in the same circumstance it is impossible to indicate the momentum of the same object, and vice versa. Based on this, the founders of quantum mechanics, who were called representatives of the "Copenhagen school," made a simple conclusion: in quantum mechanics, reasoning about trajectories of micro-objects like in classical mechanics makes no sense. Some physicists went even further and put forward incorrect statements: when in a fixed quantum state a micro-object has a fixed coordinate, in the same state it has no momentum, and therefore has no trajectory. Based on this and other similar statements, an incorrect conclusion was made – quantum objects generally have no trajectories.

Einstein was against such a representation of micro-world reality and supported a quite logical opinion – all objects, including micro-objects, always have both momentum and coordinate, and consequently – a trajectory. To demonstrate this, the authors of (Einstein et al, 1935) theoretically considered an imaginary experiment, based on which they allegedly showed that the coordinate and momentum of a quantum object can be indicated simultaneously. This contradicted Heisenberg's uncertainty principle and accordingly – the principles of "Copenhagen representations." The arguments presented in (Einstein et al, 1935) were later called the "EPR Paradox."

In a response publication by N. Bohr (see (Bohr, 1935)), the source of errors in these arguments was indicated – an incorrect account of the role of the “observer factor” in describing the processes of the micro-world. Bohr's article did not convince all critics of the "Copenhagen school" representations, and in the same year Schrödinger's article was published (see (Schrödinger, 1935)), in which the term "quantum entanglement" first appeared. Schrödinger's reasoning was a continuation of the discussion begun in the two publications mentioned above, and it made the following statement:

According to the principles of quantum mechanics, interacting micro-objects of a conservative system are in a unified quantum state, which is described by a unified state vector. After the end of interaction, when objects become independent of each other and free, they still continue to be in a unified quantum state, which is reflected in the following fact: let, for example, the system consist of two quantum particles. According to the principles of quantum mechanics, when measuring the momentum of one particle, the measurement result will always be a random variable. In a specific measurement act, a specific value of the random momentum variable is discovered and a quantum state corresponding to this momentum is formed. Since the total momentum of a conservative system is a conserved characteristic, information about the momentum value of the first particle – which was formed in this measurement act – is instantaneously transmitted to the second object and instantaneously reflected in the formation of the physical state of the second object in such a way as to ensure fulfillment of the momentum conservation law of the conservative system. Consequently, after the end of the interaction, the quantum state of the system of these objects remains informative - i.e. “quantum entangled”, and therefore the quantum state of the system cannot be reduced to a simple set of quantum states corresponding to the independent existence of objects in this system. Accordingly, after the end of interaction, the system's state vector is not reduced to a simple tensor product of corresponding state vectors of independently existing objects.

This statement represents the essence of the "quantum entanglement" phenomenon, and we will address this question in more detail in the fifth part of our research. In this part, we will focus only on the statements of publication (Einstein et al, 1935) concerning the observer factor.

Statement 1: All objects, including quantum objects of microscopic dimensions, always simultaneously have both coordinate and momentum, and accordingly – trajectory.

To demonstrate this idea, the authors of (Einstein et al, 1935) considered the following imaginary experiment: one quantum object with known momentum decays into two objects. The process is completely conservative and the momentum conservation law acts in the decay act. According to this law, the momenta of the final objects satisfy the relation:

$\vec{P}_0 = \vec{P}_1 + \vec{P}_2$;

$\vec{P}_0$ – momentum of the initial object; $\vec{P}_1$ and $\vec{P}_2$ – momenta of the created objects. Since according to quantum mechanics principles – in one quantum state it is impossible to simultaneously measure and indicate both coordinate and momentum of an object, the authors of (Einstein et al, 1935) devised a simple technique allowing them to bypass this limitation: measure the coordinate of one object and the momentum of the second, which is not limited by quantum-mechanical principles in any way. Using the momentum conservation law, one can also indicate the momentum value of the first object. That is – without additional impact on the quantum state of the first object with measured coordinate – which would cause destruction of this state, one can indicate the momentum of the same object without destroying this state. As a result of these considerations, a second statement was made:

Statement 2: Heisenberg's uncertainty principle, according to which – in a fixed quantum state it is impossible to simultaneously indicate coordinate and momentum – inadequately reflects the physical reality of the micro-world. Consequently:

Statement 3: The quantum-mechanical description of reality, based on Heisenberg's uncertainty principle, is incomplete.

These statements constituted the essence of the "EPR Paradox," and to obtain them, there was no need to introduce the phenomenon of "Quantum Entanglement" into the reasoning. It should be noted that the reasoning in (Einstein et al, 1935) was based on a quite sound initial assumption – quantum objects have trajectories, but to prove this statement, erroneous arguments were used. Based on the erroneous EPR arguments, Schrödinger – also erroneously – introduced the phenomenon of "quantum entanglement" into the discussion.

Since, starting from the 1990’s, these erroneous considerations of Schrödinger became more popular than Bohr's arguments, we will try to bring more clarity to the essence of the "observer factor."

Chapter II: The Observer Factor in Classical Mechanics - "The Principle of Neglecting the Insignificant"

The foundation of all mechanical representations is the "Principle of Neglecting the Insignificant," which, in turn, is closely connected with the ancient Greek essence of the term "mechanics."

By the term "mechanics," they meant devising such "physical techniques" with the help of which individual "large and heavy" bodies could be studied separately, i.e., ignoring insignificant influences from other bodies. The main goal of searching for such "techniques" was to make it possible in the studied question to separate the "significant" from the "insignificant." As a result, it became possible to neglect numerous insignificant details, accounting for which was associated with great practical difficulties.

The search for such "techniques" remains the foundation both for describing modern empirical facts and for obtaining most theoretical results.

It is not difficult to understand that in the case of "large and heavy" bodies, corresponding "techniques" can be found insofar as the physical characteristics of these bodies possess the property of great inertia. Therefore, successfully selected "observation techniques" introduce insignificant changes in the values of measured characteristics.

The second fundamental principle for forming theoretical representations of different mechanics is the "Principle of Mutually Unambiguous Dependence of Properties of the Whole and Its Parts."

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This principle is also based on ancient Greek representations and consists of the following: a material whole consists of parts, empirical proof of which is the possibility of dividing the whole into constituent parts. These parts, by themselves, represent material wholes consisting of even smaller parts. According to this principle, the quantitative characteristics of parts obtained as a result of each subsequent act of division will decrease. The extreme case is the spatial dimensions of parts when they transition into points. Regarding this case, in ancient Greek philosophy, there existed the following judgment:

Matter occupying a volume with zero dimensions possesses physical characteristics whose numerical values equal zero. This, in turn, means that in a volume with zero dimensions there is no matter.

In addition to this:
It is impossible to create matter from nothing, i.e., from a point, and when dividing matter into small parts, it is impossible to make matter disappear at a point. Consequently, there must exist parts of matter of minimum size that cannot be divided, that is, they will be indivisible.

In ancient Greek language, these indivisible parts were called "atoms." According to the same philosophy, the diversity of atoms is finite. In reality, however, the observed diversity is much greater and may even be infinite. This diversity was explained partly by the finite number of diversity of atoms themselves, and mainly by the infinite number of diverse possible ways of constructing a whole from spatially extended and diverse atoms. Behind this reasoning followed the main statement:

The properties of the whole are completely determined by the properties of its constituent atoms and the specific rules for constructing this whole from the corresponding atoms. The reverse statement was also considered valid – with complete knowledge of the properties of the whole and the laws to which these integral bodies are subject, one will be able to indicate both the properties of constituent atoms and the laws to which these atoms are subject, as well as the rules by which these integral bodies are constructed with the help of these atoms.

The application of "successful observation techniques" always showed that the laws governing "large and heavy" bodies are deterministic in nature. Since, in the case of atoms, finding similar "techniques" was impossible, based on the outlined "Principle of the Whole and Parts," the following statement was made:

Since the laws governing "large and heavy" bodies have a deterministic nature, the laws to which atoms are subject must also have the same nature.

In ancient Greek philosophy, such ideas were held by representatives of Democritus's school. But one representative of this school – Epicurus – did not fully share all the statements and said: since human behavior is often characterized as random, the existence of such a whole indicates that in the list of various atoms, there must also exist such whose nature is also subject to the laws of random events (see (Epicurus, 1983)).

Newtonian natural philosophy was also based on ancient Greek ideas, in which the role of atoms was played by "material points." A material point represented a spatially continuously extended corpuscle whose linear dimensions were so small compared to the dimensions of the studied "large and heavy" bodies that they could be neglected. In such a mechanical "technique," the mass of the corpuscle was attributed to one of its internal points. The transition from continuously extended corpuscles to point ones was considered only a "convenient mathematical technique" with the help of which corresponding mathematical principles necessary for describing empirical reality could easily be introduced. It should be noted that the tools of mathematical analysis created by us do not give the possibility to directly describe spatially continuously extended objects and are suitable only for describing point objects. For example, a continuous line segment is parameterized by its two points (usually boundary ones). In mathematical analysis methods, we cannot simultaneously indicate an infinite number of continuously located points of a segment. Therefore, continuous distribution of points is replaced by a set of discretely located points.

In the Newtonian mechanical model of natural philosophy, all characteristics of "large and heavy" bodies are effectively replaced by summary characteristics and, similar to the case of corpuscles, are attributed to one selected point of the body, called the center of mass of this body. If in processes involving these bodies, the magnitude of change in the shape of bodies is very small compared to the dimensions of the considered body, then these changes can also be neglected and rigid connections can be introduced between different points of the body so that a set of a finite number of material points takes the same geometric spatial form as the considered unified body. In the same method of "techniques," when calculating the summary characteristic effectively substituting the real characteristics of an extended body, one could find such a case when the shape of the entire set of points remained unchanged, and the number of points became infinite. In this limiting case, using a countable discrete set of points, it was possible to model the continuous spatial distributed whole and in the same language record corresponding empirical laws, which allowed effectively obtaining quantitative relationships corresponding to empirical reality. These sums were later called integrals. The possibility of finding such "techniques" and implementing them in mathematical principles of natural philosophy became even more accessible after Euler and Lagrange's variational problem allowed mathematically correctly introducing rigid connections, which was impossible at the level of Newton's equations. Based on this, it became possible to create such a mathematical algorithm that would be compatible with the method of representing a continuous whole in the form of atoms or corpuscles. Unfortunately, the mathematical algorithm corresponding to a system of rigid connections based on the Lagrange multiplier method was never

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implemented in examples of specific problems, which is probably related to critical assessments that followed interpretations of Euler-Lagrange equations. In particular, in the variational problem, when obtaining Euler-Lagrange equations, it is necessary to fix the coordinates of material points at two moments of time. The self-consistency of the method required that equations obtained under such conditions be solved with the same boundary conditions. But this contradicted the physics representations of that time, according to which the correct description of reality corresponded to boundary conditions when coordinate and velocity are fixed at the initial moment of time. This critical assessment was shared by both Lagrange and Euler, and the variational method with which equations were obtained was presented as mathematical speculation to which deep physical meaning should not be attributed. It is generally accepted that this problem was solved in Hamilton's formalism. But it is not difficult to see that even in this formalism, when obtaining corresponding equations, it is necessary to introduce the same two conditions on coordinate as when obtaining Euler-Lagrange equations. However, in Hamilton's formalism, this detail was no longer paid attention to. In 19th-century physics, the problem of continuously extended, rigidly connected bodies was no longer relevant and remained a "black spot" of classical mechanics, which had a significant influence not only on the further formation of representations of this mechanics but possibly also on the formation of representations of quantum mechanics. The material point of classical mechanics corresponded to a model mathematical idealization, while three-dimensional continuously extended bodies were considered real. In quantum mechanics, point objects are considered to really exist – so-called "Fundamental elementary particles," while continuously distributed objects correspond to the abstraction of mathematical modeling. This opposition of ideas also manifested itself in describing micro-world processes – point particles are attributed not only non-zero physical characteristics but also imitations of "intrinsic rotation" – so-called "spin characteristic." When defining this characteristic, the condition is additionally included that the point particle "rotates as if," and not in reality.

Since the spin phenomenon is directly related to the topic of "quantum computing," we will discuss this phenomenon in more detail in the part on "quantum discreteness." Here we return to questions of the "EPR Paradox" and consider an analog of the theoretical experiment indicated in (Einstein et al, 1935) for macroscopic objects.

Let us imagine two identical "large and heavy" rigid balls placed in a rigid tube with explosive material placed between the balls. For simplicity, let us assume that in the observer's reference frame the construction is motionless and has no interaction with the external world except for the observer. After the explosion of the explosive, the balls will fly in opposite directions, and our goal is to describe the movement of these balls. As in the case of (Einstein et al, 1935), we know that the total momentum of the balls equals zero, but we do not know the coordinate and momentum of individual objects. Let us proceed to empirically indicate these quantities. For this, it will be necessary to fix the positions of the balls several times. Since the balls are "large and heavy," we can easily find a suitable "technique" to achieve this goal, using which we do not introduce large changes in the physical characteristics of the observed process. Suppose, with the help of illumination, we fixed the locations of one of the balls – $\{\vec{R}_1(t_1),\ \vec{R}_1(t_2),\ \vec{R}_1(t_3)\}$ at time moments $\{t_1,\ t_2,\ t_3\}$. It is clear that by illuminating the moving ball with light to fix coordinates, we act on it, causing a change in its momentum. It is also clear that this change would not have occurred if the act of observation had not introduced corresponding changes in the ball's coordinates as well. Therefore, the radius vectors indicated above should be represented as follows:

$\vec{R}_1(t) = \overline{R}_1^0(t) + \Delta\vec{r}_1(t);$ (1)

where: $\Delta\vec{r}_1(t)$ denotes changes in the position of the ball's center of mass caused by the act of "observation" performed at moment t; $\vec{R}_1^0(t)$ is the radius vector of the ball's center of mass that the ball would have in the absence of "observation" and consequently changes $\Delta\vec{r}_1(t)$; $\vec{R}_1(t)$ is the result of observing the ball's center of mass. Since the balls are "large and heavy," we can select devices for determining the ball's location such that the following condition is fulfilled:

$|\vec{R}_1(t)| \gg |\Delta\vec{r}_1(t)| \to 0;\ \Rightarrow\ \vec{R}_1(t) \approx \vec{R}_1^0(t);$ (2)

This condition corresponds to the fact that the act of "observation" insignificantly changes the position of the observed object. As a result of the impact of the act of "observation," the direction of movement may be changed, i.e., the ball's momentum will change. Consequently, it is necessary to check whether the vectors $[\vec{R}_1(t_1)$ - $\vec{R}_1(t_2)]$ and $[\vec{R}_1(t_2)$ - $\vec{R}_1(t_3)]$ are parallel. If within the accuracy we use these vectors are parallel:

$[\vec{R}_1(t_1) - \vec{R}_1(t_2)]\ ||\ [\vec{R}_1(t_2) - \vec{R}_1(t_3)];$ (3)

this will be evidence that the velocity and momentum of the freely moving ball are not changed by acts of "observation." Based on these data, if we calculate the momentum-$\vec{P}_1$ of the first object, then – proceeding from the momentum conservation law – we automatically learn the momentum of the second object $\vec{P}_2$ = - $\vec{P}_1$. This relationship is easy to verify empirically if we conduct similar observations on the second ball as well. Our knowledge about the fact of existence of the momentum conservation law follows from the results of such observations. Using the "principle of neglecting the insignificant," this law is also attributed to the freely moving balls themselves – without our "observations." Moreover, we say that condition (3) is realized only insofar as an analogous property is present for quantities of the type $\vec{R}_1^0(t)$. That is, (3) is conditioned precisely by this fact, and not vice versa.

That is, all laws, including the momentum conservation law, are characteristics of things without our observations.

Our "observations" represent a totality of actions by means of which we try to fix for ourselves the existence of the mentioned laws. For this, we devise various "clever observation techniques." When observing microworld objects, it becomes impossible to find such "clever techniques" so that relationships of type (2) are fulfilled. In connection with this, in observation results, knowledge of quantities of type $\Delta\vec{r}_1(t)$ corresponding to the "observer factor" becomes essential. The situation becomes similar to Kant's description of reality, according to which: there is "Thing in itself" and there is "Thing for us". "Thing in itself" corresponds to reality without our "observations," and "Thing for us" corresponds to the results of our observations of "Things in themselves". Things by themselves – i.e., "Thing in itself" – are governed by physical laws whose indication is the main task of physics.

When things are "large and heavy," the results of our observations – i.e., "Thing for us" – with great accuracy coincide with "Things in themselves." At the same time, within the accuracy of our "observations," we discover that the laws governing "large and heavy bodies" are deterministic in nature. For this reason, the same nature is attributed to quantities of the type $\Delta\vec{r}_1(t)$, but essentially these quantities significantly differ from quantities of the type $\vec{R}_1^0(t)$ and $\vec{R}_1(t)$. The fact is that the more successful a "technique" is selected for accurate measurement of quantities of the type $\vec{R}_1^0(t)$, the more the numerical values of quantities of the type $\Delta\vec{r}_1(t)$ decrease. At some stage of decrease, the physical characteristics of quantities of the type $\Delta\vec{r}_1(t)$ will become uncontrollable for us, since due to the macroscopic dimensions of the observation instruments we use, acts of observation are naturally accompanied by limited measurement accuracies. The quantities $\Delta\vec{r}_1(t)$ corresponding to the best "techniques" will become completely uncontrollable for us. In methods of mechanical observations, uncontrollable quantities are called random. And if not for condition (2.2), then quantities of the type $\vec{R}_1(t)$ corresponding to "Things for us" would also be random.

Some events involving macro-bodies we still call random. The most well-known examples are coin tossing and dice throwing. If we throw a die or coin in Earth's gravitational field and observe the result of falling on a horizontal surface, then after stopping, we will discover one of the faces on the upper side of these objects. If these faces are somehow marked, and we repeat the throwing action, then the same face or another may appear on the upper side. Because of this, we say: if in repeated actions, results can be different, then we call the results of such actions random.

When introducing this definition, an important detail corresponding to the "Principle of Neglecting the Insignificant" is used – repeated actions. According to this principle, we consider each throwing of the mentioned objects as identical actions. From a physical point of view, it is completely clear that these actions are not identical and therefore not exactly repeatable. But we, for some subjective considerations, ignore the difference and call the corresponding physical circumstance a "Game Mode." It should be noted that to obtain deterministically fixed results, it is not necessary to exactly repeat throwing actions. Simply, one must select such "throwing techniques" with the help of which we get deterministic results. Since these objects are "Large and heavy," this is possible in principle, but not so easy to implement. Indeed, transmitting the necessary momentum to these objects in such a way that as a result we get the desired result is quite complex. Despite the complexity, the macroscopic dimensions of these objects still allow – by the method of "Trial and error" – to find such areas for the values of transmitted momenta, the transmission of which by corresponding "techniques" will lead to the same results in such repeated actions. The physical circumstances of corresponding actions assume such movement of these objects in which "very powerful and large actions" do not occur. The fact is that controlling the physical characteristics of very "powerful and large actions" relative to the scales of dice and coins is quite difficult. Therefore, in such actions, corresponding results acquire a random character. To avoid this, one should choose such "throwing techniques" so that results turn out to be both predetermined and at the same time ensure macroscopic repeatability of throwing acts, even if through not very correct use of the "principle of neglecting the insignificant." We note that criteria for evaluating the magnitude of actions are unambiguously connected with the dimensions of objects that are thrown. Therefore, realizable actions can become large both as a result of transmitting large momenta and in case of decreasing the dimensions of the mentioned objects. In both cases, due to our limited control of "throwing techniques," the results of these events in both cases will be random in nature. "Game mode" corresponds to a physical situation when the dimensions of actions are not large, but results still have a random character. This mode implies a physical circumstance in which the "ensemble of repeated events" includes the maximally wide spectrum of possible "mechanical throwing techniques" corresponding to various deterministic results mentioned above. In such an ensemble of "repeated events," all possible outcomes become equally expected. We will touch on the mathematical principles of this question in the part "Quantum superposition" when we discuss the principles of probability theory in describing statistical data of events of throwing these objects. At this stage, we will end the discussion with the following important remark: as the linear dimensions of gaming objects decrease, the spectrum of permissible "techniques" for obtaining deterministic results also narrows. From certain threshold values of dimensions and below, only such "techniques" will remain at our disposal whose corresponding events will be only random outcomes. For these objects, names were invented – "quantum coins" and "quantum dice." These names are in agreement with representations according to which the necessity of probabilistic description in quantum mechanics arises precisely because the scales of the micro-world are much smaller compared to deterministically controlled scales from the side of the "large observer," and devising "cunning techniques" to overcome this factor becomes impossible in principle for such an "observer."

Chapter III: "EPR Paradox" and "Observer Factor" in Quantum Mechanics

We begin the discussion of the "EPR Paradox" by examining one of the statements mentioned above: **I.1 – the act of**

"observation" violates conservation laws that were in effect before the act of "observation".

As we mentioned in the second subsection - when one object conservatively decays into two objects, conservation laws apply to the objects participating in this process with the status of "thing-in-itself", including the law of conservation of momentum. This law can be written as a chronological relationship:

$\vec{P}_0^0(T|T \leq t_0)$=$\vec{P}_1^0(t|t \geq t_0)$ + $\vec{P}_2^0(t|t \geq t_0)$; (4)

where:

- $\vec{P}_0^0(T|T \leq t_0)$ – momentum of the original object before decay
- $\vec{P}_1^0(t|t \geq t_0)$ and $\vec{P}_2^0(t|t \geq t_0)$ - momenta of objects resulting from decay
- t_0 – moment of decay of the original object

At moment $t = t_1 \geq t_0$, we fix the momentum of the first object through an act of "observation". This characteristic corresponds to an "object for us" and is given by the relationship:

$\vec{P}_1(t_1)$ = $\vec{P}_1^0(t_1)$ + $\Delta\vec{p}_1(t_1)$; (5)

$\Delta\vec{p}_1(t_1)$ is the magnitude corresponding to the result of uncontrolled influence introduced by the act of "observation" into the momentum of the "observed" object. Because we cannot control acts of "observation" at the microscopic level, this magnitude has a random character for us. It's clear that when the fraction $\Delta\vec{p}_1(t_1)$ in (5) is not small, the momentum $\vec{P}_1(t_1)$ also becomes a random variable.

As N. Bohr noted: the phenomenon where, due to the random character of $\Delta\vec{p}_1(t_1)$, $\vec{P}_1(t_1)$ also becomes a random variable, is the "observer factor" of quantum mechanics.

Therefore: quantum mechanics is based on a method of describing empirical reality using statistical methods, which - unlike the dynamic-chronological method of description in classical mechanics - does not assume chronological description of studied events and their results. As an alternative to chronological description, so-called "expectation functions" are introduced, which are otherwise called "probability functions". Consequently, the mathematical principles of quantum mechanics are realized precisely in the probability space.

As a rule, the cause of quantum mechanical paradoxes and myths is incorrect interpretation of the principles of the probabilistic method of description and improper use of elements of this method. The "EPR Paradox" corresponds to one such case, which will be demonstrated below.

For this, we note that since we don't know the exact value of $\Delta\vec{p}_1(t_1)$, we cannot restore the exact value of $\vec{P}_1^0(t_1)$ from (5). Therefore, by empirically fixing $\vec{P}_1(t_1)$, we cannot restore the momentum value of the second object "existing by itself", since by the law of conservation of momentum, its momentum was connected with the momentum of the first object "existing by itself".

Additionally, if at moment t_2 ($t_2 > t_1$) we repeat the momentum measurement of the freely moving first object, we will obtain the value $\vec{P}_1(t_2)$, which in general will not coincide with $\vec{P}_1(t_1)$. This fact determines the basis of the random character of measurement results in the micro-world.

Due to the mentioned phenomenon, the existence of the law of conservation of momentum - even in the case of free motion - cannot be explicitly detected empirically, since each act of observation will uncontrollably and significantly change the momentum of the given freely moving object:

$\vec{P}_1(t_{i+1})$ = $\vec{P}_1(t_i)$ + $\Delta\vec{p}_1(t_{i+1}) \neq \vec{P}_1(t_i)$; (6)

Taking into account the presented reasoning, we can conclude that the statement which forms the basis of the "EPR Paradox" - ***"the act of observation does not violate conservation laws acting before the act of observation"*** **- is incorrect.**

Let's proceed to analyze the second statement and determine whether Heisenberg's uncertainty principle indicates that ***quantum objects simultaneously do not have coordinate and momentum***. According to the principles of quantum mechanics, the numerical values of coordinate and momentum of a quantum object correspond to eigenvalues of corresponding operators, and these operators are connected by a non-chronological relationship:

$[\hat{Q}_i, \hat{P}_j]$ = ihδ_{ij}; (7)

where $\hat{Q}_i$ and $\hat{P}_j$ are spatial components of coordinate and momentum operators of a point quantum object. Note that in condition (7), operators $\hat{Q}_i$ and $\hat{P}_j$ do not depend on time, which is one of the main characteristics of quantities described by statistical methods.

Time independence is also present in Heisenberg's uncertainty relation obtained from (7):

$\Delta Q_i\ \Delta P_j \geq$ (h/2) δ_{ij}; (8)

Often, the statistical nature of (8) is forgotten, and ΔQ_i and ΔP_j are interpreted as accuracies of individual measurement acts and called "measurement errors" of coordinates and momenta at one moment in time. This corresponds to an incorrect interpretation of relation (8). This error logically leads to another false statement: when in a single measurement act the coordinate of a quantum object is unambiguously fixed, resulting in measurement accuracy becoming zero - ΔQ_i = 0, then according to (8) in this state $\Delta P_i = \infty$, and this indicates ***that in the mentioned state, the given quantum object has no momentum*** as a physical characteristic at all**.** Conversely - if momentum is fixed in a given state and ΔP_i = 0, for the same reason - coordinate as a physical characteristic does not exist. This type of interpretation was subjected to quite justified criticism both from N. Bohr and other authors. For example, in 1951, an article was published (see (Blokhintsev, 1951)) examining the erroneous interpretation of Heisenberg's uncertainty principle.

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Its author - D.I.Blokhintsev - quite correctly noted that the quantities ΔQ_i and ΔP_i indicated in (8) do not represent numerical values obtained in a single measurement act, and therefore, based on them, one cannot judge the simultaneous existence or absence of coordinate and momentum in a quantum object.

As indicated, these quantities represent characteristics of a statistical "ensemble". Namely - ΔQ_i and ΔP_i are determined in a set of statistical data obtained as a result of observing numerous identical objects that were in identical macroscopic physical conditions during "observation" and are constructed from quadratic deviations from the statistical mean. Here we should note that following these quite correct comments came a very interesting observation from the same author, but one that is not entirely correct from the standpoint of the probabilistic method of describing statistical data:

"When physical characteristics of an object are in the quantum domain, we cannot repeat the experiment on this object because the very act of observing it significantly changes the state of this object. Therefore, for conducting repeated experiments, it's impossible to repeatedly use the same object, but it's necessary to place a multitude of non-interacting identical particles - from a macroscopic point of view - in identical physical conditions and conduct joint observation of this multitude."

The mentioned phrase corresponded to emphasizing the essentiality of uncontrolled influence caused by the "observer factor." But, as a result of not entirely correct indication of the essence of this phenomenon, this statement can also become a source of erroneous interpretations. Under this phrase by D.I. Blokhintsev, one should understand only that we cannot organize microscopically repeatable physical circumstances, which is the main characteristic of the "observer factor." But this does not prohibit repeatedly conducting macroscopically repeating experiments on one specific particle — exactly as we can place many objects in macroscopically identical physical states and observe them many times. Likewise, we can repeatedly place one particle in macroscopically repeating conditions and conduct multiple observations on it. But, at the same time, a fundamental question arises, due to which this phrase by D.I. Blokhintsev becomes interesting – can we detect a single particle and place it in some physical conditions. This question arises quite naturally, since "observations" for detecting a single particle we can conduct only using macroscopic instruments. To detect the trace of a single particle, the trace must also be macroscopic. But if the trace has macroscopic characteristics, then we cannot unambiguously say that these characteristics were formed only by the one particle of interest to us. The fact is that the observation instrument itself consists of quantum particles, which can also take essential participation in forming the trace characteristics. In such a situation, we can make an error - attributing the fact of appearance of this trace precisely to the particle of interest to us. Therefore, when we conduct reasoning for a "statistical ensemble" in quantum mechanics, we implicitly use one of the main characteristics of the statistical method of description, which is used in the case of "large and heavy" bodies:

In "game mode," that is, under certain macroscopically repeating circumstances, the multitude of statistical data obtained by throwing one die (coin) N times, and the multitude of statistical data obtained by simultaneously throwing N identical dice (coins), are carriers of absolutely identical statistical status when describing the results of these events by the statistical method. Moreover - the larger N, the greater the intersection of these multitudes. In the limit $N \to \infty$, these multitudes become identical.

This statement generalizes to all types of random events, including - the results of observation of micro-objects, and represents a general principle of statistics:

A statistical data set obtained as a result of observation of an ensemble of N non-interacting identical quantum particles in a unified, i.e. - macroscopically identical physical condition, has exactly the same statistical status as a data set obtained as a result of N-fold act of observation on one of them - macroscopically repeated in the same physical conditions. In the limit $N \to \infty$, both these two multitudes and the statistical regularities - obtained as a result of their phenomenological investigations, will be identical to each other. These results and regularities - as probabilistic characteristics, should be attributed both to the ensemble of these particles and to individual particles.

Accordingly, one and the same statistical ensemble can be obtained both by means of an event in which many identical objects participate simultaneously, and from many repeating events occurring with one object of this multitude. At the same time, all these events must be realized under identical macroscopic conditions.

Thus, Blokhintsev's second statement corresponds to describing the processes of the micro-world by a more fundamental standard than is implied by the "mechanical techniques" of quantum mechanics. According to these principles, the observation instrument introduces only uncontrolled quantitative changes in the characteristics of the observed processes of the micro-world, while the phenomenon of the process itself remains completely the same as it would have been without the act of observation. This statement has the status of a "mechanical assumption technique," but without its introduction – as a justified approximation, it would have been impossible to attribute to individual quantum objects those characteristics that will be obtained when observing statistical ensembles - constructed by a multitude of identical objects. At the same time, in "mechanical observation techniques" one must use only those that ensure the application of this assumption.

We will conclude discussions on this issue with a remark: in the list of quantum-mechanical principles, the main one is not the phenomenon of quantumness, i.e. - discreteness, but the statistical character of the method of describing reality, by means of which these principles are introduced. And most importantly — we choose the use of this method not for

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subjective considerations, as is done for a die or coin, but because of our limited ability to control the processes of the micro-world with arbitrary precision. In connection with this, it is necessary to clearly indicate the following:

The probabilistic nature of the principles of quantum mechanics is not a direct characteristic of the micro-world itself - as is often erroneously claimed, but is the result of our limited ability to describe this micro-world with arbitrary precision. Thanks to the strengthening of the role of the "observer factor," caused by the imbalance of scales of the "observer" and the "observed," from the "things in themselves" of the micro-world objectively arises "things for us," whose physical characteristics manifest as random quantities.

Based on the reasoning presented here, regarding the last statement (Einstein et al, 1935), the following remark can be made: of course - quantum mechanics as knowledge based on the statistical-probabilistic method of describing empirical "reality for us," is imperfect compared to classical determinism; But, on the other hand, Bohr's statement also – in the "market of our possibilities" there are no possibilities for a more complete description of reality than based on the statistical-probabilistic method - is also completely correct and understandable.

In accordance with this statement, let us note one well-known opinion: physics is built by postulates, i.e., principles corresponding to empirical "Phenomena of Epicurus," while mathematics - by axioms, i.e., principles corresponding to phenomena of mental imagination, i.e., "Phenomena of Plato." This circumstance is the main distinguishing feature of these two knowledges. For physics - mathematics — is a "tool of work" and should not be confused with "neither the goal of work, nor the results of work." Together, they create more complete knowledge than they could separately.

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