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Physical thinking and the GHZ theorem.

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Abstract Most scientists believe in quantum mechanics because of its practical success. But the rejection of realism by the creators of quantum mechanics has led to the degradation of physical thinking since, as Einstein was understanding correctly, realism is the presupposition of every kind of physical thinking. The well-known GHZ theorem demonstrates most clearly that the rejection of realism results to the degradation of physical thinking. The authors of this theorem deduce contradiction of quantum mechanics with locality on the base of the principle of quantum mechanics according to which quantum mechanics cannot contradict locality. This logical contradiction became possible because of ignoring the questions about the subject of the description of quantum mechanics and the essence of realism.

Keywords Foundations of quantum mechanics · quantum debate · GHZ theorem · rejection of realism in quantum mechanics · essence of realism · EPR correlation · non-locality · Bell's inequalities · operators acting on different particles commute · operators of finite rotations of coordinate system · entangled spin states · Dirac jump

1 Introduction

The progress of technology in the twentieth century is largely related to quantum theory. But this theory arose as a result of fierce controversy between its creators, Planck, Einstein, Schrodinger, and others on the one hand, and Bohr, Heisenberg, Dirac, and others on the other hand. The main point of the controversy was the question of the permissibility of abandoning realism to describe paradoxical quantum phenomena. The most famous episode of

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the controversy between the creators are articles [1,2] with the same title but opposite statements. These opposite statements of A. Einstein, B. Podolsky, and N. Rosen (EPR) [1] and N. Bohr [2] provoked numerous publications of articles [3–9] and books [10–13] and resulted to the idea of new quantum information technologies [14]. The authors of the modern publications, continuing the dispute between the creators of quantum theory, argue [15–18] about Bell's inequalities proposed first in 1964 [19], see also in the book [20].

The relentless interest in Bell's inequalities was provoked by the confidence of many authors that their violation could refute realism. The first reliable evidence for the violation of Bell's inequalities was obtained by Alain Aspect with co-authors forty years ago [21–23]. Since then, many experimental evidences of violation of Bell inequalities have been obtained. But doubts remained about the final refutation of realism. Seven years ago Alain Aspect stated in his Viewpoint: "*By closing two loopholes at once, three experimental tests of Bell's inequalities remove the last doubts that we should renounce local realism. They also open the door to new quantum information technologies*" [24]. In additional to the three experimental tests [25–27], which Aspect referred to, cosmic Bell's test [28,29], Bell's test with human choices and many other experiments were made which testify to the violation of Bell's inequalities [30]. Nevertheless, quite a few authors continue to question Bell's test [31–34].

The fundamental difference between the modern dispute and the dispute between the creators of quantum theory is the neglect by modern authors of the issue about the sense of realism. This issue was one of the main subjects of dispute between the creators. Heisenberg was calling the old-fashioned attitude toward the problem of reality as dogmatic realism and metaphysical realism: *"Dogmatic realism claims that there are no statements concerning the material world that cannot be objectivated $\cdots$ actually the position of classical physics is that of dogmatic realism. It is only through quantum theory that we have learned that exact science is possible without the basis of dogmatic realism. When Einstein has criticised quantum theory he has done so from the basis of dogmatic realism"* [35]. Einstein's famous dictum *"I like to think that the moon is there even if I don't look at it"* is a manifestation of dogmatic realism.

Dogmatic realism is not an extreme form of delusion according to Heisenberg: *"Metaphysical realism goes one step further than dogmatic realism by saying that 'the things really exist'. This is in fact what Descartes tried to prove by the argument that 'God cannot have deceived us'"* [35]. Einstein would have said, "I'm sure that the moon really exists even if I don't look at it," if he had followed metaphysical realism. Einstein followed dogmatic rather than metaphysical realism since he was understanding the validity of Kant's avowal that "*it always remains a scandal of philosophy and universal human reason that the existence of things outside us (from which we after all get the whole matter for our cognitions, even for our inner sense) should have to be assumed merely on faith, and that if it occurs to anyone to doubt it, we should be unable to answer him with a satisfactory proof*" [36].

According to Kant's philosophy realism is the regulative principle of our reason, which determines the very possibility of empirical cognition of Nature. It is easy to understand without philosophy why realism determines the very possibility of empirical cognition. Realism (dogmatic according to Heisenberg) states that the moon exists even if no one look at it. Therefore, we must explain how our mind creates the moon when observing if we reject realism. Einstein, like Kant, understood that realism is "*the presupposition of every kind of physical thinking*" [37] rather than a claim which can be disproved with any experimental results. According to Einstein's understanding, the rejection of realism means the rejection of physical thinking. Many years of discussions about Bell's inequalities indicate that Einstein was right. The rejection not only of realism, but also of the understanding of the sense of realism led to the loss of the ability to think physically. The well-known Greenberger-Horne-Zeilinger (GHZ) theorem is considered critically in this work since the lack of physical thinking in the derivation of this theorem is especially obvious.

2 The assumption used by EPR is used at the deduction of the GHZ theorem

The GHZ theorem was proposed in 1989 by Daniel Greenberger, Michael Horne, and Anton Zeilinger [38] and described in more detail in the article [39]. The theorem is considered in many articles [40–50] and is popularized in the books [10–12]. Only a few authors [51] were critical of the GHZ theorem. No one, including the critics, did not notice that the authors [39] used the main assumption of the EPR [1], which was been contesting by Bohr [2]. The expectation values Eq. (F3) was deduced from Eq. (F1) in the Appendix F of the article [39] on the base of the assumption that the measurement of spin projection of one of the particles of the GHSZ state, for example 1 along $\mathbf{n_1}$, does not change the states of other particles 2, 3, 4. The EPR [1] used exactly this assumption in order to prove the inadequacy of quantum mechanics.

The authors [39] do not justify the use of the main assumption of the EPR [1]. The authors of the book [11], in which the GHZ theorem is been popularizing, justify the independence of the measurement results of different particles by the well-known principle of quantum mechanics that the operators can fail to commute only if they act on the same particle. They did not take into account that the EPR [1] could defeat Bohr [2] even without the requirement of locality if this principle of quantum mechanics was not rejected, since according to quantum formalism "*the commutability of the operators is a necessary and sufficient condition for the physical quantities to be simultaneously measurable*" [52]. The authors [39] claim that they demonstrate "*that the premises of the Einstein - Podolsky - Rosen paper are inconsistent when applied to quantum systems consisting of at least three particles. The demonstration reveals that the EPR program contradicts quantum mechanics even for the cases of perfect correlation*".

This claim cannot be correct according to logic since the authors [39] used the same premise which the EPR [1] used. Einstein with his co-authors [1] used the law of momentum conservation in order to refute the Heisenberg uncertainty principle and the Bohr complementarity principle. We can know exactly the total momentum of two particles A and B, for example $p_{x,A} +$

$p_{x,B} = 0$. Therefore we can know exactly the momentum of the particle A $p_{x,A} = -p_{x,B}$, after accurately measuring the momentum $p_{x,B}$ of the particle B. Then we can measure exactly the coordinate x_A of the particle A in the same state in which we know the exact value of its momentum $p_{x,A}$ if the operators acting on different particles commute and the measurement of the particle B cannot change the state of the particle A, as it is assumed at the deduction of the GHZ theorem [39,11]. Einstein and his co-authors [1] added the requirement of locality for greater persuasiveness, which was unnecessary if we, like the authors [39], do not reject the principle of quantum mechanics that operators acting on different particles commute.

The EPR paradox [1] revealed first of all the internal inconsistency of quantum mechanics: the Heisenberg uncertainty principle and the Bohr complementarity principle are logically incompatible with the principle that operators acting on different particles commute. The authors [39] should have clarified what quantum mechanics they mean when they claimed that the EPR program contradicts quantum mechanics. The EPR program [1] does not contradict, but corresponds to the quantum mechanics that is used at the deduction of the GHZ theorem [39]. Rather Bohr than the EPR had to contradict this quantum mechanics in order to save the uncertainty principle and his complementarity principle.

First of all, Bohr had to reject the principle of quantum mechanics that operators acting on different particles commute. But judging by the GHZ theorem [39] and the numerous publications about this theorem, no one noticed this. It is more known that Bohr postulated 'spooky action at a distant, i.e. the instantaneous influence of measurement of the particle A on the state of particle B independent of the distance between these particles, in his response [2] to the EPR article [1]. But Bohr expressed himself so vaguely that only John Bell and few others understood the sense of his claim. Only therefore, as Bell wrote in Appendix 1 - "The position of Bohr" of the article [53], "*most contemporary theorists have the impression that Bohr got the better of Einstein in the argument and are under the impression that they themselves share Bohr's views*". The deduction of the GHZ theorem [39] and numerous publications about this theorem reveal clearly that this impression is deceptive. The authors [39] follow rather the EPR [1] than Bohr [2].

Bell was right when he "*felt that Einsteins intellectual superiority over Bohr, in this instance, was enormous as vast gulf between the man who saw clearly what was needed, and the obscurantist*" [54]. Bohr claimed that the EPR expression "*without in any way disturbing a system*" is ambiguous [2] instead of clearly saying that we must reject the principle of quantum mechanics that operators acting on different particles commute and the principle of physics 'no action at a distance' in order to save the base of quantum mechanics. He wrote extremely obscurely and inconsistently: "*Of course there is in a case like that just considered no question of a mechanical disturbance of the system under investigation during the last critical stage of the measuring procedure. But even at this stage there is essentially the question of an influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system*" [2].

Bell was admitting: "*While imagining that I understand the position of Einstein, as regards the EPR correlations, I have very little understanding of the position of his principal opponent, Bohr*" [53]. But he understood that rather Bohr's claim than the EPR expression is ambiguous: "*Indeed I have very little idea what this means. I do not understand in what sense the word 'mechanical' is used, in characterizing the disturbances which Bohr does not contemplate, as distinct from those which he does. I do not know what the italicized passage means - 'an influence on the very conditions...'. Could it mean just that different experiments on the first system give different kinds of information about the second? But this was just one of the main points of EPR, who observed that one could learn either the position or the momentum of the second system. And then I do not understand the final reference to 'uncontrollable interactions between measuring instruments and objects', it seems just to ignore the essential point of EPR that in the absence of action at a distance, only the first system could be supposed disturbed by the first measurement and yet definite predictions become possible for the second system. Is Bohr just rejecting the premise - 'no action at a distance' - rather than refuting the argument?*" [53].

Most contemporary theorists, in contrast to Bell, believe up to now that Bohr rather than Einstein was right in the debate about the EPR correlations. This belief has tremendous practical consequences. Most contemporary scientists, and not only scientists, are sure in reality of new quantum information technologies [24], in particular quantum computation [14], in spite of the contradiction of the EPR correlation with realism. The authors of the GHZ theorem [38,39] share the majority opinion. They are sure that quantum mechanics contradicts locality and predicts the EPR correlation and violation of Bell's inequalities. But they don't realize that their confidence is false because of the quantum principle of the independence of the measurement results of different particles which they use in the deduction of Eq. (F3) from Eq. (F1) in [39].

3 The assumption used at the deduction of the GHZ theorem makes impossible the EPR correlation

The authors [39] are sure that results of the observation of spin projection in the same direction z_1 of two particles with spin 1/2 in the EPR state

$$\psi_{EPR} = \frac{1}{\sqrt{2}}(| \uparrow_A \downarrow_B> + | \downarrow_A \uparrow_B>) \tag{1}$$

will be opposite with the probability 1: if the spin projection of the particle A is found spin up $\uparrow_{z1}$ then with the certainty it will be found spin down $\downarrow_{z1}$ for particle B, and vice versa. This perfect correlation is known as the EPR correlation although A. Einstein, B. Podolsky, and N. Rosen (EPR) [1] were sure that such paradoxical correlation not only impossible but even unthinkable.

This perfect correlation is indeed unthinkable if the operators $\mathbf{z_{1A}}$ and $\mathbf{z_{1B}}$ describing measurements of spin projection of different particles A and B

commute, as it is assumed in [39]. The state only of the measured particle can change in this case in accordance with the postulate about the Dirac jump. Dirac postulated in 1930 "*that a measurement always causes the system to jump into an eigenstate of the dynamical variable that is being measured*" [55]. Dirac jump is better known as wave function collapse or reduction of quantum state, in terms introduced by von Neumann in the book of 1932 [56]. Only the measured particle jumps into an eigenstate according to the Dirac postulate. Therefore the EPR state should jump into the state

$$\mathbf{z_{1A}}\psi_{EPR} = \frac{1}{\sqrt{2}} | \uparrow_{A,z1}> (| \downarrow_B> + | \uparrow_B>) \quad (2)$$

when Alice will observe that her particle A has deflected up with the probability 1/2. Bob will observe spin up $\uparrow_{z1}$ with the probability 1/2 according to (2). No correlation is predicted in this case.

Quantum mechanics can predict the perfect correlation between results of observation of Alice and Bob only if the principle of quantum mechanics used in [39] is rejected. The only way to provide the EPR correlation is to extend the Dirac jump [55] to the particle that is not measured. We will call the jump of the both particles of the EPR pair (1) into an eigenstate of the dynamical variable of one of the particles that is being measured as the Bohr jump, since this jump was postulated under the influence the Bohr claim about 'spooky action at a distance' in [2]. David Bohm was probably the first who postulated the Bohr jump in the section "The Hypothetical Experiment Einstein, Rosen and Podolsky" of his book [57] under the influenced of the Bohr claim and blind faith in quantum mechanics. Bohm did not understand that he had to reject of the quantum principle that operators acting on different particles commute in order to replace the Dirac jump by the Bohr jump.

Bohm's lack of physical thinking provoked not only the mistake made in the deduction of the GHZ theorem [38,39,11], but also the mass delusion about the EPR correlation. Bohm falsely interpreted in [57] the EPR correlation as a consequence of a real interaction, contrary to Schrodinger, who defined in 1935 the EPR correlation as the entanglement of our knowledge [58,59]. Schrodinger's definition is the only correct and possible one, firstly because the probability of the result of an upcoming observation describes the knowledge of the observer, and secondly because only knowledge can change instantly and non-locally, while any real interaction must be local.

Alice knew before her observation from (1) that she will see spin up with the probability 1/2 at measurement of spin projection in any direction of any of the particles of the EPR pair (1). Her knowledge will be described by a new expression

$$\psi_A = | \uparrow_{A,z1}> | \downarrow_{B,z1}> \quad (3)$$

when she sees that her particle A has deflected up along z_1 and the both particles will jump from the EPR state (1) to the eigenstates along z_1 in the accordance with the Bohr jump. The new state (3) provides, in contrast to (2), the perfect correlation between results of measurements of spin projection along the same direction z_1 by Alice and Bob. This jump, the Bohr jump, but not the Dirac jump, provides also the prediction of violation of Bell's inequalities by quantum mechanics.

4 The assumption used at the deduction of the GHZ theorem makes impossible the prediction of violation of Bell's inequalities

The authors of the GHZ theorem [38,39], like the majority, are sure that violation of Bell's inequalities refutes theories of hidden variables and proves the validity of quantum mechanics. This opinion cannot be correct for two reasons: 1) quantum mechanics, as the authors of [38,39,11] and of other publication understand it, does not predict violations of Bell's inequalities, and 2) Bell deduced Bell's inequalities without hidden variables in the article [53]. Bell started with the trivial inequality

$$P_{0+}P_{45-} + P_{45+}P_{90-} \geq P_{0+}P_{90-} \quad (4)$$

in which P_{0+}, P_{45-}, P_{45+}, and P_{90-} are the probabilities of deflection of a particle with spin 1/2 up (+) and down (−) at different orientations of the analyzer at angles $\theta = 0^o$, $\theta = 45^o$, $\theta = 90^o$ relative to some direction. Inequality (4) is obvious. When the probabilities P_{0+}, P_{45-}, P_{45+}, and P_{90-} are measured in the same spin state, any particle that is deflected up at $\theta = 0^o$ and down at $\theta = 90^o$ (increasing the third probability $P_{0+}P_{90-}$ in (4)), when the orientation $\theta = 45^o$ can be deflected up (increasing the probability $P_{45+}P_{90-}$ in (4)) or down (increasing the probability $P_{0+}P_{45-}$ in (4)).

But quantum mechanics predicts violation of the obvious inequality (4). The probability $P_{\theta+}$ is the ratio $P_{\theta+} = N_+/(N_+ + N_-)$ of the number of the observations spin up N_+ to the total number of observations $N_+ + N_-$. The first measurement of a particle along any direction θ_1 should give the probability $P_{\theta 1+} = 1/2$ when $N_+ + N_-$ particles are in random states. But the probability of the results of the second measurement will depend of the angle $\theta_2 - \theta_1$ between directions of the first θ_1 and second θ_2 measurements because of the Dirac jump [55]. The particles jump "*into an eigenstate of the dynamical variable that is being measured*" [55], i.e. the eigenstate along θ_1 after the first measurement. The eigenstate $\psi_{\theta 1} = |\uparrow_{\theta 1}>$ along θ_1 is superposition of state

$$|\uparrow_{\theta 1}>= \cos\frac{\theta_2 - \theta_1}{2}|\uparrow_{\theta 2}> + \sin\frac{\theta_2 - \theta_1}{2}|\downarrow_{\theta 2}> \quad (5)$$

along any other direction, for example θ_2, according to the basis of quantum mechanics [52]. The operator of finite rotation of the coordinate axes about the y-axis [52] is used in (5). Thus, quantum mechanics predicts that the probability of the second observation

$$P_{\theta 2+} = |\cos\frac{\theta_2 - \theta_1}{2}|^2; \; P_{\theta 2-} = |\sin\frac{\theta_2 - \theta_1}{2}|^2 \quad (6)$$

depends on the directions of both first θ_1 and second θ_2 measurements whereas the probability of the first observation $P_{\theta 1+} = 1/2$ and $P_{\theta 1-} = 1/2$ depends on no direction. This difference between the first and second observation is possible only if the operators do not commute.

Quantum mechanics predicts violation of the obvious inequality (4) due to this difference between the first and second observation. The inequality (4) would require according to quantum mechanics prediction

$$\frac{1}{2}\sin^2\frac{45^o}{2} + \frac{1}{2}\sin^2\frac{45^o}{2} \geq \frac{1}{2}\sin^2\frac{90^o}{2} \qquad (7)$$

or

$$0.1464 \geq 0.2500 \qquad (7a)$$

which is not true.

The prediction of the violation of the inequality (4) basically repeats the prediction of the violation of Bell's inequalities in the Bell article [53]. The equality (6) and the inequalities (7) repeat the equality and the inequalities in [53]. But Bell considered in [53] the observation of spin projection of two particles with spin 1/2 in the EPR state (1) rather than single particles. Quantum mechanics would not predict violation of Bell's inequalities if only the Dirac jump was postulated and the operators acting on different particles commute, as it is assumed at the deduction of the GHZ theorem [11,39]. The probability to observe spin up of both particles of the EPR pair (1) should be equal 1/2 if only the measured particle jumps into an eigenstate of the dynamical variable that is being measured, i.e. if the Dirac jump from (1) to (2) takes place at the Alice observation. No Bell's inequality can be violated according to this prediction of quantum mechanics, for example $1/2 \times 1/2 + 1/2 \times 1/2 = 1/2 > 1/2 \times 1/2 = 1/4$.

Bell [53] could predict violation of Bell's inequality only with the help of the Bohr jump postulated by Bohm [57]. The assumption about the EPR correlation allows to write the equality $P_{\theta A-} = P_{\theta B+}$ and to deduce Bell's inequality

$$P_{0A+}P_{45B+} + P_{45A+}P_{90B+} \geq P_{0A+}P_{90B+} \qquad (8)$$

from the inequality (4). The Bohr jump from the EPR state (1) to the state (3) provides the same probability

$$P_{\theta 1A+}P_{\theta 2B+} = \frac{1}{2}|\sin\frac{\theta_2 - \theta_1}{2}|^2 \qquad (9)$$

to observe spin up $\uparrow$ of the first A and second B particles of the EPR pair (1) which (6) the Dirac jump provides for the first and second measurements of single particles. Bell did not specify that a quantum mechanical predicts the equality (9), providing predictions of violation of Bell's inequality (8), if only the Dirac jump is replaced with the Bohr jump and the principle of quantum mechanics according to which operators acting on different particles commute is rejected. Perhaps if Bell had done this, the authors [38,39] would not have made obvious mistakes.

Perhaps in this case the authors not only of [38,39] but also other numerous publications about Bell's inequalities could understand that Bell's inequalities reveal the difference rather between the Bohr jump and the Dirac jump than between quantum mechanics and a theory of hidden variables. Unfortunately, the sense of Bell's inequalities is often misunderstood. The GHZ theorem is often referred to as "Bell's theorem without inequalities" [12] in accordance with the title [39]. This opinion cannot be correct since the GHZ theorem and Bell's theorem are based on different quantum mechanics. The operators acting on different particles commute and measurement of a particle cannot change the quantum state of other particles according to quantum mechanics used at the deduction of the GHSZ theorem [39]. Bell's theorem does not make sense according to this quantum mechanics, which does not predict violations of Bell's inequalities, the EPR correlation and does not contradict locality.

5 The operators of finite rotations of coordinate system cannot be applied to entangled spin states

The probability to observe spin up $\uparrow$ of the first particle $P_{\theta 1A+} = 1/2$ is fundamentally different from the probability to observe spin up $\uparrow$ of the second particle $P_{\theta 2B+} = |\sin(\theta_2 - \theta_1)/2|^2$ of the EPR pair (1), according to (9). This difference is fundamentally impossible without the Bohr jump and if the quantum principle that operators acting on different particles commute was not rejected. Nevertheless, the authors [39] created the illusion in the Appendix B that they can have deduced the expression (B4) similar to the expression (9) without the Bohr jump. The equality between the probabilities of observation of the first and second particles cannot be violated in principle if operators acting on these particles commute. Therefore the Appendix B and the Appendix F of the GHSZ article [39] contradict each other.

The authors [39] violate in the Appendix B the equality between the first and second particles with a strange method that they do not substantiate. They apply the operators of finite rotations of coordinate system to the both particles of the EPR pair at the measurement of the first particle and only to the second particle at the second measurement. This method cannot make sense because the operators of finite rotations of coordinate system [52] cannot be applicable to entangled spin states. The authors [39] demonstrate in the Appendix A the rotational invariance of the EPR state (1) in their article $\psi_{EPR} = (1/\sqrt{2})(|\uparrow_A\downarrow_B> -|\downarrow_A\uparrow_B>)$. But this entangled spin state is probably the only one that does not change when the coordinate system is rotated. The rotation of the coordinate system around the y-axis [52] by an angle θ transforms the expression (1) for the EPR pair to the expression

$$\psi_{EPR} = \frac{1}{\sqrt{2}}(-\sin\theta|\uparrow_A\uparrow_B> + \cos\theta|\uparrow_A\downarrow_B> + \\ + \cos\theta|\downarrow_A\uparrow_B> + \sin\theta|\downarrow_A\downarrow_B>) \quad (10)$$

according to which the probability $P_{\theta A+} = (1 - \sin 2\theta)/2$ to observe spin up $\uparrow_A$ at the first observation depends on the direction θ, in contrast to the initial expression (1).

This fundamental change in the prediction of the probability of the result of the first observation as a consequence of the rotation of the coordinate system cannot make physical sense since the space is considered as isotropic. It is important to recall that the rotation operators are derived based on the idea of the isotropy of the real three-dimensional space [52]. According to the point of view adopted by the majority "*In both classical and quantum mechanics, the law of conservation of angular momentum is a consequence of the isotropy of space with respect to a closed system. This already demonstrates the relation between the angular momentum and the symmetry properties under rotation. In quantum mechanics, however, the relation in question is a particularly far-reaching one, and essentially constitutes the basic content of the concept of angular momentum, especially as the classical definition of the angular momentum of a particle as the product* $\mathbf{r}\times\mathbf{p}$ *has no direct significance in quantum mechanics, owing to the fact that position and momentum cannot be simultaneously measured*", see the beginning of Chapter VIII "Spin" of the book [52].

According to this point of view a spinor, like a vector, exists in the real isotropic three-dimensional space and its components change with the rotation of the coordinate system [52], similar to the components of a vector. For each vector, for example a magnetic moment $\mathbf{m} = (m_x, m_y, m_z)$, a coordinate system exists in which this vector is directed along z-axis, for example z_1: $\mathbf{m} = (0, 0, m)$. Similarly, a coordinate system exists in the real three-dimensional space in which the spin state is the eigenstate along z-axis: $\psi_{z1} = |\uparrow_{z1}>$ [52]. The operators of finite rotations of the coordinate system are deduced on the base of our notion about the isotropic space for spinors [52], like for vectors although the transformation of spinors under rotation differs from the transformations of vectors. The vector $\mathbf{m} = (0, 0, m)$ directed along z_1 transforms to $\mathbf{m} = (m\sin\theta, 0, m\cos\theta)$ after rotation of the coordinate axes about the y-axis on an angle θ, whereas the the eigenstate transforms to superposition of states $\psi_{z1} = \cos\theta/2|\uparrow_{z2}> + \sin\theta/2|\downarrow_{z2}>$ [52]. θ is the angle between z-axises in the first z_1 and second z_2 coordinate systems.

The state of a system of N particles with spin 1/2 along a z-axis can be described as the product

$$\psi_{noEnt} = \Pi_{i=1}^{i=N}(\alpha_i|\uparrow_{i,z}> + \beta_i|\downarrow_{i,z}>) \tag{11}$$

of the states $\psi_i = \alpha_i|\uparrow_{i,z}> + \beta_i|\downarrow_{i,z}>$ of each of the particles, when these states are not entangled. One can write in the general case $\alpha_i = \exp(-i\phi_i/2)\cos(\theta_i/2)$, $\beta_i = \exp(i\phi_i)\sin(\theta_i/2)$ and $\psi_i = \exp(-i\phi_i/2)\cos(\theta_i/2)|\uparrow_{i,z}> + \exp(i\phi_i)\sin(\theta_i/2)|\downarrow_{i,z}>$ since $|\alpha_i|^2 + |\beta_i|^2 = 1$. The angles ϕ_i and θ_i determine a direction z_i relatively the z-axis in the real three-dimensional space in which the spin state of i - particle is an eigenstate $\psi_i = |\uparrow_{i,zi}>$.

But the entangled spin states cannot be written as the product (11) and the equality $|\alpha_i|^2 + |\beta_i|^2 = 1$ of the probabilities cannot be valid in this case. Therefore the entangled spin states cannot have a direction in which this state is an eigenstate. For example, no one can say in which direction the spin states of the particles of the EPR pair (1) are eigenstates. Moreover we must conclude that the amplitude of the probability in (1) cannot differ from $1/\sqrt{2}$ since we cannot know which particle A or B will be measured first. This requirement is valid also for for the expression (1) in the article [39]. The prediction to observe spin up $\uparrow$ with the probability 1/2 in any direction means that no direction is in the real three-dimensional isotropic space along which the spin states of the particles of the EPR pair are eigenstates. Therefore the demonstration of the rotational invariance of the only expression in the Appendix A of [39] can not prove that the operators of finite rotations of the coordinate system [52] can be applied to the entangled spin states.

The impossibility of the existence of eigenstates of the particles A and B of the EPR pair (1) in real three-dimensional space is another proof that Schrodinger's definition [58,59] of the EPR correlation is the only possible one. The expression for the EPR pair (1) can describe only the knowledge of the observer that the first measurement of spin projection in any direction of any particle will give spin up $\uparrow$ with the probability 1/2. The eigenstates of the both particles of the EPR pair (1) will appear only after this measurement. Quantum mechanics predicts this emergence because of both the Dirac jump (2) and the Bohr jump (3). The measured particle obtains the eigenstate in the direction of the measurement of spin projection according to both jumps, see (2) and (3). The state of the second particle is eigenstate in a direction which is perpendicular to the direction in which the projection of the first particle was measured according to the Dirac jump (2) and is opposite to this direction according to the Bohr jump (3).

6 The rejection of realism results to the absurd

Einstein argued that the concept of reality in our ideas about Nature is necessary in order we can escape solipsism [37,60]. Einstein was right. We cannot escape solipsism if we reject realism. The Bohr jump postulated by Bohm demonstrates the correctness of Einstein's logic most clearly. According to the Bohr jump Alice can create the eigenstates (3) of the both particles A and B along z_1 direction if she will measure first her particle along z_1. Other observer, Bob can create other eigenstates of the same particles

$$\psi_B = |\uparrow_{A,z0}> |\downarrow_{B,z0}> \qquad (12)$$

if he will measure first his particle along z_0 and will see that his particle B has deflected down. The spin states (3) differ from the one (12) since the eigenstate along z_1 is the superposition of states along the other direction z_0 and vice versa. For example

$$|\uparrow_{A,z1}>= \cos\frac{\theta}{2}|\uparrow_{A,z0}> + \sin\frac{\theta}{2}|\downarrow_{A,z0}> \qquad (13a)$$

$$|\downarrow_{B,z1}>= \sin\frac{\theta}{2}|\uparrow_{B,z0}> + \cos\frac{\theta}{2}|\downarrow_{B,z0}> \qquad (13b)$$

$$|\uparrow_{A,z0}>= \cos\frac{\theta}{2}|\uparrow_{A,z1}> - \sin\frac{\theta}{2}|\downarrow_{A,z1}> \qquad (14a)$$

$$|\downarrow_{B,z0}>= -\sin\frac{\theta}{2}|\uparrow_{B,z1}> + \cos\frac{\theta}{2}|\downarrow_{B,z1}> \qquad (14b)$$

when the angle between z_1 and z_0 is θ. The operator of rotation about the y-axis is used in (13) and (14) [52]. Thus, according to quantum mechanics recognized by the authors of [39] and of many other publications two observers, Alice and Bob, can create different states of the same particles orienting their analyzers along different axis z_0 and z_1 of the real three-dimensional space. This prediction of quantum mechanics is an obvious absurdity, which can logically be avoided only with the help of solipsism, i.e. the denial of the existence of a second observer.

The EPR correlation and the prediction of violation (7) of Bell's inequality (8) are deduced from the assumption that only the first observer can create the eigenstates, (3) or (12), of the both particles of the EPR pair. The second observer measures the spin projection of his particle in the spin state created by the first observer. That is why the probability of his observation of spin up (9) depends on the angle $\theta_2 - \theta_1$ between the directions of the first θ_1 and second θ_2 observations. But we can say who measures first, Alice or Bob, if only the principle of locality is valid. But if this principle is not valid, as the authors of [39] and of many other publications are sure, then who will be the first can depend on the subjective choice of an inertial reference frame according to the Einstein theory of special relativity.

7 'Dogmatic realism' and 'metaphysical realism'

The absurdity of quantum mechanics once again proves that the rejection of realism means the rejection of physical thinking. The lack of physical thinking was manifested primarily in the fact that not only most physicists, but even the creators of quantum mechanics confused the description of the observer's knowledge with the description of reality. They followed not even 'dogmatic realism' (from Heisenberg's point of view), as Einstein did, but 'metaphysical realism', even when they refuted realism. Bell wrote that the creators of quantum mechanics had to reject realism because of such quantum phenomena as the Stern-Gerlach experiment [61]: "*Phenomena of this kind made physicists despair of finding any consistent space-time picture of what goes on the atomic and subatomic scale*" [53]. Einstein and Ehrenfest [62] drew attention to the complexity of a realistic description of the Stern-Gerlach effect just after its discovery in 1922 [61]. Bell explained in detail in [53] why the Stern-Gerlach effect cannot be described realistically: it is impossible even to imagine how the projection of the magnetic moment can have only discrete values in any direction.

The creators of quantum mechanics did not try even to imagine how the magnetic moment of a particle with spin 1/2 can be directed only up or down in any direction. They created the illusion of solving the problem limiting themselves to the description of the probability to observe spin up $\uparrow$ and spin down $\downarrow$. The probability describes a knowledge of an observer about a result of upcoming observation. For example, an observer knows from previous experience that he will see with a probability of 0.5 that the thrown coin fell with face up. The observation of the spin 1/2 projection has something in common with the observation of a coin that only two observation results are possible. But there is a fundamental difference between these two cases related to the paradoxical nature of the Stern-Gerlach effect, which the creators of quantum mechanics not only did not explain, but even ignored.

We can think that the coin was lying face up before we looked at it. But we cannot think so in the case of observing the spin projection, since the projection can be measured in different directions. Therefore the creators of quantum mechanics, as Bell wrote, "*asserted that atomic and subatomic particles do not have any definite properties in advance of observation. There is nothing, that is to say, in the particles approaching the magnet, to distinguish those subsequently deflected up from those subsequently deflected down. Indeed even the particles are not really there*" [53]. They did not take into account an elementary logic: if properties are absent before observation and appear after observation then the mind of the observer creates these properties.

The knowledge of an observer about the probability changes by jump at the observation: the probability to see the coin lying face up was 0.5 before the observation and became 0 (if the coin is not lying face up) or 1 (if the coin is lying face up) after the observation. Heisenberg justified the postulate of the jump in quantum mechanics by a discontinuous change in our knowledge: "*Since through the observation our knowledge of the system has changed discontinuously, its mathematical representation also has undergone the discontinuous change and we speak of a quantum jump*" [35]. But Dirac postulated the jump of the quantum system into an eigenstate rather than the jump of our knowledge. Quantum mechanics could predict a possibility to see one particle in different places at each observation of the same dynamical variable, i.e. the obvious absurd, without the Dirac jump.

Einstein, back in 1927 during the discussion at the Fifth Solvay Conference [63], drew attention to the fact that the need for the Dirac jump logically follows from Born's proposal to consider the Schrodinger wave function as a description of the amplitude of the observation probability. Einstein noted also that the needed jump "*leads to a contradiction with the postulate of relativity*" [63]. This contradiction is a consequence of the dual nature of the quantum state in orthodox quantum mechanics. On the one hand, for example, spin states (13) or (14) describe the observer's knowledge about the probability to observe spin up or spin down in different directions. On the other hand, spin states are considered as real states existing in the real three-dimensional space. The creators of quantum mechanics on the one hand rejected 'dogmatic realism' but on the other hand they surpassed even 'metaphysical realism'.

"*Metaphysical realism goes one step further than dogmatic realism by saying that 'the things really exist'*" [35]. The observer's knowledge is not a thing. Nevertheless the creators of quantum mechanics considered spin states (13) or (14), which describe the observer's knowledge, as really exist in the real three-dimensional space. Bohm surpassed 'metaphysical realism' even more than the creators of quantum mechanics did. He considered in [57] even entangled spin states, in particular the EPR pair (1), as really exist in the real three-dimensional space. He wrote about the particles in the EPR state (1) that "*every component of its spin angular momentum opposite to that of the other one*" [57]. But for something to be the opposite of something, it must exist.

Bohm, like most physicists and unlike some creators of quantum mechanics, did not understand that components of spin angular momentum of particles do not exist before observation even if the states of these particles are not entangled. If the states are entangled, as in the EPR state (1), then even the spin states of the particles do not exist. The component of spin angular momentum of the particles A and B in the spin states (3), emerging after Alice's observation in accordance with the Bohr jump, are opposite each other but along the only direction z_1. The measurements in any other direction will give the same spin projections of the particles A and B, $\mid \uparrow_{A,z0}> \mid \uparrow_{B,z0}>$ or $\mid \downarrow_{A,z0}> \mid \downarrow_{B,z0}>$ with a non-zero probability, according to (13). This probability should be equal 1/2 when the direction z_1 and z_0 are perpendicular each other, i.e. $\theta = \pi/2$.

Bohm postulated the EPR correlation as a real interaction on the base of the claim that "*each atom would continue to have every component of its spin angular momentum opposite to that of the other one*" [57]. He substantiated this claim by the law of conservation of the components of spin angular momentum. But it is nonsense to use the law of conservation for non-existent variables. The law of conservation cannot be applied even for hidden variables since these variables are hidden because of their inevitable and unpredictable changes during measurement. Bohm, like most physicists, constantly forgot that quantum mechanics describes not what exists, but what is observed. The Bohr jump was also substantiated by Bohm on the base of the law of conservation.

The mistakes made by the authors of the GHZ theorem [38,39] are a direct consequence of Bohm's delusion, who considered the non-existent as existing. The authors [38,39], like Bohm [57], consider the entangled spin states, for example, the EPR state (1), the GHZ state [11] and the GHSZ state [39]

$$\psi_{GHSZ} = \frac{1}{\sqrt{2}}(\mid \uparrow_1 \uparrow_2 \downarrow_3 \downarrow_4> - \mid \downarrow_1 \downarrow_2 \uparrow_3 \uparrow_4>) \qquad (15)$$

as really existing in the real three-dimensional space.

The Bohr jump, postulated by Bohm [57] and accepted by almost all physicists as part of quantum mechanics, gave the EPR state (1) at least a subjective sense. Each observer knows that first measurement of the spin projection in any direction of any of the particles will give the result spin up with a probability of 1/2. The observer also knows the probability (9) to observe spin up of the second particle depends on the angle $\theta_2 - \theta_1$ between the measurement directions of the spin projections of the first and second particles. But no Bohm, no one else has said anything about how measuring one particle in the GHZ state [11] or in the GHSZ state [39] can affect the state of other particles. Therefore these states cannot have even the subjective sense. No quantum mechanics postulates that three [38] or even four [39] particles should jump into an eigenstate of the dynamical variable that is being measured on one of the particles. Therefore, the authors [39] had to limit themselves to the Dirac jump when they were deducing (F3) from (F1).

The authors [39,11] claim that perfect correlation should be observed for results of observations of the spin projection of three particles in the GHZ state and four particles in the GHSZ state. But quantum mechanics predicts no correlation if only the Dirac jump is postulated. The GHSZ state (15) predicts that measurements of spin projection in the same direction will give spin up with the probability 0.5 for all four particle if measurement of one particle does not have an influence of other particles. Moreover, the GHSZ state (15) predicts the probability 0.5 for measurements of spin projection in any direction of the first three particles since the mind of the observer can create a spin state in the real three-dimensional space only of the fourth particle, according to the Dirac jump (2).

The authors [39] misled themselves and others because they, like Bohm [57], surpassed "metaphysical realism" even more than the creators of quantum mechanics did. They, following to Bohm [57], were considering the entangled spin states in the GHSZ state (15) as really existing in the real three-dimensional space. According to quantum mechanics [52] the angles θ and ϕ, used in the expression for the expectation value (8) in [39] determine the direction in which spin projection will be measured relatively a z-axis in which this state is an eigenstate.

According to the Appendix F of [39] all four particles of the GHSZ state have eigenstates along the same z-axis. The expression (F7a) predicts that measurements of spin projections of each of the four particles of the GHSZ state along this z-axis will give spin up with the probability 1. But this prediction contradicts the prediction of the expression for the GHSZ state (7) in [39] ((15) in this work) according to which spin up should be observed with the probability 1/2 in any direction of the real three-dimensional space. This internal contradiction of the well-known publication [39] is a consequence of the naive realism not only of the authors of this publication, but also of many modern physicists who, even refuting realism, consider the spin state, which describes the observer's knowledge, as a real state existing in the real three-dimensional space.

8 Why variables can be hidden

The GHZ theorem [38,39] is one of the most obvious evidence of the mass misconception that resulted from a false understanding of quantum mechanics by most physicists. The title of the articles [1,2] contributed to this misconception. The title "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" is misleading for two reasons: 1) quantum mechanics describes the results of observation rather than physical reality; 2) this description is not complete, since quantum mechanics does not describe the observation process.

Einstein tried to convince young Heisenberg in 1926: "*But on principle, it is quite wrong to try founding a theory on observable magnitudes alone. In reality the very opposite happens. It is the theory which decides what we can observe. You must appreciate that observation is a very complicated process. The phenomenon under observation produces certain events in our measuring apparatus. As a result, further processes take place in the apparatus, which eventually and by complicated paths produce sense impressions and help us to fix the effects in our consciousness. Along this whole path - from the phenomenon to its fixation in our consciousness-we must be able to tell how nature functions, must know the natural laws at least in practical terms, before we can claim to have observed anything at all*" [64].

John Bell, who was agree with Einstein, wrote 63 years later: "*Einstein said that it is theory which decides what is observable. I think he was right - 'observation' is a complicated and theory-laden business. Then that notion should not appear in the formulation of fundamental theory*" [65]. But most physicists have never understood and do not understand now why it is quite wrong to create a theory on 'observables' rather than 'beables' [66]. Although Einstein explained to Heisenberg quite clearly that his proposal does not simplify, but complicates the task of the theory.

If we cannot create a theory of some quantum phenomena, for example, the Stern-Gerlach effect, in which no description of observation process should be, then we especially cannot create a theory in which this description should be. Heisenberg's proposal can simplify the task of the theory if only the theory of the observables does not describe the observation process. Quantum mechanics has created the illusion of describing paradoxical quantum phenomena by hiding all the difficulties in the observation process, which no theory can describe. Only Schrodinger [67] and few other critics were understanding that quantum mechanics is a trick rather than a physical theory. This fact is one of the manifestation of the degradation of physical thinking.

This degradation was also manifested in the ignoring by almost all authors of publications about Bell's inequalities of the seemingly obvious question: "Why can variables be hidden?" The answer to this question given by Bell in his first article [68] allows to unambiguously understand the sense of Bell's inequalities. Bell noted first of all in this article that variables should be hidden in order quantum mechanics could be an adequate theory: "*These hypothetical 'dispersion free' states would be specified not only by the quantum mechanical state vector but also by additional 'hidden variables'-'hidden' because if states with prescribed values of these variables could actually be prepared, quantum mechanics would be observably inadequate*" [68].

But only the desire to consider quantum mechanics an adequate theory is not enough to answer the question: "Why can variables be hidden?" Bell answers this question when he explains in [68] why it is incorrect to believe that "*the question concerning the existence of such hidden variables received an early and rather decisive answer in the form of von Neumann's proof on the mathematical impossibility of such variables in quantum theory*". Bell noted that von Neumann's proof and other proofs "*require from the hypothetical dispersion free states, not only that appropriate ensembles thereof should have all measurable properties of quantum mechanical states, but certain other properties as well. These additional demands appear reasonable when results of measurement are identified with properties of isolated systems. They are seen to be quite unreasonable when one remembers with Bohr [69] 'the impossibility of any sharp distinction between the behaviour of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear'*" [68].

Bohr and other creators of quantum mechanics wrote about the interaction with the measuring instruments rather than with the mind of the observer. Although hardly anyone can answer the question: "How can the measuring instruments interact with the probability of observation?" The

Dirac jump was postulated on the base of the Dirac assumption that "*after the first measurement has been made, there is no indeterminacy in the result of the second*" [55]. The degradation of physical thinking was manifested also in the ignoring of the obvious contradiction of this Dirac assumption with the Heisenberg uncertainty microscope [70] and the Bohr quantum postulate [71] according to which the interaction with the measuring instruments at the first measurement increases the indeterminacy in the result of the second.

One can agree with Heisenberg and Bohr that the first measurement can increase the uncertainty of the result of the second measurement. But it is impossible to understand how an interaction with the measuring instruments during the first measurement can ensure the determinacy of the result of the second measurement. Dirac obviously wrote in [55] measurement instead of observation. We know from our everyday experience that after the first observation has been made, there is no indeterminacy in the result of the second observation since our knowledge changes at the first observation. We know that we will see with the determinacy (with the probability 1) the coin lying face up at the second observation if we saw the coin lying face up at the first observation. We can think in the case of the coin that the determinacy is the result of the objective reality, the coin was really lying face up, and only our knowledge was changed because of the first observation.

But we cannot think so in the case of the observation of spin projection which can be measured in various directions. The Dirac jump, needed in this case, postulates a change in the spin state under influence of the change in the knowledge of the observer. Most physicists did not want to admit with this obvious conclusion of physical thinking. The EPR paradox [1] and Bell's inequalities [19] were needed only because of this unwillingness to admit this obvious logical conclusion. Bell's inequalities allow only to distinguish the trick with 'observation' in quantum mechanics from the trick with 'measurement' in a theory of hidden variables. If both theories postulate that neither the process of 'observation' nor the process of 'measurement' can be described in any way, then the requirement of locality is the only way to distinguish an observation, that is non-local, from a measurement, that should be local.

9 Conclusion

Young Heisenberg wanted to study the philosophy of science. He said Sommerfeld in 1920: "*Even so, I am much more interested in the underlying philosophical ideas than in the rest*". Sommerfeld answered: "*You must remember what Schiller said about Kant and his interpreters: 'When kings go a-building, wagoners have more work'. At first, none of us are anything but wagoners*" [64]. Quantum mechanics is a consequence of the revolt of Heisenberg and other creators of quantum mechanics against the king. This revolt was successful for three main reasons: 1) the success of quantum mechanics; 2) only a few modern scientists understand the meaning of the Kant philosophy; 3) most modern scientists believe that all our knowledge about Nature is based only on our experience.

This revolt is one of the manifestations of the revolt of the masses about which Jose Ortega y Gasset, the great Spanish philosopher according to

Schrodinger's opinion [67], wrote in his famous book "The Revolt of the Masses" published 1930 [72]. According to Ortega y Gasset the unprecedented increase in the number of scientists has led to "the barbarism of 'specialisation'", i.e. misunderstanding and even ignoring by most contemporary scientists of philosophical foundations of natural sciences: "*The most immediate result of this unbalanced specialisation has been that today, when there are more scientists than ever, there are much less 'cultured men' than, for example, about 1750*" [72]. Most contemporary scientists are sure that all our knowledge about Nature is based on experience. They follow in this confidence the representatives for early empiristic philosophy, Locked, Berkeley and Hume. But contemporary scientists, in contrast to 'cultured men' about 1750, do not know that no empirical cognition of Nature is possible if our knowledge is based only on experience.

Heisenberg knew that the empiristic philosophy "*was extended to an extreme scepticism by Hume, who denied induction and causation and thereby arrived at a conclusion which if taken seriously would destroy the basis of all empirical science*" [35]. But Heisenberg, unlike Einstein, did not understand that only the Kant philosophy saved the possibility of empirical science. His revolt against Kant is a consequence of his lack of understanding of the Kant philosophy. Unfortunately, most modern physicists understand philosophy much worse than Heisenberg.

Ortega y Gasset saw in this ignorance the main reason for the crisis of physics: "*Newton was able to found his system of physics without knowing much philosophy, but Einstein needed to saturate himself with Kant and Mach before he could reach his own keen synthesis. Kant and Mach - the names are mere symbols of the enormous mass of philosophic and psychological thought which has influenced Einstein - have served to liberate the mind of the latter and leave the way open for his innovation. But Einstein is not sufficient. Physics is entering on the gravest crisis of its history, and can only be saved by a new 'Encyclopaedia' more systematic than the first*" [72].

An example of the misunderstanding by Heisenberg of philosophy is in his memoirs [64]. Greta Herman, German mathematics and philosophy, tried in the early thirties to convince Heisenberg and Weizsacker that quantum mechanics cannot be a scientific theory: "*In Kant's philosophy, the causal law is not an empirical assertion which can be proved or disproved by experience, but the very basis of all experience - it is part of the categories of the understanding Kant calls 'a priori'. ⋯ The causal law is a mental tool with which we try to incorporate the raw material of our sense impressions into our experience, and only inasmuch as we manage to do so do we grasp the objects of natural science. That being the case, how can quantum mechanics possibly try to relax the causal law and yet hope to remain a branch of science?*" [64].

The objection of Heisenberg and von Weizsacker testified that they did not understand that it was logically impossible to refute a priori knowledge, which is a condition for the very possibility of experience, on the base of experience. This misconception of the creators of quantum mechanics has led to the confidence of the authors of [39] and of other numerous publications that realism can be refuted with the help of experimental results. They do not understand that realism and determinism are the regulative principles of our reason, which determine the very possibility of empirical cognition. The creators of quantum mechanics, in their desire to describe paradoxical quantum phenomena at any cost, forgot that our ideas about Nature are based not only on empirical knowledge, but primarily on a priori knowledge, such as logic and mathematics. That's why there are so many contradictions with logic and even mathematics [73] in quantum mechanics. The mistakes made by the authors [39] are one of the consequences of neglecting a priori knowledge.

The prediction by Ortega y Gasset of the crisis of physics and the creation of quantum mechanics roughly coincided in time. Another evidence of the crisis of physics is the theory of superconductivity created in the fifties [74,75]. The theory of superconductivity [74,75], like quantum mechanics, is one of the most successful theories of twentieth-century physics. Apparently, because of this success, only in 2020 attention was drawn [76–78] to the internal inconsistency of this theory: the one hand, the theory [74,75] is created within the framework of equilibrium reversible thermodynamics, and on the other hand, it predicts Joule heating.

This inconsistency appeared because of a mistake made by experts in superconductivity after the discovery of the Meissner effect in 1933 due to belief in the second law of thermodynamics [79,80]. The mistake made in 1933 is obvious [80]. But no one noticed this mistake for almost ninety years. This fact indicates that the majority believes rather than understands generally accepted theories. Einstein foresaw this attitude to quantum mechanics as early as 1928 when he wrote to Schrodinger [81]: "*The soothing philosophy - or religion? - of Heisenberg-Bohr is so cleverly concocted that for the present it offers the believers a soft resting pillow from which they are not easily chased away. Let us therefore let them rest. · · · This religion does damned little for me*", see also page 99 of [11].

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