On understanding of quantum entanglement: contemporary holistic approach

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Abstract. Idea of quantum entanglement is discussed in the context of debate about the Einstein-Podolsky-Rosen thought experiment and some theoretical studies of quantum systems. It is noted that Schrödinger invented this idea in 1935 in order to fix some features of the quantum-mechanical description of two systems with temporary interaction. However, he did not grasp essence of these features really. In view of the concepts of mixture and statistical operator proposed by von Neumann and adopted by Schrödinger in 1936, it is argued that the idea of entanglement and related terminology are not necessary in quantum mechanics. One can use this idea and terms «entanglement» etc. as «visual» surrogates for the «mixture – statistical operator» pair.

Deeper comparative analysis of several theoretical works by Schrödinger, von Neumann, and Landau showed that the modeling of non-trivial complex quantum systems as quasi-classical aggregates has been gradually overcome. Instead, wholeness of such quantum systems was actually recognized step by step. Thus, wholeness is immanent not only to quantum phenomena, as Niels Bohr had argued, but also to the quantum systems themselves, objectively. The pair «mixture – statistical operator» and especially the pair «mixed state – density matrix» similar to it appear to be adequate tools to comprehend and describe wholeness of diverse quantum reality. It is insisted, it is advisable to understand the surrogate idea of entanglement and relevant terminology in the same sense. In mature quantum paradigm, they are possible but not necessary theoretical tools to grasp wholeness of reality. Respectively, acceptable understanding of quantum entanglement must be based on recognition of quantum wholeness.

The clarified understanding of quantum entanglement, as well as Bohr's substantiation of wholeness of quantum phenomena, demonstrates irreducibility of the Universe to any quasi-classical aggregate. Moreover, all this supports the view of the Universe as real wholeness, which rational holism intends to grasp. It is concluded, contemporary rational holism has clear potential to replace the hitherto widespread worldview in the spirit of Democritus and pure analytical methodology of knowledge.

Keywords: quantum entanglement, Einstein-Podolsky-Rosen thought experiment, quantum wholeness, wholeness of the Universe, rational holism.

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I. Introduction

The Nobel Prize in Physics 2022 was awarded to Alain Aspect, John F. Clauser and Anton Zeilinger for experiments with entangled photons, establishing the violation of Bell's inequalities and pioneering quantum information science. In this regard, the Royal Swedish Academy of Science noted in the press release that each of these scientists have conducted groundbreaking experiments using entangled quantum states, where two particles behave like a single unit even they are separated [1].

Even initial analysis allows to comprehend that the described situation relates to some inequalities derived by John S. Bell in the 1960s and to experimental verification of their violation. To explain this violation, reference is made to *entanglement* of states of quantum objects, in particular photons.[1] However, are the key idea of entanglement and relevant terms understood fully and finally? In the regular human world, entanglement is easily visualized, for example, as a tangle of twisted threads and grasped in everyday reasoning. However, is it possible to spread this simple visualization and related idea to the systems formed from photons or electrons, which, although supposedly «separated», nevertheless behave as «single unit», that is, one indivisible whole? And if the situation is not quite simple and clear, what are scientists really dealing with?

Correct understanding of the idea of quantum entanglement seems to be a necessary step to reveal the revolutionary potential of quantum mechanics for physics and philosophy: this revealing is uncompleted until now, although it has been going on for almost a century. Moreover, it will be important to update the current worldview, basic methodology of knowledge. Some essential grounds in order to achieve this multilateral progress are discussed in my exploration (see also [3], [4]).

[1] In 2010, Aspect, Clauser and Zeilinger were awarded the prestigious Wolf Prize in Physics for their fundamental conceptual and experimental contributions to the foundations of quantum physics, specifically an increasingly sophisticated series of tests of Bell's inequalities, or extensions thereof, using entangled quantum states [2]. Thus, firstly, significance of their results has been verified during decades. Secondly, here attracts attention the recognition of not only new experimental data, equipment or methods, but also, perhaps above all, the fundamental conceptual contribution to the foundations of quantum physics, to the contemporary worldview in general at the end.

II. Emergence of the idea of quantum entanglement (1935)

History of the idea of entanglement in quantum mechanics began with Erwin Schrödinger's article «Discussion of Probability Relations between Separated Systems», published on October 28, 1935 [5]. This invention emerged under influence of Albert Einstein, Boris Podolsky and Nathan Rosen (EPR) publication «Can Quantum-Mechanical Description of Reality Be Considered Complete?» dated May 15, 1935 [6]. That is why, in order to understand the idea of quantum entanglement it is necessary to take into account the context of its emergence, directly formed by this article with the EPR thought experiment at its core. This experiment was proposed in frame of wide discussion about completeness of quantum mechanics. Briefly, it dealt with different direct and indirect measurements on «two systems, I and II, which we permit to interact from the time $t = 0$ to $t = T$, after which time we suppose that there is no longer any interaction between the two parts» [6, p. 779]. It is worth noting that from the very beginning EPR articulated just a thought experiment. This means that they operated with some ideal models and theoretical propositions ordered logically and expressed mathematically (see, e.g., [7, p. 181-185]).[2] Schrödinger, among other, attempted to fix some essential features of the evolution of «systems I and II» and to clarify quantum-mechanical description of it.

> When two systems, of which we know the states by their respective representatives, enter into temporary physical interaction due to known forces between them, and when after a time of mutual influence the systems separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own. I would not call that *one* but rather *the* characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction the two representatives (or ψ-functions) have become entangled. To disentangle them we must gather further information by experiment, although we knew as much as anybody could possibly know about all that happened. Of either system, taken separately, all previous knowledge may be entirely lost, leaving us but one privilege: to restrict the experiments to one only of the two systems. After reestablishing one representative by observation, the other one can

[2] Over time, this thought experiment, reformulated by David Bohm in 1951, provided the ground for the Bell's inequalities derivation and their real experimental verification (see, e.g., [8], [9]).

> be inferred simultaneously. In what follows the whole of this procedure will be called *the disentanglement* [5, p. 555].

This passage shows how in 1935 Schrödinger modeled in his thought the evolution of «two systems» under condition of some «mutual influence». Initially, they exist absolutely independently of each other; their states are known and described by the representatives ψ_1 and ψ_2. Then they enter into some «temporary physical interaction» and by this way coexist together. After a time, the interaction ends, and the same two separate systems with qualitatively the same representatives should appear anew. All this is quite consistent with the classical ideas of mechanism and mechanical evolution.[3] More generally, one has here a quasi-classical model of quantum reality. However, is this model true? Because of the «mutual influence», even after it ends, the renewed «separate systems» «can no longer be described in the same way as before». Indeed, they do not have simply others or even unknown representatives ψ_i: the very possibility to use these representatives as formerly is lost. However, in the 1935 article Schrödinger did not have any other theoretical tools to describe the interacted systems than such sort representatives. To overcome this deadlock he invented *a non-former way of using the former representatives*: he *hypothesized* their entanglement. Given not only the classical model of the «two systems» evolution but also classical mode of thinking and description in general, this idea looked like a strange deus ex machina. Referring directly to EPR article, Schrödinger also stated the following.

> Attention has recently been called to the obvious but very disconcerting fact that even though we restrict the disentangling measurements to *one* system, the representative obtained for the *other* system is by no means

[3]In the classical paradigm, mechanism is a unity of distinct objects, something composite, *an aggregate.* As Hegel dialectically pointed out, in this relation and dependence the objects remain equally independent; and they are external to each other [10, p. 274]. In other words, each of these *distinct objects is closed*, that is, completely separated from others and, even under any external mutual influence, internally self-sufficient, unchangeable by essence. Thus, classical mechanism is *a set*, a composition of separate qualitatively unchangeable constituents aggregated externally by means of «ropes and forces» – of the Democritus «hard atoms» in the very end. It is essential here that these constituents are considered qualitatively equivalent to both the initial components and the products of the mechanism decomposition; they all are described by the same representatives. Typical examples of the mechanism are mechanical clock or the Solar system according to Newton. One supposed that the mechanical aggregate must be completely knowable by means of regular analysis, which goes to structured sets of smaller and smaller constituents – down to a set of atoms and their external connectors: methodologically it means widespread until now pure *analytical approach* (see in detail [3, p. 233-235], [11, p. 47]).

> independent of the particular choice of observations which we select for that purpose and which by the way are *entirely* arbitrary. It is rather discomforting that the theory should allow a system to be steered or piloted into one or the other type of state at the experimenter's mercy in spite of his having no access to it [5, p. 555–556].

Seeing a paradox here, the theorist developed its description by means of the mathematical apparatus of quantum mechanics. For this, he used the idea and term «entanglement» again.

> Let x and y stand for all the coordinates of the first and second systems respectively and $\Psi(x, y)$ for the normalized representative of the state of the composed system, when the two have separated again, after the interaction has taken place. What constitutes the entanglement is that Ψ is not a product of a function of x and a function of y [5, p. 556].

According to this fragment, the idea of entanglement relates to the fact that because of temporary «mutual influence» of the «systems I and II» the resulting wave function $\Psi(x, y)$ cannot be factorized into independent functions of the coordinates x or y. This significantly differs from the wave function of the trivial set of initial components with known representatives $\psi_1(x)$ and $\psi_2(y)$, which has the form $\Psi_0(x, y) = \psi_1(x) \times \psi_2(y)$.

In general, according to Schrödinger's 1935 article, the idea of entanglement was directly invented to fix some unusual features of the mathematical description of quantum reality. First, no wave functions can be assigned to constituents of non-trivial complex systems. Secondly, the complex systems wave function are not factorable. It was clear, that these features differed essentially from both the classical model expectation and relevant mode of description at all. However, any reasonable *physical interpretation* of these mathematical features has not been proposed.

The exploration of quantum systems led Schrödinger to the original hypothesis and new terminology. To fix the «characteristic trait of quantum mechanics» ordinary expressions of everyday reasoning and communication were used – «entangle» and «disentangle», «entanglement», etc., but with the radical change in their content and scope. However, these inventions looked quite problematic, since they did not elucidate *physical essence* of the «trait», even more so – its worldview or methodological significance. Therefore, there is no reason to speak about real understanding or clarification of the idea of quantum entanglement in Schrödinger's 1935 paper.

III. The idea of entanglement is not necessary in quantum mechanics (1936)

To clarify the idea of quantum entanglement one must analyze following Schrödinger's article «Probability Relations between Separated Systems», published on October 26, 1936. It may come as a surprise at first, but this idea and relevant terminology were unused in this publication absolutely. How could this happen? In parallel with exclusion of the term «entanglement» etc., the Austrian theorist included two new ones for him – «*mixture*» and «*statistical operator*», which were proposed by John von Neumann a few years earlier.

> A well-known example of mixtures occurs when a system consists of two separated parts. If the wave function of the whole system is known, either part is in the situation of a mixture, which is decomposed into *definite* constituents by a *definite* measuring programme to be carried out on the *other* part. All the conceivable decompositions ... of the first system are just realized by all the possible measuring programmes that can be carried out on the second one [12, p. 452].

It is easy to see that Schrödinger's 1936 article had the same context as the previous 1935 one. Really, this article dealt with the EPR thought experiment with the key issue that «all the conceivable measuring programmes» on one part of the complex quantum system instantly «decomposed» another its separate part into relevant type of state. To grasp namely the *parts* of the system, Schrödinger used the concept of mixture; every mixture is described by the appropriate mathematical tool – statistical operator. In this way, the theorist actually recognized qualitative difference between the quantum system parts from its original components or from the quasi-classical mechanism elements; he confirmed the quantum-mechanical tools of describing these parts. Generally, the previous attempt to reduce composed, non-trivially complex quantum systems to quasi-classical aggregates was partially overcome.[4]

According to the 1936 publication, essential change of initial components into parts should be understood as the transformation from states with certain ψ-functions into «situations of mixture» with relevant statistical

[4] Schrödinger no longer thought about the distinct systems that coexist together because of temporary external interaction and must return to the qualitatively unchangeable states after some time. However, he still speculated about clearly «separated parts» of the «whole system». In general, the model of a complex system as a definite set of separate constituents, quasi-classical aggregate has not been overcome completely. Methodologically, Schrödinger's approach remained purely analytical.

operators. In view of the terms «mixture» and «statistical operator» the terms «entangled», «entanglement», etc. in fact turned out to be redundant. One can conclude that these inventions helped as some kind of *surrogates* for the term «situation of mixture», or simply «mixture», at a certain moment in the quantum theory development. However, quite quickly they exhausted the role of temporarily useful tools of theoretical thinking: this is main reason for their exclusion in the 1936 publication of their author.

IV. The idea of entanglement is a surrogate tool to describe wholeness of reality

Is it not too hasty to conclude that the idea of quantum entanglement and relevant terms are not necessary in consistent description of quantum-physical reality? And whether does not exist something essential in the EPR experiment, in composed quantum systems in general, that is grasped by this idea, not by the concept of mixture? To answer these important questions one has to expand the field of research. First of all, it seems promising to turn to von Neumann's results, which Schrödinger referred to.

Von Neumann argued introduction of these concepts of mixture and statistical operator by statistical nature of the quantum reality description. He distinguished two sources of this. There exists a statistical distribution of the quantity R, even though φ is one individual state, the theorist insisted. But such statistical consideration acquire a new aspect when one do not even know what state is actually present – for example, when states $\varphi_1, \varphi_2 \ldots$ might be presented with respective probabilities w_1, w_2 $\ldots$ (all non-negative, and sum to 1). This quite widespread situation is grasped theoretically as a mixture of all probable states and described by means of relevant statistical operator [13, p. 193-194].

Without plunging into deep physical and mathematical studies of von Neumann, now one will limit to stating that the theorist used the concepts of mixture and statistical operator also to describe complex quantum systems. Considering the system resulted from two initial components I and II, von Neumann noted that when I is in the state $\varphi(q)$ and II is in the state $\varsigma(r)$, then I + II will be in the state $\Phi(q,r) = \varphi(q)\varsigma(r)$. On the other hand, when a complex system is in the state $\Phi(q,r)$, which does not have the form $\varphi(q)\varsigma(r)$, then its constituents are to be mixtures, and Φ determines unambiguous relation between akin physical quantities of these constituents [13, p. 274–283].

The theorist recognized in this way, there are two different classes of quantum entities in general: separate individual systems described by some wave functions, as well as something qualitatively different – mixtures described by some statistical operators. These second entities are parts of non-trivial complex system. In addition, wave function $\Phi(q, r)$ of the complex system is not a product of factors depending respectively only on q or r, that is, it is not factorable. Thus, von Neumann, a few years before Schrödinger, had known the facts, which brought into life the idea of entanglement and relevant terminology. However, he had no need for these hypothetical inventions to describe complex quantum systems and their parts. Von Neumann's approach and results had predicted in advance that in 1935 there was no an unavoidable necessity in the Schrödinger's inventions. There is no such necessity today also. Hence, using early Schrödinger's terms «entanglement» etc. is not prohibited absolutely, but they are acceptable as some imperfect surrogates only.

In 1936, Schrödinger relied on the von Neumann's 1932 book «Mathematical Foundations of Quantum Mechanics» directly. Lev Landau's article «The Problem of Damping in Wave Mechanics», published in 1927, was apparently unknown to him. However, taking into account this publication of one of the well-known theorists of the 20th century allows a deeper understanding of complex quantum systems nature and consistent description.

At the very beginning of first paragraph «Coupled Systems in Wave Mechanics», nineteen-year-old Landau noted that a system cannot be uniquely defined in wave mechanics; we always have a probability ensemble (statistical treatment). If the system coupled with another, there is double uncertainty in its behavior, he added [14, p. 8]. Thus, such system differs from the initial system essentially. It has no wave function at all. Respectively, wave function for «the two systems together», i.e. resulted complex system, is not factorable. To describe this case Landau introduced a new tool – some «quantities α_{nm}», but he defined them only mathematically, without any special name [14, p. 9].

It is not hard to see that in fact Landau avoided equating complex quantum systems with quasi-classical aggregates. At the same time, it must be recognized that he used the term «system» without proper logical division, ambiguously – to describe both initial components of complex quantum systems and its real constituents. Such use did not exclude the model of complex system as definite set of separate entities connected by some external interaction: this is not too far from the classical paradigm. This conceptual and terminological inconsistency in Landau's 1927 article did not prevent him to derive important physical and mathematical results. One can understood this as a typical problem in transition from old to new physical paradigm: the early development of quantum mechanics still carried some «birthmarks» of the classical one. A few decades later in the quantum mechanics textbook written by Landau and his pupil Evgenii Lifshitz two different tools to describe quantum reality were used.[5] While did not rejecting description by means of wave function, Landau and Lifshitz did not consider this theoretical tool to be universal.

> Let us consider a system which is a part of a closed system. We suppose that the closed system as a whole is in some state described by the wave function $\Psi(x, q)$where x denoted the set of co-ordinates of the system considered, and q the remaining co-ordinates of the closed system. This function in general does not fall into a product of functions of x and of q alone, so that the system does not have own wave function [15, p. 38].

From this fragment and further explanation it becomes clear that a closed, self-sufficient and clearly separated system has a certain wave function. Instead, if the system begins to interact with something external and by this way really transforms into a part of a new larger system, then the possibility of description by means of a wave function just for this part is lost.

> We introduce the function $\rho(x', x)$ defined by
>
> $\rho(x', x) = \int \Psi^*(q, x')\Psi(q, x)\, dq,$
>
> where the integration is extended only over the co-ordinates q; this function is called the density matrix of the system... Thus the state of a system which does not have a wave function can be described by means of a density matrix. This does not contain the coordinates q which do not belonging to the system considered, though, of course, it depends essentially on the state of the closed system as a whole. The description by means of the density matrix is the most general form of quantum-mechanical description. The description by means of the wave function, on the other hand, is a particular case of this... [15, p. 38-39].

States of parts of complex quantum systems described by relevant density matrixes were called *mixed* – as opposed to distinct systems' *pure* states with some wave functions. One can see that the terms «mixed state – density matrix» partially correspond to the terms «mixture

[5] It is worth noting that this textbook was translated into English by John Stuart Bell in collaboration with British physicist and lexicographer John Bradbury Sykes. The first edition was published in 1958, the second in 1965. Bell derived his inequalities just within this period. Thus, one cannot exclude some hidden theoretical influence of Landau in the «Bell affair» absolutely.

– statistical operator» used by von Neumann and Schrödinger.[6] Thus, in the world-widely approved textbook, which represented the mature quantum-mechanical paradigm, the principal difference between closed, completely separate initial components and relevant parts of complex quantum systems was recognized definitely. The tools to consider and describe these related but principally different entities were fixed finally.

It is important to note that the emphasized dependence of density matrixes of parts on the wave functions of whole systems reflects the essential dependence of these parts on quantum systems as whole, on other related parts. One can conclude that in non-trivial complex quantum systems no parts exist separately from relevant others: they are not simply connected by some external forces but *non-self-sufficient* and *non-separable*.[7] Any such systems are not quasi-classical aggregates in all senses; strictly speaking, each of them are special *quantum wholeness*.[8] Due to this elucidation, both model of complex quantum system in the spirit of Schrödinger's 1935 article and analytical methodology of its knowledge are finally overcome in essence.

There is no an unavoidable necessity to use the idea of entanglement or related terminology in the mature quantum paradigm. At the same time, there is no categorical prohibition to all these to surrogate the pair «mixed state – density matrix» in order to grasp wholeness of non-

[6] Today it is recognized that factually von Neumann introduced density matrix in order to develop quantum statistical mechanics and theory of quantum measurements. In contrast, Landau was motivated by impossibility of describing a subsystem of a complex quantum system by a state vector (see, e.g., [16]). Hence, motives for this innovation, as well as its interpretation, in the researches of Landau and von Neumann were not the same.

[7] Well-known physicist and mathematician Aleksandr Aleksandrov provided an apt explanation of non-separability. There are no two electrons in a helium atom, but there is a «two-electron», which is formed from two electrons and from which one or two electrons can be separated, but which does not consist of two electrons, the academician noted in 1973 [17, p. 337] (see also [11, p. 50]). This statement is supported definitely in «Scientific Background of the Nobel Prize in Physics 2022»: «That a pure state is entangled means that it is not separable» [9, p. 1(18)]. It is worth to add that after entanglement the states will not be pure states of distinct objects: they will be mixed states of parts of whole quantum systems.

[8] Non-trivial complex quantum system is not really a set of separate constituents with some entangled states – instead, it is a special physical wholeness. However, if one tries to model the wholeness as a set in accordance with the analytical approach, the idea of entanglement must be introduced to make this model work. In other words, the idea of entanglement is a «correction for wholeness» under condition of using the quasi-classical model and analytical methodology to quantum reality. There are other similar «corrections», for example, the idea of exchange interaction in many-electrons atoms (see also [11, p. 50–52], [9, p. 1(18)]).

trivial complex quantum systems. Generally, in quantum physics the idea, term «entanglement» etc. are possible but not necessary theoretical tools to describe wholeness of reality. Respectively, acceptable understanding of quantum entanglement must be based on recognition of quantum wholeness, this is an issue of contemporary *rational holism.*

Comparative analysis of the theoretical results of Schrödinger, von Neumann, and Landau leads not only to understanding of irreducibility of complex quantum system to quasi-classical aggregate but also to recognition of its objective wholeness. Hence, wholeness is inherent not only to quantum phenomena, which Niels Bohr insistently emphasized [18, p. 2, 4], [3, p. 228-230]. Wholeness is immanent to non-trivial complex quantum systems in themselves, beyond measurement procedures. This is a basic attribute of quantum reality in general case.[9] One can generalize further: since the Universe is fundamentally quantum in nature, it is a true wholeness with necessity (see also [4, p. 70–72]).

The Universe is not absolutely ungenerable and imperishable, indivisible and immovable *the One.* Due to numerous critical studies of the Parmenides doctrine, this statement has been beyond even theoretical doubt long ago. At the same time, it is impossible to reduce the Universe to any *Set* of separate elements, similar to atoms of Democritus, and to their various compositions aggregated by means of «ropes and forces». With this in mind, one can say that no purely holistic or purely analytical approaches to understand the Universe have any significant prospects. Instead, the fundamental intellectual challenge remains actual today – to develop and regularly implement some contemporary synthesis, namely *rational holism*, or *holistic rationality.* The exploration of the idea of quantum entanglement, as similar as Bohr's substantiation of wholeness of quantum phenomena, some other findings seems right steps on this path (see also [11]). Therefore, the contemporary holistic approach has undoubted potential to replace still popular worldview in the spirit of Democritus and related analytical methodology of knowledge.

V. Conclusions

Schrödinger invented the idea of entanglement and related terminology in a 1935 article directly stimulated by the EPR thought experiment discussion. According to this Schrödinger's original publication, two

[9] Complete recognition of wholeness of quantum reality is an essential result of the long-term discussion of the EPR thought experiment. Final explanation of this thought experiment includes consideration of both appearances of quantum wholeness.

characteristic features of the mathematical description of quantum reality constitutes the entanglement: firstly, no wave function might be ascribed to constituent of composed, complex quantum system; secondly, the complex system wave function is not factorable. However, the theorist did not grasp this situation essence; he did not propose a physical interpretation of these mathematical features. Therefore, there is no reason to speak about real understanding or clarification of the idea of quantum entanglement in the 1935 article.

Schrödinger never once used the term «entanglement» and its derivatives in the following 1936 publication. Instead, he introduced two new for him terms – «mixture» and «statistical operator», directly taking them from the von Neumann book. Due to these ones von Neumann, a few years before Schrödinger, actually described that features, which in 1935 brought into life the idea of entanglement. Moreover, his results prepared rejection of the Austrian theorist's inventions: in order to describe complex quantum systems von Neumann had no need in the terms «entangled», «entanglement», etc. Hence, conceptually and in terminological apparatus of physical science they were not necessary unconditionally. These ones worked as not very consistent surrogates for the terms «mixture – statistical operator» at a certain moment in the development of quantum systems theory only.

Further comparative analysis of several theoretical results of Schrödinger, von Neumann, and Landau demonstrates, firstly, gradual overcoming of the modeling of complex quantum systems as quasi-classical aggregates in the spirit of Schrödinger's 1935 paper. Secondly, wholeness is immanent not only to quantum phenomena, which Bohr insistently emphasized, but also to complex quantum systems in themselves, beyond measurement procedures. This definitely objective wholeness finds recognition and theoretical description in the terms «mixture – statistical operator» and especially in the similar pair «mixed state – density matrix», associated with Landau. Given this, thirdly, their acceptable surrogates must be interpreted in the same sense. Hence, in advanced quantum paradigm the idea of entanglement and related terminology are possible but not necessary theoretical tools to describe wholeness of reality. Respectively, acceptable understanding of quantum entanglement must be based on recognition of quantum wholeness.

Both the exploration of the quantum entanglement idea and Bohr's reasoning about quantum phenomena demonstrate irreducibility of the Universe to any set of Democritus' atoms and their diverse combinations, to quasi-classical aggregates at all. Moreover, this enriches the view of the

Universe as real wholeness. One can conclude that further development and regular implementation of rational holism have the undoubted potential for revolutionary replacement of the hitherto widespread worldview in the spirit of Democritus and pure analytical methodology of knowledge.

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До розуміння квантової сплутаності: сучасний холістський підхід

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Анотація. Ідея квантової сплутаності обговорюється у контексті дискусії щодо мисленого експерименту Ейнштейна – Подольського – Розена і деяких теоретичних студій квантових систем. Вказано, що Шредінгер вимислив ідею квантової сплутаності у 1935 році з метою фіксації деяких особливостей квантово-механічного опису двох систем з певною взаємодією. Проте насправді він не осягнув сутність цих особливостей. А з огляду на поняття суміші та статистичного оператора, що були запропоновані фон Нейманом і у 1936 році запозичені Шредінгером, аргументовано, що ідея квантової сплутаності й пов'язана з нею термінологія не є необхідними у квантовій механіці. Цю ідею і термін «сплутаність» тощо припустимо використовувати як «наочні» сурогати пари «суміш – статистичний оператор».

Поглиблений компаративний аналіз низки теоретичних праць Шредінгера, фон Неймана і Ландау показує, що моделювання нетривіальних квантових систем як квазі-класичних агрегатів було поступово подолане. Натомість крок за кроком визнавалась цілісність квантових систем. Таким чином, цілісність іманентна не тільки квантовим явищам, що доводив Бор, а й квантовим системам самим по собі, об'єктивно. Пара «суміш – статистичний оператор» й особливо схожа з нею пара «змішаний стан – матриця щільності» виявляються адекватними засобами розуміння та опису цілісності багатоманітної квантової реальності. Стверджується, що доцільно розуміти сурогатну ідею сплутаності й відповідну термінологію у цьому ж сенсі. У зрілій квантовій парадигмі вони являють собою можливі, але не необхідні теоретичні інструменти осягнення цілісної реальності. Відповідно, прийнятне розуміння квантової сплутаності мусить базуватися на визнанні квантової цілісності. Філософськи кажучи, ідея сплутаності піддається розумінню і умовному прийняттю з огляду на сучасний раціональний холізм, або холістську раціональність.

З'ясоване розуміння квантової заплутаності, як і обґрунтування Бором цілісності квантових явищ, демонструє незвідність Всесвіту до будь-якого квазі-класичного агрегату. Більше того, усе це підтримує погляд на Всесвіт як на реальну цілісність, котру намагається осягнути раціональний холізм. Зроблено висновок, що сучасний раціональний холізм має явний потенціал заміни дотепер поширеного світогляду в дусі Демокрита та чистої аналітичної методології пізнання.

Keywords: квантова сплутаність, мислений експеримент Ейнштейна – Подольського – Розена, квантова цілісність, цілісність Всесвіту, раціональний холізм.

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