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Implicative logical nature of quantum correlations

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The well-known mysteries of quantum mechanics come down to two questions: (1) why the probabilities are primal in the description of physical reality, and (2) why these probabilities in the so-called pure quantum state are marvelously correlated, as confirmed by EPR experiments.

Evidently, there are no separate answers to these questions, because as soon as we know the nature of quantum probabilities we should know also the nature of their correlation. Both ends can be achieved by the trusted method of extending the general relativistic approach in physics to the ultimately general concepts of an 'element' and 'set'. Relativization of the concepts of 'element' and 'set' means that the world exists as an indivisible wholeness rather than as a set (of some elements) [1]. This is precisely in line with the quantum picture of the world. Since quantum systems in the so-called pure state cannot be completely expanded into sets of elements, we have to describe them in terms of the potential possibilities of extraction of such elements, and in terms of the corresponding probabilities that represent the objective real structure of quantum systems.

On the other hand, this quantum property of the world as an indivisible wholeness is responsible for the implicative logical properties of the structure of the potential possibilities of the quantum system, which has been rigorously confirmed by quantum correlation experiments. *Reduction of the wave function and the quantum correlation effects are a trivial consequence of the implicative logical organization of the potential options in quantum systems. These effects depend on relativism rather than on physical causality or materialism, and are produced by the changes* (resulting from measurement or physical interaction) in the structure of relations of the mutually complementary sides of reality. One of these sides reflects the actually existing structure of the system as a real (and physically verifiable) set, which only is relatively selectable (relatively because the system is ultimately not decomposable into elements and sets). The other side of the system — which is no less real — expresses the sets of potential options that are objectively available for the system and are generated by the same property of non-decomposability of the system into elements and sets. This property of ultimate non-decomposability of the system into elements and sets represents the third and the most fundamental aspect of physical reality — the quantum property of the world as indivisible unity. It is this property that governs the world of the potential options of the quantum system by the laws of logical implication depending on what takes place in its actual manifold configuration under the influence of measurement (or physical interaction).

[1] The term 'wholeness' has becomé a cliche, but its meaning in the quantum context is very precise albeit somewhat unconventional: whole as opposed to a set — that is, the ultimate unity that does not render itself to decomposition into elements and subsets, which are thus not applicable to its description. It is only this ultimate wholeness or unity that can be the natural source of the property of inseparability of particles described by the unified non-factorizable ψ-function.

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1. General relative approach

Simon Kochan [1] at the symposium on the foundations of modern physics in Singapore suggested that the paradoxes of quantum physics might be overcome through the general relative approach that was used successfully for overcoming the paradoxes of relativity (Lorentz contraction, etc.). It would be interesting to compare the special theory of relativity (STR) with quantum mechanics (QM) and see how helpful the application of the general relative approach can be in the problems of interpretation of quantum theory.

With this purpose, let us see what was needed in the interpretation of special relativity to gain an understanding of the kinematic nature of relativistic effects, and to remove the apparent contradictions. At the same time, we shall keep on looking for analogies in the foundations of quantum physics that could throw new light on its paradoxes. It is well known that even in the early years of his discussions with Einstein, Bohr emphasized the analogies in these so different theories.

It will be worthwhile to start with the key issues in the foundations of relativity.

In parallel, we shall address the foundations of quantum mechanics and try to follow in detail the analogy between STR and QM — noted by the classics of the new physics — on every key point, establishing a correspondence between each selected point in relativity and some issue in quantum mechanics. Strikingly, with all the difference in the content of these two fundamental theories of modern physics, we still find wonderful similarities and analogies in their foundations (Table 1). Looking at this table, we can make the following preliminary conclusions:

1. Essentially all that we see in Nature is *relations*, and all our knowledge eventually comes down to the knowledge of relations. All kinds of 'elements' and 'objects' that we introduce into the picture of the world are in the end certain 'nodes' in relations and on the network of relations. Or otherwise, these elements or objects, initially introduced as undefined, eventually find their definitions through the totality of the associated relations (the idea of the bootstrap, etc.). This is what the *relation* approach in physics is about.

2. The acceptance of quantum theory implies that the world eventually exists as an indivisible wholeness, and not as a set. This peculiar quantum property of the world as an indivisible unity gives rise to the implicative structure of the potential possibilities of quantum systems.

Without doubt, the proposed relation approach allows one to see certain similarities and even analogies in the foundations of relativity and quantum mechanics. At the same time, there are of course considerable differences in the foundations of these two branches of knowledge, that have to be emphasized (Table 2).

2. The nature of probabilities in quantum mechanics

The specifics of QM deserve a special treatment: the actual manifold and the potentially possible are two opposite although complementary and inseparably bound sides of the world. Hence the irremovable jumps and discontinuities in

Table 1. Comparison between special relativity and quantum mechanics (similarities and analogies).

Special relativity	**Quantum mechanics**
1. Formal source of the theory: introduction of the constant *c* as the speed limit for the propagation of physical signals, which imposes certain restrictions on measurements aimed at establishing space-time relationships.	1. Formal source of the theory: introduction of the constant *h* as the smallest possible portion of action, which imposes certain restrictions on physical operations aimed at establishing detailed states of physical system.
2. Rejection of absolute space and time	2. Rejection of the universal and absolute nature of the concepts of a set (and element) in the description of physical reality, because experimental verification of these concepts is limited by the finiteness of *h*.
3. Relativization of concepts of 'simultaneity', 'length', 'time' etc., based on the acknowledgement of their operator nature and on account of the finite speed of propagation of physical signals in the physical procedures of their determination.	3. Relativization of concepts of 'individual object', 'element', 'set of elements' in the description of physical reality based on the acknowledgement of their operator nature and on account of the finiteness of the constant *h* in the physical procedures of their determination.
4. Introduction of a new invariant — the four-interval in space-time.	4. Introduction of Planck's cell h^N (where *N* is the number of dimensions of the system) as an absolute invariant in the phase space of the system.
5. The object of description in STR are the space-time relations on manifolds of objects having a finite rest mass. The particular cross section of space-time relations is determined by the selection of reference frame.	5. The object of description in QM are sets of potential possibilities of the system that arise because the system cannot be completely decomposed into elements and sets. The particular combination of the potential possibilities of the system is determined by its actual manifold structure (definite value of momentum, energy, total spin, coordinate or difference of coordinates of particles comprising the system, etc.), which in its turn is formed by the particular macroscopic conditions of the existence of the system.
6. Upon transition from one reference frame to another, the relativistic invariant — the space-time four-interval — acts as a certain 'controlling factor' which sets the exact relations between the different cross sections and projections of the unified space-time depending on the selection of reference frame.	6. Upon transition from one actual manifold state of the system (determined by the macroscopic conditions) to another as a result of measurement or physical interaction, the cell h^N, always remaining whole and indivisible, acts as a 'controlling parameter', which transforms sets of potential possibilities in accordance with the changes that take place in the actual manifold state of the system.
7. As a result, the Lorentz transform of mechanical variables is a purely *kinematic* effect, caused by the *changes* in the space-time *relations* due to the transition from one frame to another.	7. As a result, the reduction a the ψ-function and quantum correlation effects are *not physically causal* and not even substantial in nature, but purely *relational*: these effects are a natural consequence of changes in the structure of relations of mutually complementary sides — the macroscopically determined actual manifold side and the inseparably connected and well-defined system of potential possibilities, caused by the physical non-feasibility of exhaustive decomposition of the system into elements and sets.

Table 2. Comparison between special relativity and quantum mechanics (important differences).

Special relativity	**Quantum mechanics**
1. Complete determinism	1. Fundamentally statistical nature
2. Continuous mathematical formalism and continuous transforms from one frame to another: the velocity of frames may vary continuously from 0 to *c*.	2. Irremovable mutual complementarity of the two sides in the state of the quantum system: (a) actual manifold side, determined by the macroscopic conditions and physically verifiable; (b) the set of potential possibilities in the structure of the quantum system, corresponding to this manifold side and governed by the inherent phenomenon of quantum wholeness, which is clearly and vividly manifested in the reduction of wave function and quantum correlation effects.

the transitions from one side to the other:

(a) the transition from the potentially possible to the actual manifold is always a jump because the potential and the real are opposites;

b) because of this, the physicist 'tears apart' the ψ-function in the act of reduction, but obviously only because the needle of his instrument already points to the corresponding jump (and discontinuity) in nature itself, in the state of the system. Both this jump and its result are essentially and irremovably probabilistic.

The main difference between QM and STR consists in the fundamentally probabilistic behavior of quantum objects, in the presence of irremovable sets of potential possibilities that are contained in the structure of quantum system. Now what is the objective source of quantum behavior of quantum systems?

In principle, there are two ways of obtaining probabilistic behavior for an object. The first is classical: we have a very concrete *individual object* that behaves in a stochastic way - for example, a die with six sides. We throw it a large enough number of times, and obtain a certain distribution of probabilities for each of the six possible outcomes, depending on the proper shape of the die, the position of its center of mass, etc. This is the subject of the ordinary (Kolmogorov) theory of probabilities. If we want to know the probability of getting any one of two or more outcomes, we simply add the individual probabilities, because they are the probabilities of independent events.

Such an approach, however, does not work in the case of quantum phenomena. It does not give an answer to the main questions: why is it that the probabilities represented by the ψ-function are, firstly, fundamentally irremovable, and secondly, interferable even when they are distributed over the entire infinite space - that is, why they are concerted and correlated, which is vividly manifested by the quantum correlation effects. In other words, why is it that in quantum mechanics we add amplitudes of probabilities rather than probabilities themselves?

The second — truly quantum — method for constructing the probabilistic description is different in principle. If we accept the thesis of the relativity and nonuniversality of the concept of an element (or set) in the description of physical reality, and the fundamental property of wholeness and non-decomposability of the world into elements and sets, then *we do not have any die as a separate element* (or event), even behaving in a stochastic way. We only have certain *possibilities* for selection (formation) in the experiment of one or another quantity (characteristic of the object), but always selected from the physical situation that is whole and ultimately non-decomposable into elements and sets. This particular quantity is revealed only through wiping out (dissolution, vanishing) other canonically conjugated non-commutating quantities. Thus, they never exist as jointly defined quantities: there is no quantum object as a separate and well-defined entity (like a die) — there are *only probabilities* of formation of certain characteristics, governed by the particular macroscopic conditions. The probabilities that arise here relate to the possibility of selection of particular elements from the state that is whole and unified, and not decomposable into elements, and so they are naturally concerted and correlated by the mere fact that they belong to this unified and indivisible whole state. This implies that the interference of probabilities can *only* be observed with the probabilities belonging *to one and the same event*, and not for two different events occurring in two different experiments, or different realizations of an event in the same experiment.

Indeed, as predicted by the theory and demonstrated in the experiment of R L Pfeegor and L Mandel [2], a photon only interferes with itself, and never interferes with another photon generated in another act of emission.

In this way, owing to the fundamental property of wholeness and indivisibility (formally expressed by the cell h^N in the phase space of the system), a quantum system *is not* a set (manifold) of certain entities, but a system of *relations* between macroscopically defined (macroscopically determined) elements (for example, a certain value of momentum, coordinate, total spin, etc.), and — owing to the fact that the system cannot be decomposed into elements and sets — the state-specific sets of potential possibilities of selection (definition) of the corresponding conjugated quantities (elements). For example, a two-particle system with total spin 0 will have certain combinations of potentially possible values of spins of constituent particles, each of which in its turn will appear as a superposition of probabilities of certain values of spin projections on three mutually perpendicular axes. It is important to note that the mutual complementarity of the actual manifold (but only relatively separable) side with the corresponding set of potential possibilities is based on the fundamental wholeness and ultimate indivisibility and non-decomposability of a quantum system into any sets of elements.

Finalizing the comparison of STR and QM, we may say that all paradoxes of quantum physics call for the development of the approach that was useful for resolving the paradoxes of relativistic physics: as soon as it came across that the relativistic effects are kinematic in nature, and therefore arise from the changes in relations caused by the transition from one frame to another, everything clicked into place, and relativistic mechanics ceased to be 'incomprehensible'.

A similar step is required in the development of foundations of quantum physics, with the important difference that while relativistic mechanics deals with sets of space-time relations that may be actually defined and jointly existing (from the standpoint of actually selected and coexistent reference frames), quantum mechanics describes mutual relationships of worlds that are in a certain sense opposite and complementary: the manifold world actually defined by the physical conditions of observation (or measurement), and — owing to its irreducibility to elements and sets — the potentially possible and probabilistic world, which is inseparable from the former. All the mysteries of quantum mechanics eventually come down to the relations between these two worlds, or, to be more precise, between the two opposite sides of one and the same unified world, which is ultimately indivisible and not decomposable into separate sets.

The ultimately detailed (pure) state of the physical system as defined by its ψ-function corresponds to a certain configuration of its actual manifold aspect, defined by the macroscopic conditions and represented by certain values of the observables. It includes the superposition of its possible states (or manifestations) in the world of elements and sets — the so-called potential possibilities of a quantum system. Any actually implemented changes in the real manifold aspect of the system (for example, resulting from measurement, physical interaction, etc.), which realize certain potential possibilities of the initial state and create new values of the observables, naturally create a new pattern of the mutual relationship of the actual manifold aspect of the system and a new set of potential possibilities corresponding to this new state. This means that the old wave function has to be crossed out and replaced with a new one corresponding to the new value of the observable (or the new actualized observable).

From this standpoint, both the reduction of the wave function and the quantum correlation effects are not physical processes, but rather changes in the mutual relations between the two sides in the states of physical systems: the actual manifold (and physically verifiable) side, and, owing to the incomplete decomposability of any physical state into sets and elements, the set of potential possibilities of the system, represented for each particular maximally detailed state by the appropriate wave function. And nothing more than this. We believe that this interpretation of the concept of wholeness in quantum mechanics will satisfy the most cool and sound-minded physicist. The only thing that is needed is the development of Bohr's phenomenological concept of wholeness to its logical end — to the rejection of the concept of a 'set' in a situation where this concept objectively loses its reasonable applicability.

Then the 'act of viewing' by the observer and the 'comprehension' of reading of the instrument is only a way in which the observer brings his knowledge about the state of the system into conformity with the objective changes in the structure of internal relations. The responsibility for the reduction of potential possibilities and quantum correlation effects in the system falls on the phenomenon of wholeness of the system as the objective basis of mutual linkage and mutual correlation of the actual manifold aspect of the system and the corresponding set of potential possibilities in the system.

3. Quantum holism as the theory of implicative structures of probabilities in quantum systems

The very feasibility of formulation of the famous Bell inequalities that led to experimental verification of quantum correlation effects implies that physical objects exist as real elements and sets exist on their own. Accordingly, the properties that enter Bell's inequalities characterize the object *by itself*. In the set of such objects any linkage between them is precluded, which is reflected in the properties of 'locality' and 'separability' of sets of such objects. This means that a system for which Bell's inequalities hold can and must be exhaustively represented as an actual set of certain objects or elements, which are characterized by the actual *inherent* (*immanent*) properties.

Let us illustrate this point with an example of Bell's inequality (see Ref. [3]). Assume that we have an object characterized by three variables A, B, C, each of which takes on the value of ± 1. If we assume that each particle exists as a particular element of the set of such objects, then each particle actually possesses quite definite one-time values of all three parameters A, B, B. Let us denote the case when $A = +1$ by A^+, and the case when $A = -1$ by A^-, and use the same convention for B and C. Then for any ensemble of such particles with arbitrary ABC we have

$$N(A^+B^-) = N(A^+B^-C^+) + N(A^+B^-C^-)\,,$$

where N is the number of particles with the appropriate properties. Let us write out the other equations as well:

$$N(B^-C^+) = N(A^+B^-C^+) + N(A^-B^-C^+)\,,$$

$$N(A^+C^-) = N(A^+B^+C^-) + N(A^+B^-C^-)\,.$$

From the last two equations it obviously follows that

$$N(A^+B^-) \leqslant N(B^-C^+) + N(A^+C^-)\,,$$

which is one of Bell's inequalities. Let us once again emphasize (this is clear from the above derivation of Bell's inequality) that the very feasibility of their formulation implies that the objects for which such inequalities hold exist as quite definite elements that are actually defined and actually characterized by these properties as such. In the sets of such elements any kind of linkage or interdependence is precluded. The algebra of observables with commutability is exhaustively realized on such an abstract set of actually defined and independent objects, which constitutes the essence of the mathematical scheme of classical mechanics (see Ref. [4]).

Instead of the quantities A, B, C one may speak of three mutually perpendicular projections of spins of particles, which for the photons assume the values of $+1$ or -1. Now one only needs a real experiment to verify these Bell's inequalities against the actual distribution of values of spins of photons resulting from the decay of some common quantum state according to the scheme of the known EPR experiment. Such experiments have been staged, and Bell's inequalities were disproved! Thus, the experiment brings us back to the view that the properties described by non-commutating operators are relations to the instruments, and do not exist 'by themselves' [3].

Assume that we have a quantum system consisting of two particles with total spin zero. The system occurs in the ultimately detailed so-called pure quantum state, described by the common wave function. Since the system cannot be detailed further (that is, the system cannot be decomposed into elements and sets), and exists as an indivisible whole, we have to speak of the constituent particles in terms of probabilities of their separation. This means that the structure of the system in this state is formed by the sets of potential possibilities of the states of its constituent particles. None of these states is real, and at the same time each virtual state contributes to the probabilistic structure of the total system. Actually and eventually existent here are only the sets of probabilities of separation of such entities as the first or the second particle, but not the particles themselves.

The existence of the world not as a set, but as an ultimately indivisible wholeness, is the most significant, most real and most plausible objective fact. In a sense, this fact is the expression of absolute reality.

Such wholeness is formally introduced in quantum mechanics through Planck's constant h. For each physical system this wholeness is manifested through the existence of the indivisible cell h^N in its phase space. Since the space of any real physical experiment or measurement is always a particular cross-section of the phase space, the existence of a whole and indivisible cell h^N in the phase space warrants the impossibility of achieving exact and exhaustive results of any physical measurement. The wholeness and ultimate non-decomposability of a quantum system into elements and sets, as determined by the cell h^N, forces us to describe its structure in terms of probabilities of decomposition of the system into elements in the experiment.

Hence follows an important conclusion: probabilities are primal (and non-removable) in observation. As a matter of fact, however, these probabilities are secondary with respect to the unobservable in principle and only logically comprehensible and absolutely objective phenomenon of wholeness, because they originate from it (from the property of ultimate non-decomposability of quantum systems into elements and sets).

The fundamental property of the wholeness of quantum reality, being the source of the potential possibilities of quantum systems, at the same time ensures their mutual consistency and correlation. The measurement of the spin projection of one of the particles after the decay of the initial system at the same time implies the transformation of the ψ-function for the second particle into the state with the appropriate (and strictly definite) anticipated result of measurement of the similar spin projection of the second particle, which follows from the initial value of total spin and the spin projection for the first particle measured at the first stage of the experiment.

This quantum correlation of the states of the particles (demonstrated in the EPR experiment) is a trivial consequence of the implicative logical organization of the probabilistic structure of the initial pure state of the primary total system, which follows from the quantum property of wholeness and ultimate non-decomposability into sets of elements of any kind. At the same time, these quantum correlations that arise in response to our free choice in the measurement of some observable or other, demonstrate the outstanding controlling function of the phenomenon of wholeness of the system. This indicates that even after the decay of the system the particles are not absolutely separate from one another. On the subquantum level both particles (separated from the initial state) and the entire world together with them exist as an indivisible unity [2].

For the sake of clarity, the arguments developed above were based on the semiclassical approximation, relying on the concepts of the phase space of the system and the cell h^N in the phase space. Today's mathematical formalisms of quantum mechanics have gone far from these constructions. However, our fundamental conclusions concerning the relativity of the ultimately abstract concept of a manifold in the description of quantum systems, the phenomenon of wholeness and the ultimate non-decomposability of quantum systems into elements and sets as the source of the irremovable probabilities in their description remain completely valid, being totally independent of the selection of the particular mathematical scheme of quantum mechanics. The same equally applies to the implicative logical organization of these probabilities in pure quantum states and the consequent implicative logical 'mechanism' of the quantum correlation effects.

In the most general form, the mathematical scheme of quantum mechanics can be represented as a physical realization of one of the algebras with the property of noncommutativity [4]. In this case, all the characteristic features of quantum mechanics are naturally derived from just one abstract property of noncommutativity of the observables (and noncommutativity of the corresponding operators): the primal and irremovable nature of probabilistic description of the observables, the uncertainty relations, the discrete values of the observables, the observables that are simultaneously non-measurable and simultaneously have no definite values (and hence the property of complementarity), and the like. What is wonderful is that in this way we eventually derive a certain constant whose value is found from experiment (and which is Planck's constant!). In this very general algebraic representation the mathematical scheme of quantum mechanics differs from the mathematical scheme of classical mechanics by one and only one feature — the property of noncommutativity. Accordingly, one may say that in the formal algebraic sense the entire specifics of quantum mechanics consist in the property of noncommutativity.

Now what lies behind such very general property of noncommutativity of certain elements: $AB - BA \neq 0$, or, which is the same, $AB - BA = C$ (where C is some constant)?

On this matter we can say the following.

First: the property of noncommutativity introduces a certain irremovable, non-eliminable, and non-selectable — with the aid of any manifold mechanisms (using auxiliary manifolds, 'hidden parameters', etc.) — linkage between the elements A and B. Otherwise these elements would become classical objects described by the commutative algebra.

[2] Another example of implicative structures are the structures of reasoning and consciousness, which are governed by the phenomenon of wholeness inherent in the psyche or mind. Hence the numerous appeals to consciousness in the search for the solution of quantum paradoxes.

Second: this linkage is so tight that the elements A and B are not only inseparable from one another, but even their individual existence as elements becomes *inevitably relative*, so that one of them can only acquire a sense of actual existence and actual definitiveness only at the expense of losing all definitiveness with respect to the conjugated element.

This means that the property of noncommutativity necessarily implies an essentially probabilistic description of the corresponding elements, so that the non-commutating elements $AB - BA \neq 0$ must be described in terms of probabilities (of their realization or definition).

Third: the nonzero commutator, being under certain conditions a constant, ensures normalization, mutual consistency and mutual correlation of the probability distributions for the possible values of the non-commutative elements A and B. In other words, it performs the same function of a 'controlling factor' in the organization of mutual correlation of probabilities for elements A and B that was discussed using the example of the cell h^N in the semiclassical approximation.

If in the course of further measurements in the experiment the elements A and B assume well defined values, the pure quantum state is destroyed, and the specifically quantum linkage between these elements is lost (referred to as 'indivisibility', 'inseparability', etc.). As a result, such elements render themselves to a classical description — that is, become the elements of commutative algebra or 'Bell's objects' for which Bell's inequalities hold.

4. Quantum holism and the many-worlds interpretation of quantum mechanics

Future historians of physics will certainly cite the Everett–Wheeler many-worlds theory as the most exotic interpretation of quantum mechanics. This interpretation exceeds in extravagance the conceptions of an absolutely elastic ether that had appeared before the advent of STR but lost their utility as soon as Einstein turned to the operational analysis of the real space-time relationships in the spirit of the relational approach. The same lies in store for the many-worlds interpretation, whose current popularity is explained by its utmost clarity. This concept is so consistently clear that the central problem for which it was invented in the first place — the problem of reduction of the wave function — is resolved simply by renouncing the very phenomenon of reduction of the wave function! To wit, it is assumed that the function describing a certain initial state represented by the superposition

$$\Psi(x) = c_1\psi_1(x) + c_2\psi_2(x) + \ldots + c_k\,\psi_k(x)\,,$$

describes at once a multitude of actually existent infinite worlds similar to ours. In other words, each term in this superposition has its own whole world that includes the measured subsystem, the instruments, the observer — in a word, to each his own, and a universe for each term in the superposition. Strictly speaking, this theory ought to be named the concept of many (or even infinitely many) world branching universes, because every new act of measurement generates a new layer of universes, corresponding to the new superposition of the new ψ-function, *et cetera ad absurdum*.

Since every time there are as many worlds as alternative results of measurement, and all worlds are equally real, the problem of measurement reduces to the issue of the observer getting into 'his' world — that is, the world he is actually observing.

As a result, even though this conception does not raise the issue of the 'mechanism' of reduction of the wave function, it raises the question of how the observer gets into this particular Everett world. The weakness of this theory becomes immediately all too obvious when we try to use it to explain the quantum correlation experiments. For this purpose we shall need to 'smear' every and all observers with certain weighted probabilities over all worlds represented in the initial superposition (which in some cases will be infinitely numerous!). In the EPR experiment with delayed selection we shall have to explain how the observer in Paris, who entered by random selection of the measurement the world with a given X projection of the spin of the measured particle, could — definitely after the departure of particles — shift the railway switch for the 'paired' observer in Tokyo in the appropriate strictly defined direction — to the world with the required X projection of spin of the Tokyo photon predetermined by the result of measurement in Paris.

None of the numerous advocates of the Everett–Wheeler theory has so far managed to demonstrate what happens to the observers, if they believe that the worlds are predetermined and that nothing happens with the worlds.

In brief, the problem is that even though the worlds are all predetermined, the observer in Paris at his own discretion and definitely after the departure of particles of the EPR pair can readjust his instruments and measure X, Y or Z projection of spin of his photon, thereby switching the rails for the observer in Tokyo, who is thus in a fatal and inexplicable dependence on the volition in Paris. After all, as demonstrated in Menskiĭ's paper [5], this conception, like any other existing one, appeals eventually to the consciousness of the observer. M B Menskiĭ greatly simplified the unavoidable appeal to the consciousness in the interpretation of quantum mechanics by identifying the consciousness with... the selection of one of the alternative results of measurement! Admittedly, the inevitable appeal to consciousness in any more or less consistent and well-developed interpretation of quantum mechanics is a notable historical fact. One only needs to recall the discourses on this topic by Niels Bohr, Wolfgang Pauli, John von Neumann, Erwin Schrödinger, and David Bohm, to name but a few. All this implies that there is a profound linkage between quantum mechanics and the functioning of consciousness. This allows M B Menskiĭ to speak of two unsolved fundamental problems: (1) how is one of the alternatives selected in quantum measurement, and (2) how does the consciousness work. In fact, the first problem is not stated clearly. Quantum theory is intrinsically and fundamentally probabilistic. Today everybody has got used to this fact. In the context of quantum holism, quantum theory is intrinsically probabilistic owing to the relative nature of the concept of an element in the description of physical reality. Therefore, the answer to the first question in the formulation of M B Menskiĭ was and remains a quantum mechanical standard: "the selection of an alternative in quantum measurement is random". Now we understand that this randomness is inevitable and irremovable, or fundamental.

Then M B Menskiĭ, feeling the connection between the problem of consciousness and the problem of measurement, resolves the linkage between them in a rather straightforward way — simply by announcing that the selection of the alternative is the word of consciousness, interpreting the 'selection' as the 'comprehension' of what takes place in reality. This path, however, has already been walked by von Neumann in his much more elegant and shrewd analysis, when he demonstrated that a consistent analysis of the problem of measurement inevitably leads to consciousness (to the act of comprehension of the reading of the instrument) as the last authority responsible for the *reduction* of the wave function.

Let us emphasize the major difference between the views of von Neumann and M B Menskiĭ. Von Neumann obviously accepts the standard Copenhagen interpretation of quantum mechanics with its initial and c o r r e c t (as proved by the entire evolution of quantum theory) idea of the primacy of probabilities. Therefore, he does not have the question posed by M B Menskiĭ "(1) how is one of the alternatives selected in quantum measurement". The answer is obvious — at random (with certain weight coefficients for different alternatives).

Of real importance is a different question considered by von Neumann: what happens in the act of measurement to the other terms in the superposition of the initial state — that is, to the other alternatives. This is the famous question of the reduction of the Ψ-function: what is the mechanism of reduction of the Ψ-function? So the correct formulation of the question raised by M B Menskiĭ ought to be different: (1) what is the mechanism of reduction of the wave function? Or, which is the same, what is the mechanism of quantum correlation effects (for example, in EPR experiments)? Question (2) remains the same: how does the consciousness work?

The answer to these questions is contained in the concept of the implicative structure of probabilities, represented by the nonfactorizable wave function. It is in the superposition

$$\Psi(x) = c_1\psi_1(x) + c_2\psi_2(x) + \ldots + c_k\psi_k(x)$$

that all terms of the superposition as the potentially possible states are equally real. Since their source is the property of ultimate indivisibility and inseparability of the initial state, the potential possibilities form from the outset as mutually linked and mutually correlated, which is formally reflected in the condition of normalization of the coefficients of the terms in the superposition.

Now in the act of measurement the r a n d o m realization of one of the possible states means that the coefficient for this state jumps to unity with an instantaneous vanishing of the coefficients of all other terms of the superposition owing to the implicative linkage across the entire set. This is the process of reduction of the wave function, which is implicatively logical in nature because it evolves in the world of potential possibilities, but as objectively real as any conventional causal process in the world of physical bodies and things. In the same way, the mechanism of quantum correlations has not a physically causal, but an implicative logical nature.

Thus, we have to agree that in the very foundation of Nature, in the essentially quantum domain, where the concepts of elements and sets are no longer relevant, these concepts are replaced by the world of potential possibilities of selection of some elements or sets. This world of potential possibilities is governed by the appropriate mechanism of implicative logical relations and dependences, which is manifested in particular in the effect of reduction of the ψ-function, quantum correlations like EPR linkage, and the like. As soon as we acknowledge this, we immediately understand the linkage between quantum mechanics and consciousness, of which much has been said already.

Indeed, all structures of consciousness are based on implicative (not causal) links and dependences. Psychologists know this well. For example, the founder of genetic psychology Jean Piaget based his concept of logical-algebraic structures of intellect on the idea of implicative links and dependences in the consciousness. According to him, "none of the concepts expressing physical causality... are applicable to the understanding of linkages in the realm of consciousness" (see Ref. [7], p. 19). Thus, even though it is a long way from the problem of quantum measurement to the problem of consciousness, the problem of quantum measurement uncovers a new and uncommon aspect of links and dependences in Nature, whose properties resemble the properties of consciousness and whose existence in Nature is prerequisite for the emergence of consciousness. However, the clarification of all these circumstances is a task for the future.

5. Conclusions

The main idea of quantum mechanics, whether in the form of the Planck constant or in the noncommutativity of certain observables, must be brought to the recognition of relativeness and nonuniversality of the abstract concept of set (manifold) in the description of quantum systems.

This entails the necessarily probabilistic description of quantum systems: since a quantum system ultimately cannot be decomposed into elements or sets, we have to describe it in terms of probabilities of only a relative selection of certain elements or sets in its structure. This gives rise to the potential possibilities of quantum systems in an actual physical situation and the corresponding probabilities are ontologically real, like any other physically verifiable relationships.

In this way, the quantum potential possibilities (and probabilities as their measure) are no less objectively real than the conventional reality which we identify with the physically directly verifiable elements, particles, etc. As observed by Albert Einstein, "a field for a modern physicist is as real as the chair on which he is sitting".

This remark wholly applies to the quantum field described by the nonfactorizable wave function — that is, to the distribution of probabilities related to the pure quantum state. Indeed, this distribution of probabilities is as objectively real and hard to the touch as chairs, walls and all other hard-to-the-touch physical things.

These probabilities, however, presented in the pure quantum state, have another remarkable property that cannot be imagined in the world of chairs or other macroscopic objects: in the pure quantum state the probabilities of selection of elements from the ultimately detailed state of the system are mutually coordinated and correlated by the phenomenon of wholeness of the system, and form an implicative logical structure governed by this phenomenon of wholeness.

This idea of implicative logical organization of the probabilistic structure of quantum system in the so-called pure (non-detailable) state, and the governing role of the phenomenon of wholeness (in the redistribution of probabilities depending on the nature of development of the real experiment) is in good agreement with the results of quantum correlation experiments (for example, the experiments of A Aspect, N Gisin, and others).

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Quantum measurement: decoherence and consciousness

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The letters to the editor received in response to my article in *Usp. Fiz. Nauk* [1] and published in this issue differ in content and purpose. In addition to comments on my article, their authors also present their own proposals for the development of quantum theory. Let the reader make his own judgment about the value of these proposals. In this note I will only answer the comments in my address made in three of these letters. These comments touch upon issues that are difficult in themselves, or were presented in my article too briefly. I hope that additional light will be thrown on the complicated issues raised in my article. To maintain the high level of the discussion, I will excuse myself from responding to remarks made in the other letters — in my opinion, they are addressed quite clearly in the article itself.

Article [1] is split into two parts, which are completely different with regard to the nature of the subject. The first (bigger) part is concerned with the particulars of the entangled states of quantum system and the related phenomenon of decoherence. The theory of decoherence explains how quantum measurement takes place. It resolves the paradoxes of quantum mechanics if we confine the treatment to open systems and do not attempt to find the mechanism of selection of one of the possible alternative results of measurement. This is quite sufficient for answering all the questions that can be reasonably asked within the framework of physics. From the standpoint of a physicist the question of selection is ill-posed or unnecessary, and any real system is open — it is only the entire Universe that is absolutely closed.

In the second part of the article we discuss the conceptual problems that arise when we go beyond the subject (methodology) of physics and look into the mechanism of selection. At this deeper level of analysis the paradoxicality of quantum mechanics remains, and the description of quantum measurement is not possible without explicitly including the consciousness of the observer in the consideration. To resolve the problem of selection at this level, we propose to identify two concepts: (1) the selection of the alternative quantum measurement, and (2) comprehension of the result of measurement by the observer.

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