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FROM "PARADOXES" AND "INTERPRETATIONS" TO QUANTUM PARTICLE – NEW PRIMARY IDEAL OBJECT[1]

1. Introduction

This year we celebrate the centenary of **'old'** quantum mechanics birth and 75 years since the birth of the 'new' quantum mechanics. I suggest that the **'new'** quantum mechanics is a quality jump which isn't fully understood yet. The reason is **absence of adequate concepts** (notions) of philosophical reflection. This is the reason why only in quantum mechanics we have many so called "interpretations" and debates around them. This is the foundation of the existence of so called "phenomena" of the "reduction of wave function", "quantum theory of measurement", 'incomprehension' of quantum mechanics , statements about including the consciousness in quantum mechanics and Bohr's variant of "nonseparability of quantum phenomena".

The roots of this defect lie in the empiricism of F.Bacon with its standard sequence:

$$\boxed{\textbf{Empirical facts}} \;\Rightarrow\; \boxed{\textbf{Empirical generalizations}} \;\Rightarrow\; \boxed{\textbf{Theoretical laws}} \qquad \textbf{(1)}$$

which I'll call the "Standard Empirical View" and principles of empirical verification and falsification. Going through the Viena Circle it transforms into so called "Received View" [1]. By the end of the 18th century D. Hume and I. Kant had already showed that the last step is impossible taken from inside the empirical logic. In 20th century Hume's critique was renewed by K. Popper, B. S. Van Fraassen, supported by A. Einstein. T. Kuhn, and others did a new critique of the "Standard Empirical View" from the point of view of the *history of science*. But the "Standard Empirical View" and its daughter the "Received View" is still alive even though many of its elements have been broken by the severe critiques from philosophers of science. The reason for such a situation is the absence of a good fundamental alternative. This is the resume of Patrick Suppes he said it in 1969 [1, p. 4, 12, 15] but situation didn't changed radically from our point of view.

2. The Primary Ideal Object Model View

I want to sugest a fundamental alternative to the "Standard Empirical View" and to its children. I call it the "model view" of physics. This alternative begins from G.Galiley who was almost of the same age as F.Bacon. The attempt is made to do the work the same way D.Hilbert's has done on the foundations of geometry in the end of the 19th c.

My analysis of the works of Galileo, Newton, Maxwell, and other creators of *new branches of physics* [2] shows that the development of physics is directed by **Euclidean geometry** as the fundamental prototype of a scientific theory supplemented with engineering relationship between main theoretical objects and empirical material, instead of Bacon's empirical method.

There are two very important common features in **geometry and physics**:

1st is the existence of **two types** of **ideal objects:**

a) `primary ideal objects' - PIO (such as the points, lines, and planes in *geometry* and the particles, fields, etc., in *physics*) and;

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b) `**secondary ideal objects'** (such as polygons in geometry and models of phenomena in physics);

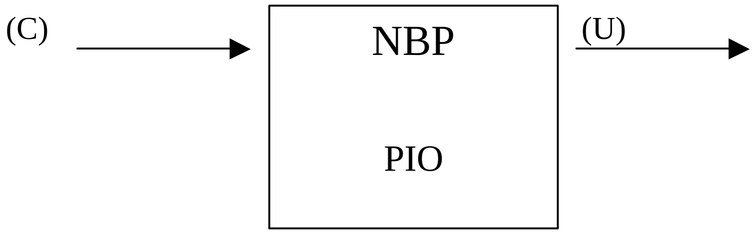
2nd is The existence of **two types of definitions:** 'secondary ideal objects' are **defined separately and explicitly** with the help of the 'primary ideal objects' and; 'primary ideal objects' are **defined implicitly and in common** within *the system of basic concepts (**notions**) for a specific branch of science.*

The most difficult task is to define the "primary" ideal objects**.** We can do it **only implicitly** with the help of ***'Nucleus of a branch of science'*** (**NBS**) which is the *minimal system of notions and postulates that define the appropriate system of basic **concepts***. In geometry its analogue is the system of axioms of geometry.

The **PIOs** are the main concepts of every branch of physics (such as classical or quantum mechanics, electrodynamics, and so on). All theories of any branch of physics (that is theoretical models of phenomena) are made of these 'bricks'.

The **two types** of ideal objects **-- `primary' and 'secondary'** lead to the existence of **two types of work in science.** The **first** is the '**creative**' one (we designate it by **'C'**). It is the most interesting for us since it represents the creation *phase* of new 'primary ideal objects' (such as quantum particle or electromagnetic field) and, accordingly, a new branch of physics (or other science). The s**econd** type of work involves the 'utilization' of the existing PIO**.** This **'utilizing'** phase (we designate it on Sch.1 by '**U**'). It takes the created 'primary ideal objects' and uses them for modeling-explanation and constructing-prediction of various natural phenomena. In the history of science these phases are fixed as various answers to the question: What is the goal of **science: "to explain" or only "to describe"** natural phenomena? For the most part the creators of new branches of physics—G. Galilee, J. Maxwell, N. Bohr, and A. Einstein (in his early works) proclaimed the "descriptive" approach.

(scheme 1)



There is nothing absolutely new in such distinction. It is common to both *A. Einstein's* division on `**principle'** and `**constructive'** theories and *T. Kuhn's* division on **'anomalous'** and **'normal'** science. However usually **in the analysis** of science only the latter 'utilizing' case is considered. We will concentrate on the 'creative' phase.

The **'nucleus of a branch of physics'** has a very clear structure common to all branches of physics. It consists of three parts: **preparatory (P), theoretical (T),** and **measurement (M)** (Sch.2). In 'utilizing case it represents the structure of an experiment, where

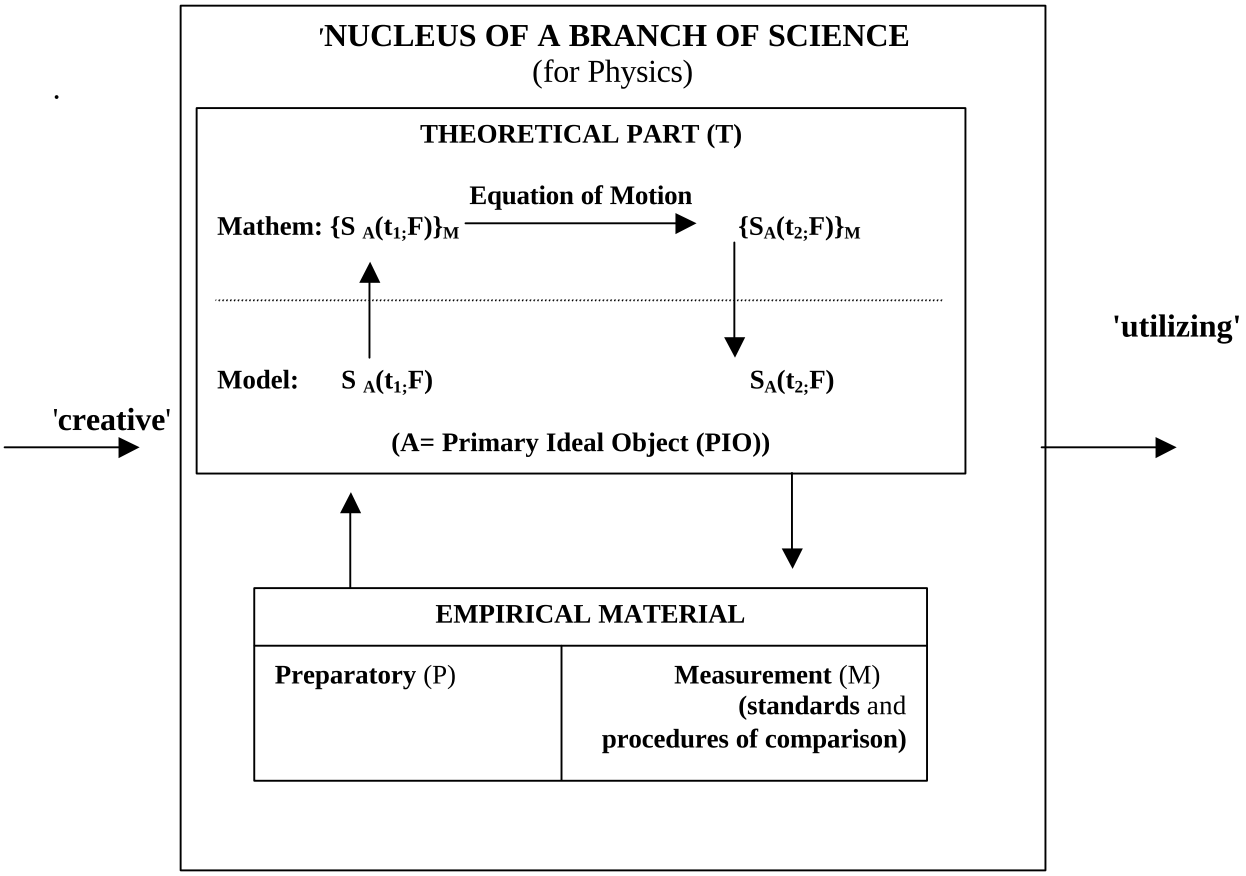
(Scheme 2)

P	T	M

the theoretical part is a leading one. Any experiment exists only in connection with the theory, which says what to prepare and what to measure. Without the theory one can say about an observation only. The theoretical part, **T**, consists of **mathematical** (**Math) stratum** and **physical model (Mod) stratum** illustrated in ‘scheme 3’.

In the simplest case the theoretical part includes the **physical system (A)** composed of one primary ideal object, and the **states** of the system ($\mathbf{S_A(t)}$) at time t. There are external action **F** (external forces and so on). The whole structure gives the representation of **motion as a transition** in time from one state to another.

Scheme 3



The connection of states is defined with the help of the **Math-stratum,** which contains the mathematical representatives (images) of the elements of Mod-stratum and the **equation of motion** (EM), which integrates all the elements of the Math-stratum and forms a mathematical representation of motion. The equation of motion defines the dynamical or "**diachronical"** qualities of the system, and also its "**synchronical**" qualities (the range of states of the system).

I want to emphasize that **all these concepts are defined implicitly and in common!**

All the elements of the Model stratum must have a **realization in empirical material**. This is fulfilled with the help of the **preparatory** (P), and **measurement** (M) parts. The physical system and its initial state are created in the preparatory part. The measurement part contains the **standards** and procedures of comparison with it for every measurable quantity[2] or observable (such as distance, velocity, mass, etc.).

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[2] We try to use term 'measurable quantities' instead of conventional 'observables' to stress the difference between a phenomenon which is *observable* (the subject of theory) and '*measurable quantities*' which are observable but cannot be the subject of theory.

3. <u>The postulates of quantum mechanics</u>

All above concerns any branch of physics[3]. It is a subject of my book [2]. Now let's apply these concepts to quantum mechanics.

My statement is that in the **'old'** quantum mechanics the **famous "wave-particle paradox ('dualism')"** was formulated and **in** the **'new' quantum mechanics** it was solved by its transformation into the new 'primary ideal object' - the **quantum particle**. The transformation was realized by few steps, which fill the structure on schemes 2-3 with concrete content.

The **1st step** is Schroedinger's postulates. They introduce the *mathematical representation of a state* and the Schroedinger's *equation of motion* (we'll show the general scheme on the example of this Schroedinger's representation)

$$i(h/2\pi)\partial\Psi_A/\partial t=H_A^{op}\Psi_A,$$

Here Schroedinger's wave function (ψ-function) is a **mathematical image of the state** of a system. **Hamiltonian operator (**$H_A^{op)}$ **is the mathematical image of system A** (including external action if it is), which is a quantum particle or a system of quantum particles.

For completeness we are to add here **the principle of superposition**, which says that superposition of any two states of a system is a state of a system too.

The **2nd step** is N. Bohr's postulates which define the **procedure of quantization** of the "**starting classical system**". According to this procedure we begin from the starting classical model of particles (f. e., model of atom as an electron in central positive electric field). Then the classical Hamiltonian is constructed for this model. Then **after Bohr the kinetic and dynamic variables are replaced by abstract symbols (now called operators)**[4], which belong to a noncommutative algebra [3]. So indirectly **through the classical model** a correspondence between quantum system and its mathematical image (the operator of Hamilton H_A^{op}) is established.

$$\begin{tikzcd} H_A^{cl} \arrow[r] & H_A^{qu} \\ A^{cl} \arrow[u] & A^{qu} \arrow[u] \end{tikzcd}$$

(scheme 4)

Thus nonclassical mathematical representation is confronted with the "starting classical system". As a result we get the model with nonclassical behavior.

It establishes a correspondence between the main mathematical representative of the system in Math-stratum - Hamiltonian (or Lagrangian in quantum theory of field) and its physical model (the left arrow on scheme 3). Look for the origin of the Hamiltonian of any concrete quantum mechanical problem and you find this procedure.

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[3] In fact the basic postulates (`experimental facts'), from which all branches of physics are deduced, give answers to questions: 1) about the physical system; 2) about the states of system; 3) about their mathematical representations; 4) about the equation of motion; 5) about the procedures of connection between the 1st & the 2nd and the 3d. Since these elements are linked to a certain inertial reference frame, the question arises 6) about the transformation from one frame to another, and 7) how to determine the measurable standards and procedures for observabkes (M). Answers to these questions form the substance of the nucleus of a branch of science in physics [2].

[4] By replacing momentum p in classical Hamilton function by differential operators $ð^{op} = -(ih/2\pi)\partial/\partial õ$, which act on Schroedinger's wave functions.

The unusual moment here is the distinguishing of the physical system and its mathematical representation, and especially of the state of physical system and its mathematical representation – wave function. Very clearly (distinctly) model stratum is manifested in using different 'mathematical representations' (i.e. mathematical images of the physical system, its states, and corresponding equation of motion): such as Schroedinger's, Heisenberg's, interaction and others for one problem (task) (this is the reason for the headache for the philosophers who reduce the theoretical part to equations). But most clearly the model stratum appears in the procedures of quantization of the "starting classical system".

The **3d step** is Born's **rules of probability interpretation of wave function** *(PIWF)*, which establishes the correspondence between the mathematical representatives in the Math-stratum of the physical **state** of a system and the procedures of measurement in **empirical material**-stratum (right arrows on scheme3). Just these rules **bring probability in quantum mechanics**. Notice that the connection of states in quantum mechanics, which is determined by Schroedinger's *equation of motion,* is as deterministic (unique) as in classical mechanics.

By Born's rules mathematical images of measurable quantity *U* is presented by the set of functions $\{\chi^u{}_k\}$ in the same Gilbert space[5]. By **Born's rules** the results of measurement are to be equal to one of the u_k with the probability of this result to be proportional to the square of the amplitude of the corresponding component of the wave function spectral expansion in terms of the $\{\chi^u{}_k\}$ (that is $|c_k|^2$ if ψ-function looks like $\psi(x,t)= \sum c_k\chi^u{}_k$).

On the other hand Born's rules of *probability interpretation of wave function* deal with the procedures of measurement to define the state of the system. There is a significant **change in the measure procedures** in comparison with classical mechanics.

Let's define more exactly the idea of the state of quantum system. I give the idea of the **state of system in physics** in the following form: we can say that we know the state of a physical system in the moment *t* if we can answer all the questions about the system's behavior possible for **this branch of physics** with the help of this knowledge[6]. We suppose that **all the questions** possible **in quantum mechanics are about the distributions of probabilities** of values of measurable quantities (observables) **not of values themselves**. Thus one needs a sufficiently large series of measurements to get the distributions of probabilities and **cannot** confront (identify) the state with a separate value **of one act** of measurement **neither before, nor after** this act[7]. Such definition of the concept of state doesn't contradict Born's postulates and is the intrinsic generalization of the concept of state in the case of quantum mechanics.

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[5] This is made with the help of the operator of measurable quantity u^{op} (there is the canon to find such operators) for every measurable quantity. Functions $\{\chi^u{}_k\}$ and corresponding values u_k are the eigenfunctions $\{\chi^u{}_k\}$ and eigenvalues u_k for the operator u^{op} such as $u^{op}\chi^u{}_k= u_k\chi^u{}_k$.

[6] This definition partly coincide with van Fraassen's one: 'if we knew the state, then we would know all there is to know about how the system will develop if left alone and how it will react if acted upon' [10, p.275]. The main difference is the exclusion of a measurement as the variant of such 'action-upon'

[7] Thus in EPR-experiment according to Born's postulate one act of measurement dasn't define the state too. And if one does a sufficiently long succession of acts of measurement for showing up the distributions of probabilities of the values of measurable quantities, he'll have a trivial result of equiprobable of opposite directions of spins' projections, and the logic of EPR-paradox is destroyed. Only the just (anti)correlation between display of two detectors remains. This correlation is usually taken as a proof of 'nonlocality' of quantum phenomena. But such correlation is possible in classical models too [11].

This is the whole system of postulates for the definition of nonrelativistic quantum particle which is the new 'primary ideal object' (PIO). For a many-particle systems we must to add the postulates of indistinguishability and identity of quantum particles which leads to the statistic of Bose-Einstein and Fermi-Dirac (and Pauli's principle in the latter case).

This was done near 1925 and after the appearance of this new PIO there is no place for so called “interpretations”. Remember the situation with the electrodynamics. There “interpretations” of Maxwell’s equations were changed to new PIO – electromagnetic field and now nobody says about “interpretations” of Maxwell’s equations. This is a result of creation of full NBS, it is not matter of a habit.

4. 'Complementarity' and the 'principles' of 'complementarity' and 'uncertainty'

Now let's consider the most striking consequences of the postulates of quantum mechanics, which determine its 'incomprehension'.

They are Bohr's 'complementarity principle' and Heisenberg's 'uncertainty principle', which became a part and parcel of 'Copenhagen Interpretations' by general opinion.

Every quantum or classical mechanical system is characterized by a set of measurable quantities (observables). But in quantum mechanics these quantities break up into ***complementary*** 'measurable parameters'. It is the result of 'wave-particle dualism'. In Math-stratum the *complementary* quantities have operators which don't commute with each other. Physical manifestation of this quality is the Heisenberg 's **'uncertainty principle'.** It says that for any system's state the product of their uncertainties is not smaller than a half of Planck's constant. The sentence "it's impossible to measure any two quantity with any accuracy" one should to understand logically, not in a temporal sense, i.e. **not in the sense that measurement of one quantity disturbs the other**. We emphasize that the 'uncertainty principle' is the property of system's state, which goes from the standard quantum **theory** – from *Schroedinger's equation* and expresses the typical wave quality. 'Uncertainty principle' isn't an additional postulate.

Starting from this accurate definition of *complementarity* a set of measurable parameters of a quantum mechanical system breaks into a number of **sets of simultaneously measurable parameters'** {u}, i.e. parameters which don't come under action of the 'uncertainty principle'. In Math-stratum every such set gives **the complete space of the states of the system and the basis** for expanding the wave function $\psi(x,t)= \sum c_k \chi^u_k$. The wave function is a mathematical image of the state of quantum mechanical system and contains the **complete information** about the state of the system. **And a measurement of** the distributions of probabilities of values of one ‘set of simultaneously measurable parameters' leaves the phases of the factors unknown and one can not get wave function from these data. But one can get the whole reconstruction of wave function (or its equivalent) "by **tomographical methods** from the measured distributions of observables that are certain combinations of the non-commutating variables forming the phase space" [4, p.150].

This feature of quantum states we compare with Bohr's **'*complementarity principle'*.** In such a single meaning performance, used in practical work in quantum mechanics the **'*complementarity principle'* looses its vagueness[8].** It looses **many features, which**

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[8] One is to take in mind that in 1949 A. Einstein said that in spite of his numerous attempts he couldn't clear up exact formulation of Bohr's complementarity principle [12, p. 674].

Bohr ascribed to it either. First of all it concerns the central Bohr's thesis about nonseparability of quantum phenomena, about " the *impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments".* **In real physical work there is no problem of distinction of "atom object' and 'measurement device'**. A physicist can prepare the state **of the system**, get the theoretical value of the wave function for the final state and thus give answers to all questions (including questions about *complementary parameters*) about it, which are sensible in the quantum mechanics.

We want to accentuate that '*complementarity principle', and* '*uncertanty principle'* are not 'principles' but properties of quantum mechanical systems and their states and **not the result of "interaction with device" under measurement**. These properties are consequences of *the Schroedinger's, Born's and Bohr's postulates* described above. They are not independent principles or postulates.

5. Myths about the "reduction (collapse) of wave function"

5.1. Analysis of basic statements

There are 3 statements in the basis of the 'phenomenon' of "reduction (collapse) of wave function":

The 1st proclaims that a measurement is a phenomenon which must be described by the quantum theory; the 2nd one proclaims that this phenomenon consists in immediate change of wave function of the system from $\Psi=\Sigma_k c_k|b_k>$ to $|\boldsymbol{b_1}\rangle$ with probability $|c_1|^2$ (according to Born's rules) and this jump is named the "reduction (collapse) of wave function"; **the 3d** one proclaims that this change cannot be described by Schroedinger's equation and **is 'illegitimate'. The problem of the "reduction (collapse) of wave function" is in include this 'illegitimate' change in quantum theory.**

The ‘ quantum theory of measurement’ has the same basis.

Since its formulation in the1930th by von Neumann this problem is regarded as very serious (in 'second', philosophical stream) and one introduces **consciousness** [5; 6] or many worlds [7] in quantum mechanics for its solution.

Thus let's **analyze** these theoretical statements and see if they are well-founded.

Already the **first thesis** is doubtful. The most important feature of scheme 2 is the non-theoretical character of **P** and **M** parts. By **'nontheoretical'** we mean **the part (such as** comparison with standard in the procedures of measurement) **which cannot be described inside the branch of physics where it is used**. The border between them may be moved but not removed.

The same problem face **in classical** mechanics if we want to include inside the Newton theory the procedures of distance measurement by a rule. Such demand is undoubted only **from the Laplace's point of view** (close to Schroedinger's one with his cat), which proclaims that as all (including man) consists from atoms, and atoms are described by mechanics, than all can be described by the laws of mechanics. The ground of such physicalist look is an atomistic paradigm by which the properties of a system are completely determined by the properties of its elements and interactions between elements. The system paradigm, which has been developing very intensively from the World War II, suggests quite a different thesis. It confirms that properties of a system may not be derived from properties of its elements (and interactions between the elements). This thesis shows the Achill's heel in the logic of Laplace, Schroedinger and their adherents. One cannot derive scientists and science, which they build, from the

Newton's or Schroedinger's equation. Quite the opposite, we are to analyze the structure of physical science to understand what elementary particles and other physical objects are. After we do it and take the heterogeneous character of the description of physical phenomena, many "paradoxes of quantum mechanics" will disappear immediately.

Now let's see the **main argument in favor of the statement (2).** It is J. von Neumann's statement that results of two successive immediate measurements of some quantity must be the same (we mean the 1st sort of measurement in Pauli classification). This statement von Neumann deduced from Compton-Simens's experiments on the photon-electron collision. This statement became the indisputable argument. But is this interpretation right?

The correct formulation of the problem of the repeated measurement in Wilson's chamber was made by L.Schiff [8] within the bounds of standard quantum mechanics based on Schroedinger's equation. Here it is the problem of calculating the distributions of probabilities of exciting two atoms by quickly passing particle (electron). The result gives the perceptible probability only in the case when the particle moves almost parallel both to the line which connects the atoms and the final direction of the particle. In other words experimental results which usually are taken as basis for the statement (2) may be described by ordinary quantum mechanics without statement (2). Thus statements (1) and (2) are baseless.

The same situation we have with the **3d statement**. Its right formulation fixes the difference between process of changing states described by Schroedinger's *equation of motion* and procedures of measurement, described by Born's rules.

Today practically all known experiments are described quantitatively by standard algorithms of quantum mechanics and Born's postulates (if the model is right).

To **sum up** we can say that Born's postulate is the basis postulate of quantum mechanics which is consistent with all known experiments. As for the concept of the "reduction of wave function" in the moment of measurement, it is a superfluous concept. The core of a measurement is the comparison with the standard, which cannot be the object of theory in principle. We suppose that understanding (intelligibility) in physics is connected with depiction of physical model of PIO and principally the situation in quantum mechanics with quantum particle after 1925-27 is like the situation with electromagnetic field in the beginning of the 20th century.

In the end I want to say that in my analyzes I tried to fulfil A. Einstein's thesis "Don't hear what they (physicists) say, but study what they do". By the latter I mean first of all my own practice (I worked in quantum theory about 10 years and my 1st dissertation was on this subject) and the practice of my late co-author of a large paper on this subject D.N.Klyshko [9], who was a great specialist in quantum optics.

1. Suppes P. The Search for Philosophic Understanding of Scientific Theories. In: The Structure of Scientific Theories (Editted with a Critical Introduction by Frederick Suppe)Urbana, Chicago, London, 1974

2. Lipkine A.I. Permissible Boundaries in the Development of the Natural Sciences. Phystech Journal.1994, vol.1, No 3, p. 85-96;

Lipkine A.I. Models of Modern Physics (the View from Incide and Outside) Moscow, 1999 (in Russian)

3. Bohr N. 'Atomic theory and mechanics', Nature Suppl. **116**, 845—852 (1925); 'Die Atomtheorie und die Prinzipien der Naturbeschreibung', Naturwiss. **18**, S.~73—78 (1930); 'Discussion with Einstein on Epistemological problems in atomic physics. In: Albert Einstein, Phylosopher--Scientist', Evanston, pp.201—241 (1949);

4. Kurtsiefer Ch, Pfau T, Mlynek J, *Nature* **386/13** 150 (1997).

5. Neumann I.von, Matematische Grundlagen der Quantenmechanik, Berlin (1932)
6. Penrose, R. *Shadows of the Mind*, (London, Oxford Press, 1994)
7. DeWitt B.S. *Phisics Today*, **23** N 9 p. 30-35 (1970); **24** N 4 p.36 (1971);
8. Schiff L I Quantum Mechanics (N.Y.:McGraw-Hill Book Co.,1955)
9. Klyshko D.N. (1), Lipkine A.I. About the "reduction of wave function", quantum theory of measurement, and incomprehension' of quantum mechanics "Electronic Journal "Investigated in Russia", 53å, p. 703-735 (2000) http://zhurnal.ape.relarn.ru/articles/2000/053e.pdf or http://zhurnal.mipt.rssi.ru/articles/2000/053e.pdf
10. Bas C. van Fraassen The Scientific Image . Oxf,1980
11. Evdokimov N.V., Klyshko D N et al. [*Physics-Uspekhi* **39** (1996)]. Klyshko D N *Physics-Uspekhi* **41** (1998)]; b) Klyshko D N *Phys. Lett.* **A 218** 119 (1996); *Laser Phys.* **6** 1056 (1996).
12. Einstein A. In: Albert Einstein: Philosopher-Scientist (Evanston, 1949)