PREMISES OF THE FORMATION OF SYNERGETICAL PRINCIPLES IN THE CONTEXT OF THE BECOMING OF THE QUANTUM-RELATIVISTIC WORLDVIEW

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ABOUT THE STRATEGY OF THEORETICAL INVESTIGATION

The strategies of theoretical investigation in scientific cognition do not remain forever given and invariable; they are changing along with the evolution of the science.

Since Bacon and Descartes, philosophy and nature study used to believe that it is possible to find the only true strict way of cognition which could guarantee formation of true theories in any situations and concerning any objects. Foundations of the classical science included this ideal. Changeability and variety of concrete methods were not denied, but the aim of investigator was considered to be a united strategy of theory yielding. It was supposed that first the investigator was to find evident and obvious principles formulated as generalization of experience, and then, on their base, to seek for concrete theoretical laws.

This strategy was believed to be the only true way, the only method which leads to the true theory. As to investigations in physics, they required creation of an integral image of the reality studied, as a preliminary condition for the following employing of mathematical means to describe it.

The development of science in the 20 century has made people reconsider these methodological attitudes. Even in the late 19 century, when historical changeability of the fundamental principles of science, relativity of their empirical justification when they are accepted by the scientific community (empiriocriticism, conventionalism etc.) were discovered, the first critical observations towards the classical strategy of investigation were made. Certain doubts in the classical methodology as an absolute, reflected in philosophy of that historical period, may be regarded as the preliminary step in formation of a new paradigm of theoretical cognition. But this paradigm itself was firmly established in science in a great part due to becoming of modern quantum-relativistic physics, the first of sciences which demonstrated non-classical strategies of yielding of a theory.

A prominent Soviet physicist L. I. Mandelshtam characterized them in the following way: "Classical physics mostly acted so that determination of links between mathematical magnitudes and real objects preceded equations, i. e. establishing laws, moreover, the discovering of equations was the main goal because the contents of the magnitudes in advance seemed clear, and scientists sought equations for them. ... Modern theoretical physics, though not deliberately, but historically it is true, has chosen a different way. It happened by itself. Now first of all we try to guess the mathematical apparatus operating magnitudes meaning of which (at least partly) is entirely unclear"[1].

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[1] Mandelshtam *Lectures on Optics, Relativity Theory and Quantum Mechanics*, Moscow. (in Russian) (1972,

This mode of investigation, which has become domineering in the 20 century physics, was connected with broad application of a special method which was called mathematical hypothesis or mathematical extrapolation.

General characteristics of this method is as follows.. In order to find laws of a new area of phenomena, we take mathematical expressions for laws of a neighboring sphere, which are then transformed and generalized so that we could obtain new correlations between physical magnitudes. The obtained correlations are regarded as hypothetical equations describing new physical processes. After corresponding experimental verification, these equations either get status of theoretical laws, or are rejected as non-fitting to experience[2].

The characteristic given reflects the most important feature of development of modern physical theories: unlike classical patterns, they start as if from top storeys — search for mathematical apparatus, and only when equations of the theory are found, scientists begin to interpret them and look for empirical justification. Though, we probably cannot extract more out of the characteristic of a mathematical hypothesis. Further specification of this characteristic requires that we determine how a mathematical hypothesis is formed in science and what is the procedure of its justification.

In synergetics only first steps have been made yet. And S. I. Vavilov's interesting observations about existence of regulative principles (correspondence, simplicity etc.) are important here, which give aim and direction to the search of adequate mathematical means[3]. S. I. Vavilov, who introduced the term "mathematical extrapolation", formulated a special group of problems connected with the discussion of the nature of corpuscle-wave dualism. It was said that specificity of mathematical hypothesis as method of today's physical investigation is not the fact that while creating a theory we transfer mathematical means from one field to another (this method has always been used in physics), but mostly in peculiarities of such a transfer itself — in today's mode.

S. I. Vavilov emphasized that mathematical extrapolation (in its modern variation) has appeared due to the fact that visual images which used to be the basis for creation of mathematical formalism in classical physics, now, in quantum-relativistic physics have lost their integrity and visuality. The picture of the world taken by modern physics reflects specific features of micro-objects by means of two complimentary representations — corpuscular and wave. Therefore, it looks impossible to work out a unified visual physical model of reality as a preliminary basis for a theory. We have to elaborate a theory concentrating on purely mathematical work connected with reconstruction of equations "dictated" by various analogue images. This is where we can see the unconventionality of mathematical extrapolation of nowadays. "Experience leads reflection of the spheres of the world, which are unfamiliar and alien to a common person, to our conscience. We lack familiar images for visual and model interpretation, but logic... in its mathematical form, still works and introduces order and links in a new, unwonted world"[4].

If we understand mathematical hypothesis this way, we have to ask a question: how does it regard the picture of the world which takes into account the specificity of new objects. It is evident that — in a hidden form — we are dealing with the problem of heuristic picture of the world as a preliminary base for search for adequate mathematical means employing in formulating laws of physics. All these problems need special discussion.

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p.329).

2 Vavilov ‘On mathematical hypothesis’, in: Vavilov, S. I., *Selected works*, vol.3, Moscow. (in Russian) (1956, pp.156-157, 282-285). Mandelshtam. (1972, pp.326-329), Kuznetsov *Selected works on methodology of physics*, Moscow. (in Russian) (1975, pp.140-155).

3 Vavilov (1972, pp.79-80).

4 Ibid, p.80.

Peculiarities of modern forms of physical picture of the world and their role in putting forward mathematical hypotheses

The specificity of modern pictures of the world may give the impression that they emerge only after a theory has been formed, and so theoretical search nowadays is not directed by their influence.

Though, we may come to conclusions of such kind only after quite prompt consideration of modern investigational situations. More profound analysis discovers that in modern investigation the process of putting forward mathematical hypotheses may also be ruled by ontological principles of the picture of the world.

An example of the said is establishment of quantum electrodynamics.

So, in connection with synergetics and its principles it is important to emphasize that new strategies of cognition do not cancel the preceding classical models. The latter, though modified, may be reproduced in modern theoretical search as well. Non-classical strategies of investigation may co-exist along with the classical ones, interact with them and appear in a spectrum of variations — from evidently alternative (to the classical models) to hybrid ones, which combine various features of classical and non-classical investigation.

In evidently non-classical situations theories really are created before the new picture of the world appears. And still, the conclusion about disappearance of directional functions of the picture of the world seems hasty. We are to bear in mind two important circumstances.

The first one concerns the process of raising problems, the process which starts construction of fundamental theories. Special relativity theory and quantum mechanics were initiated by discovery of paradoxes in the system of physical knowledge which emerged when scientists tried to correlate new facts and new theoretical conclusions generated under directing influence of previously formed picture of the world with this image itself. These paradoxes arose in terminological interpretation of corollaries of Lorentz' s transformations and corollaries of Planck' s law of radiation of absolutely black body. These paradoxes transformed into problems which encouraged theoretical research and led to construction of special relativity theory and quantum mechanics.

Though the new physical picture of the world appeared at the late stage of construction of these theories, its earlier version participated in raising problems, so we may say that certain aspects of directing role of the picture of the world remain also in modern research.

The other circumstance connected with the role of the picture of the world in construction of modern theories may be defined as reinforcement of significance of its operational aspects. We believe that this is the main feature of non-classical strategies of construction of a new theory.

Under modern circumstances, pictures of physical reality are created and reconstructed differently from the way which worked in the era of classical development of physics. They used to be created as visual patterns of structure and interaction of natural objects, i. e. types of measuring procedures, which gave an opportunity to reveal the corresponding objects, were presented in a veiled form. Nowadays the investigation uses a method which can be called — in certain aspects — contrary. The future picture of physical reality is fixed first as the most general pattern of measuring, and objects of a certain type should be inspected within its frame. The new picture of the world is given in its incipiency at this stage, while the structure of the physical reality studied is defined by means of the pattern of measuring: "nature has objective characteristics, recognized within the frame of such and such type of measurements". By the way, these characteristics first are given as a quite approximate image of structure of the interactions studied, by means of fragmentary ontological ideas which are united in a system due to explication of an operational scheme. Only later does relatively clear and "quasi-visual" idea appear, the idea of structural features of the physical reality, which is revealed in the type of measurements given and represented by the picture of the world. We can find

examples of such way of investigation in the history of modern physics. Let us regard, for instance, Einstein' s works ofthe period when he was working out the main ideas of the special relativity theory. It is well known that formation of this theory started from generalization of the relativity principle and creation of the scheme of space and temporal changes which would consider finite signal propagation velocity necessary for synchronization of watches in inertial frame of reference. First Einstein explicated the scheme of experimental and measuring procedures which was the basis of Newtonian ideas of absolute space and absolute time. He demonstrated that those ideas had been introduced due to a recent postulate: watches, which are in different frames of reference, are correlated by means of instantaneous signal transmission[5]. Since no instantaneous signals exist, and any interaction is transmitted at a finite speed, Einstein offered another scheme of measuring space and temporal coordinates in inertial frames of reference which have watches and rulers. Synchronization of the watches by means of light signals which spread at a constant speed irrespective of the movement of the light source was the central point of that scheme. Objective qualities of the nature, which could be also revealed through this type of experimental and measuring actions, were reflected in the ideas of space-temporal continuum, where space and temporal intervals, taken separately, are relative. But these ideas — in their "ontologized" form — were reflected in the physical picture of the world later, only after the special relativity theory had been created. At the early stage of yielding the new picture of the world the features of the physical reality mentioned were presented in direct connection with the operational scheme of investigation.
The same specificity, in certain sense, can be traced in the process of becoming` of the quantum picture of the world. What is more, here the history of science lets us trace clearly, how the development of atomic physics led us to changes in the classical mode of construction of the picture of the world.

In the history of quantum mechanics we can single out two stages: the first one, which based on the classical methods of investigation, and the second, modern one, which has changed the very strategy of theoretical research.

However unusual the notions of the quanta of electromagnetic energy introduced by M. Planck were, they still did not break the very method of theoretical research. After all, Faraday' s ideas of force fields were not less revolutionary than the idea of discreteness of electromagnetic radiation. So, when Planck' s works introduced the idea of discreteness of radiation into the electrodynamics picture of the world, it was a revolutionary step, because the old picture of the world was blown up from the inside. But Planck' s ideas did not exercise direct influence on the classical methods of yielding the picture of the world, which was created as a visual image of natural interactions. Further development of physics was related to efforts to create a quantum picture of reality in accordance with the ideals of the classical approach. Here de Broglie' s investigations are characteristic. De Broglie offered a new picture of the physical reality which included a statement about specificity of atomic processes, and introduced "visual" image of atomic particles as inseparably connected with the "waves of matter' . According to de Broglie, movement of the atomic particles is tied with some wave spreading in the three-dimensional space (the idea of a pilot-wave). Those ideas played a great role at the initial stages of quantum mechanics development. They gave basis to the natural analogy between the description of photons and electrons and provided transmission of quantum characteristics introduced for photons, to electrons and other elementary particles (de Broglie' s picture of the physical reality provided us with the choice of analog models and working out certain theoretical schemes, which were to explain wave qualities of electrons).

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[5] Einstein ‘Can Quantum-Mechanical Description of Physical Reality be considered complete?’, *Phys. Review* 47, pp.777-780. (1965-1967, vol.2, pp.23-25).

Though, de Broglie' s picture of the world was "the last of the Mohicans" of visual application of quasi-classical notions to the image of the physical reality. Schrödinger tried to develop this picture, introducing an idea of particles as wave packages in the real three-dimensional space, but failed, because his efforts provoked paradoxes in theoretical explanation of the facts (the problem of stability and reduction of the wave package). After M. Born had found the statistical interpretation of the wave function, it became clear that waves, a "package" of which should have formed a particle, are "probability waves". Since that time physicists have more and more often regarded as an anachronism the efforts to introduce a visual picture of the world by means of classical models. It is becoming evident that the ideas of a corpuscle and a wave complement each other but are not compatible with each other within the same visual image.

The development of science showed that the object of the new type, studied by quantum physics, is extremely unlike the objects known, and, according to S. I. Vavilov, "we lack familiar images for a visual and model interpretation of its image". But a general image of the reality studied was still necessary, as it defined the strategy of theoretical search, directing the choice of analog models and mathematical means to put forward productive hypotheses.

Under these circumstances a turn to the new method of construction of the picture of the world was happened. Here a great part belongs to N. Bohr. The image of the physical reality was now built as an "operational scheme" of objects studied, and we may say that their characteristics is what is revealed within the scheme. Bohr' s approach can be characterized not by introduction of hypothetical ideas of the structure of nature as foundation for new concrete theoretical hypotheses, which are to be verified experimentally, but by analysis of the scheme of measuring which can help reveal the corresponding structure of the nature.

Niels Bohr was one of the first scientists who clearly formulated the principle of quantum-mechanical measuring, different from the classical pattern. The latter was based on extraction of a self-identical object of the material world. It was believed that the strict demarcation line separating the object from device would be drawn since in measuring it is always possible to take into account all details of influence of the device over the object. But the objects in the quantum sphere are quite specific, and detailing of influence of the device over the object can be accomplished only with precision determined by the existence of action quantum. Therefore the description of quantum phenomena includes description of essential interactions between atomic objects and devices[6].

General features of a micro-object are defined by means of clear description of characteristics of two complementary types of devices (one is used, for instance, to measure coordinates, the other — to measure impulse). Complementary description is a method to reveal basic and profound features of a quantum object.

All these principles introduced "the operational scheme" which lay in the foundation of the new picture of the world created by quantum physics. Through such a scheme scientists could fix (as activity) essential features of a quantum object. This object, according to the new view, was presented as having a special "two-level" nature: a micro-object in its existence is stipulated by macro conditions, and they are inseparable. D. Bohm wrote that quantum mechanics makes us reject the assumption which lies in the foundation of many common statements and images: that we are able to analyze separate parts of the Universe, and each of them exists independently[7]. But this image of a quantum object has not been differentiated yet and not presented as a system-structural description of interactions in the nature. So we can

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[6] Bohr *Quantum Theory,* New York: Prentice-Hall, Inc. (1970-1971, vol.2, p.510).

[7] Bohm‘Problems of the style of thinking in natural science’, in: *Philosophy and natural science. On 70th anniversary of academician B. M. Kedrov*, Moscow. (in Russian) (1952),

predict further development of quantum-relativist picture of the world. Probably, it will lead us to notions of the structure of natural objects which include quantum characteristics as natural ones. The decisive part in such development will belong not only to new achievements of quantum physics, but also to philosophical analysis necessary to prepare usage of new system notions for description of the physical reality.

Approach to quantum objects as complicated self-organizing systems seems very fruitful. This problem has already been widely discussed in literature, including Russian literature. As early as in the 1970s authors tried to interpret the specificity of quantum mechanics description in terms of complicated systems. Yu. V. Sachkov, for instance, mentioned two-level structure of quantum mechanics' concepts: there are concepts which, on the one hand, describe the unity of the system, while on the other hand, represent typically random characteristics of the object[8]. The idea of such dismemberment of the theoretical description correlates with the idea of complicated systems which are characterized by subsystems with stochastic interaction of the elements and, on the other hand, some "controlling" level securing integrity of the system.

The idea that quantum mechanics notions may be correlated with description of the reality in terms of complicated, self-regulating systems has also been postulated by G. N. Povarov[9], V. I. Arshinov[10]. My works of the 1970s also promoted this idea[11].

The foreign literature of that time present more or less detailed concepts alike in the works of such physicists as G. Chew, H. Stapp, D. Bohm, B. Hiley, philosopher F. Kapra and others.

In the conception of "bootstrap", which appeared on base of S-matrix approach, G. Chew offered a picture of the physical reality in which all elementary particles obtain system integrity. They are as though laced together by generating reactions, but no one of them should be regarded as fundamental for others[12]. The American physicist-theorist H. Stapp worked with notions of the physical reality in the same direction. He paid special attention to ideas of non-locality, impossibility to combine requirements of causation and localization of micro-objects in a quantum mechanics description. Such incompatibility is expressed in the complementarity principle (complementarity of causal and spatial description).

Correspondingly to these ideas Stapp outlines a new ontology, which states: the physical world is a system unity, irreducible to dynamical connections between its elements. According to Stapp, besides causal connections, the decisive part belongs to non-forced interactions which unite different elements and subsystems into a whole. As a result, we have an image of a weblike global structure of the world, all elements of which are interconsistence. Any localization, any individualization of elements in this global structure is relative, stipulated by general mutual dependence of the elements[13]. Stapp interprets the fundamental probability character of the results of measuring in quantum mechanics from the point of view of correlation of the local and the global.

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8 Sachkov'Problems of the style of thinking in natural science', in: *Philosophy and natural science. On 70th anniversary of academician B. M. Kedrov*, Moscow. (in Russian) (1974, pp.71-72).

9 Povarov 'To Daidalo ptero (On cognition of scientific-technical progress)', in: *Systemic Investigations. Annual. 1971*, Moscow. (in Russian) (1972).

10 Arshinov'Conception of integrity and hypothesis of hidden variables in quantum mechanics', in: *Physics and Philosophy*, Voronezh. (in Russian) (1974), 'On Hierarchy', in: *Some Problems of Dialectics*, Moscow. (in Russian) (1973).

11 Stepin *Becoming of scientific theory*, Minsk. (in Russian) (1976, pp.290-300), 'The Structure of Theoretical Knowledge and Historical-Scientific Reconstruction', in: *Methodological Problems of Historical-Scientific Investigations*, Moscow. (in Russian) (1982, pp.169-172).

12 Chew *Strongly interacted particles*, Moscow. (in Russian) (1966), Chew, Gell-Mann and Rosenfeld *Strongly interacted particles*, Moscow. (in Russian) (1965), Chew '«Bootstrap»: A Scientific Idea?', *Science* 161, pp. 762-765. (1968).

13 Stapp 'S-matrix Interpretation of Quantum Theory', *Phys. Rev.,* D., Vol.3, No 4, pp.1314-1319 (1971).

G. Chew and H. Stapp emphasized the idea of system integrity of the world, but the problem of the level hierarchy of the elements — a very important characteristic of complicated self-regulating systems remained in the shadow. The idea of a web like network, where all elements and substructures are correlated, did not make enough stimuli for working out notions of their relative fundamentality and complexity of the elements and their connections which are found at different levels of the hierarchy. Probably, these features of the "bootsrap" conception caused the decay of interest to it among physicists while the quark model of elementary particles has been being worked out.

But the very idea of relativity of localization and individualization of physical objects and events, their stipulatedness by the qualities of a system whole became a necessary and important aspect taken into account in most modern efforts to build an integral physical picture of the world which would include quantum and relativist notions.

This approach has been well presented in the works of D. Bohm, who tried to solve the problem of the quantum mechanics ontology. Bohm stressed the need of the system of notions of the physical world to overcome the classical approach which postulated existence of local elements and events which are interconnected and may be isolated. The new image of the physical reality, according to Bohm, should be based on the idea of relative locality which depends on the integrity of the Universe, on non-dynamic relations which (along with the dynamic ones) define the structure of the nature. Bohm compares the picture of the reality with correlated substructures and elements with a carpet, where parts of the decoration do not form a whole because they interact dynamically[14]. They are individualized through inclusion into the whole and their relation to other parts of the whole. Here Bohm's images of the reality response to those offered by Stapp. But Bohm has made a new step. He suggested to regard the world as some kind of order, a hierarchy of different levels. Every level, according to Bohm, is characterized by its own non-locality and non-force interactions. Bohm emphasizes that non-locality and non-force correlations can be revealed not only in the microworld, but also at the macrolevel. In the work written together with B. Hiley, D. Bohm gives an example of the experimental facts of correlation of far atoms in super-fluid helium. These correlations disappear at high temperature, when the effect of viscid friction arises because of casual collisions of atoms, but they restore when the temperature is lower a certain threshold level[15].

As to the conception of non-locality in the microworld, it is the most brightly expressed by the reduction of the wave function — which is the corner stone for quantum physics. Even in the 1930, at the time of Bohr's and Einstein's discussions, scientists formulated so called paradox of Einstein-Podolsky-Rosen (the EPR-paradox). The point of it is that two interacting particles a wave function is assigned, and then the distance between them becomes so considerable that their dynamical interaction can be ignored. But if we measure the magnitudes characterizing the state of one particle (for instance, its impulse or coordinate), we will see reduction of the wave function, and thereby the state of the other particle will automatically change. Einstein regarded this intellectual experiment as a paradox which proves that quantum mechanics is incomplete. But further discussions of the EPR-paradox, for instance, in the 1970s, showed that it leads to a contradiction if we latently accept the principle of locality, which assumes the possibility to separate system and measure its spatially separated, distant parts independently[16].

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[14] Bohm‘On Bohr's Views Concerning the Quantum Theory', in: *Quantum and Beyond*, Cambridge. (1971, p.28).

[15] See Bohm and Hiley‘On the Institute Understanding of Nonlocality as Implied by Quantum Theory', in: *Quantum mechanics: A half century later*, Dordrecht-Boston, pp.207-225. (1977, pp.207-209).

[16] Nordin‘Determinism and Locality in Quantum Mechanics', *Synthese* 42, No 1. (1979, p.72).

But if we reject locality as an absolute principle and think that only relatively and limitedly can it be applied, we will come to probability of non-local interaction. The EPR-paradox may be interpreted as a display of non-locality.

Bohm' s picture of the world postulates existence of some hidden order which organized all other types of orders in the Universe; this order is inherent in the net of the space interactions. Bohm explains the idea of this hidden order by means of another visual analogy (like the example of a carpet ornament). He use a metaphor of a hologram in which, if we throw light to any local part, we will be able to see the entire picture, though less detailed than in case of lighting of the whole hologram. Bohm tries to correlate the idea of the hidden order and hierarchy of orders with the notions of the structure of the space. Basing on the general relativity theory and interrelation with gravitating masses and curvature, he believes it possible that these ideas may be widened and generalized within the hypothesis of topological qualities of the space correlated with the types of order in the Universe. Hiley and other Bohm' s investigation program supporters have also developed these ideas[17].

This program, as well as G. Chew' s and H. Stapp' s investigations, can be looked at as variations of some general approach to construction of a physical picture of the world, which would use the ideas of non-locality, non-forced interactions and notions of a complicated self-regulating system, where the features of parts and elements are stipulated by the features of the whole, and the probablility causality is a basic characteristic.

The philosophical and methodological basis of such approach is the rejection of methodology of "elementarism", which was domineering in physics for a long time and assumed that the features of physical systems are completely describes by characteristics of their elements. Holistic approach, opposite to elementarism, is based on the idea that the features of the whole cannot be reduced to the features of the elements and their interactions[18].

This approach was developed mainly in investigations of biological and social objects. Then it was transferred to the system of non-organic nature due to cybernetics, theory of information and the general theory of systems.

The way of investigation chosen (in various forms) by the conceptions of G. Chew, H. Stapp and D. Bohm is based on employment of the organismical methodology in the construction of the physical picture of the world. F. Capra says that Bohm' s and Chew' s conceptions are two most philosophically ingenious approaches to description of the physical reality[19]. He denotes their rapprochement — further versions of the "bootstrap" concept tried to consider elements of the S-matrix as types of orders and to link them with the space-time geometry. In Capra’s opinion both of these conceptions understand the world as a dynamic network of relations and put the concept of order in the centre; they both use matrices as means of description, and topology — as means to determine categories of order more exactly[20].

Then Capra emphasizes that Chew' s, Stapp' s and Bohm' s picture of the world present elementary particles not as immutable bricks of the Universe, but as dynamic structures, "energy beams" forming objects which belong to higher levels of organization. According to Capra, for modern physicists matter is not passive and inert, but is always dancing and vibrating, and the rhythmic patterns of the dance and vibrations are determined by molecular,

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[17] See Bohm and Hiley (1977), Philippidis, Dewdney and Hiley ‘Quantum Interference and the Quantum Potential’, *Nuovo Cimento* 52, No 1, pp.15-28. (1979).

[18] Concerning differences between those two strategies see Blauberg, Sadovsky and Yudin *System Approach: Prerequisites, Problems, Difficulties*, Moscow. (in Russian) (1969, p.49).

[19] Capra *Tao of Physics. An Inquiry of parallels between modern physics and Eastern Mysticism*, St.Petersburg. (in Russian) (1994, p.298).

[20] Ibid.

atomic and nuclear structures. The nature is in balance, but dynamic, not static[21].

Here it would be right to stress that this image of the Universe as dynamics of the physical processes, their mutual correlation and hierarchy of orders, is more likely an image of a self-regulating system, where mass, stochastic interactions are controlled by the whole and reproduce the whole. The classical picture of the world as a simple device, which dominated in classical physics, is now replaced by the image of the Universe as a self-organizing machine. Though, in this respect we are also to mention narrowness of such approaches to construction of modern physical picture of the world, which are adjoint to the images of a complicated self-organizing system reproducing the basic characteristics of the whole as a hierarchy of orders in dynamics.

Self-organization cannot be brought only to the processes of reproduction of dynamic order and level organization of the system, though this aspect is obligatory. The other aspect is irreversible changes and development connected with appearance of new organization levels and transitions from one type of self-regulation to another. If we take these aspects into consideration, we are to employ more complicated images of system organization, that is images of complicated, historically developing systems. The notions of such systems include the idea of dynamic balance, but only as one of the states of non-equilibrium processes characterized by changes of the types of dynamic balance, transitions from one type to another.

In the modern science the program, most adequate to such view, is the one connected with working out dynamics of non-equilibrium processes (I. Prigogine) and synergetics (H. Hacken, M. Eigen, G. Nicolis, E. Laszlo, S. Kurdyumov, G. Malinetsky, Yu. Klimantovich etc.). Differently from classical physics — in principle — does the synergetic paradigm see the place of non-equilibrium and irreversible processes and their correlation with equilibrium and reversible processes. While classical physics presented non-equilibrium processes as sort of declination from the standard situation, the new paradigm puts them into the focus of interest, considering them as a way to give birth to stable structures.

Stabilities appear not despite, but thanks to non-equilibrium states. In these states even small fluctuations, random influences cause attractors leading to new organization; at all levels, either level of macroscopic physics, or level of fluctuations, or microscopic level, the source of order is non-equilibrium. Non-equilibrium is what gives rise to ' order from chaos[22].

When we describe the behaviour of quantum objects in terms of self-organizing systems, we obtain new opportunities to build quantum mechanics ontology.

I. Prigogine emphasizes that we can explain features of quantum mechanics measuring connected with the reduction of the wave function as consequences of instability, immanent to the movement of micro-objects, and measuring — as an irreversible process of causing stabilities in dynamic chaos.

From the point of view of "order from chaos", the basically static character of predictions in quantum mechanics seems not the result of activity of the one who is doing the measuring, but representation of the essential characteristics of the nature itself.

Non-localities presented in the behaviour of micro-objects, according to I. Prigogine and C. George, are related to the growth of coherence of quantum ensembles in comparison with classical dynamics[23]. Coherence, in its turn, expresses a special quality of self-organizing systems, related to their non-linearity and ability to cause cooperative effects based on non-

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[21] Ibid, p.174.

[22] Prigogine and Stengers *Order out of Chaos. Man's New Dialogue with Nature*, Foreword by A. Toffler, New York-Toronto: Bantam Books. (1984).

[23] George and Prigogine *Coherence and randomness in Quantun Theory* //Physica. Amst., 1979, Vol A99, ^{1} 3(1979, p.380).

force interactions.

I. Prigogine and I. Stengers say: "In our approach, the world follows the same laws, with measuring or without measuring..."[24];"introduction of probabilities, in our approach, is compatible with physical realism, we do not need to identify it with incompleteness of our knowledge. The observer now does not play an active part in the evolution of the nature or, at least, his part is not more active than in classical physics. In both cases, we can put into action the information got from the outer world"[25].

S. P. Kurdyumov has found quite interesting solutions of problems connected with mathematical description of peaking regimes in nonlinear medium. These regimes are an essential characteristic of behaviour of synergetic systems, and their mathematical description bases on nonlinear links of space and temporal coordinates. The apparatus developed in application to such situations is effective when applied to quantum mechanics problems. It allows obtain Schrödinger' s equation and explain quantization as expression of the features of nonlinear medium[26].

Probably, with the development of all these approaches the quantum picture of the world will one day appear in objectivized form presenting the structure of the nature "by itself".

But in order to consider modern features of the theoretical research it is important that at initial stages of becoming pictures of the world in modern physics the "operational aspect" of the vision of reality is accentuated. It is the operational side that mainly determines the search for mathematical hypotheses.

It is quite indicative that modern theoretical-group approach directly connects the principles of symmetry based on various groups of transformations with characteristics of the measuring devices[27]. An attempt to use certain mathematical structure in physics in this sense is determined by the choice of a measuring scheme as the "operational aspect" of the corresponding picture of the physical reality.

So far as the starting point of investigation — choice of the picture of the world as operational scheme — often presupposes quite radical changes in the strategy of theoretical research, it requires philosophical regulation. But, unlike classical situations, when introduction of the picture of the world was mainly directed by "philosophical ontology", in modern physical investigations epistemological problems are in the focus of attention. It is significant that in regulation principles, which facilitate the search for mathematical hypotheses, theoretical and cognitive statements (the correspondence principle, simplicity etc.) are evidently represented (in concretizing with reference to physical research form).

It seems that only analyzing these problems (while regarding all the chain of relations: philosophy — the picture of the world — analog physical model — mathematics — mathematical apparatus of a physical theory) can we reveal at greatest length the mechanisms of forming of a mathematical hypothesis.

From this point of view, the discussion of the method of mathematical hypothesis in philosophical and methodological literature has been valuable not only due to verification that the fact really existed, but — to a greater extent — to the fact that the problems described above were formulated and first attempts to solve them were made.

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[24] Prigogine and Stengers *Time, Chaos, Quantum. On solution of the time paradox*, Moscow. (in Russian) (1994, p.214).

[25] Ibid, p.215.

[26] Kurdyumov 'Eigenfunctions of combustion of nonlinear medium and constructive laws of its organization building', in: *Contemporary problems of mathematical physics and computational mathematics*, Moscow. (in Russian) (1982, pp.235-236).

[27] Konopleva and Sokolik 'Symmetries and Types of Physical Theories', *Voprosy filosofii* 1. (in Russian) (1972, p.119).

Still, though we do justice to actuality of the problems raised, when we accentuate heuristic value of the mathematical methods, we should not lose sight of another, not less important aspect of theoretical research: the process of constructing a theoretical scheme which allows us to interpret the mathematical formalism introduced. Inaccurate analysis of this aspect of investigation leads to hidden introduction of a series of simplifying notions, true only in their general formulating. If they are employed without enough specification, it may lead to incorrect ideas. Such notions include:

1. Assumption that experimental verification of a mathematical hypothesis and its transformation into a physical theory is a rather obvious procedure, which is just brought to mere comparison of all corollaries of the hypothesis with experimental data (the hypothesis is accepted if its corollaries correspond to the experiment, and rejected in case of contradicting);
2. Assumption that mathematical apparatus of a developed theory can be created as a result of advancement in purely mathematical means, by mathematical extrapolation, without constructing any intermediate interpretational models.

We are going to try to demonstrate that such notions of forming of a modern theory are not correct enough.

To begin with, we will analyze the situation of construction of local theoretical schemes, and then we will turn to the process of creating a developed theory. As the former we will consider the theoretical scheme which is the foundation of Dirac' s relativist electron theory, the latter — quantum electrodynamics (the theory of interaction of quantized electromagnetic and quantized electron-positron fields).

First we have to denote that the interpretation of Dirac' s theory as knowledge corresponding to the level of local theoretical schemes can be employed only in case we take into consideration the fact that it has been assimilated by a developed theory — quantum electrodynamics — and has become a part of it as a fragment which describes one of the aspects of electrodynamics' interactions in the quantum area. In generality the theory of relativist electron surpasses such classical local theoretical schemes and laws as, say, the system of theoretical knowledge about oscillation of the pendulum (Huygens' s model) or Faraday' s observations of electromagnetic induction.

But one of the features of the method of mathematical hypothesis is that it raises local theoretical schemes and laws to a new stage of generalization; it lets us start constructing a developed theory from synthesis of theoretical knowledge of higher degree of generality — compared to classical examples.

Quantum mechanical picture of the world and its role in forming of mathematical apparatus of quantum electrodynamics

Tracing the shifts of mathematical extrapolations in the history of quantum electrodynamics, we inevitably face the problem of initial ideas, bases for this or that extrapolation. Here it becomes clear that the putting of theoretical problems and indication of the ways of their solving were generated (at starting point, at least) by physical picture of the world grown out of the development of quantum mechanics. In that image the physical reality was depicted as two linked layers: macro and microlevels, and microlevel physical systems were considered as objects included in certain macroconditions and expressing their wave-corpuscular nature. In "operational" aspect the idea of wave-corpuscular features of microobjects was revealed by means of the complementarity principle. An object was regarded as a physical system whose essential aspects, expressing in macrocircumstances fixed by strictly certain devices, could turn out mutually eliminating. But that they were regarded as some kind of projections of an integral whole, united within one and the same method of description as complementary characteristics, discovered the specificity of the microobject.

The investigator who accepted this picture of physical reality had to take into account two possible aspects of considering physical systems: from the directions of their macro and microstructure. Correspondingly, he should apply certain method of description of the system (classical of quantum mechanical). The connection between macro and microlevels of physical reality stipulated connection between mentioned description methods within the correspondence principle[28].

We may find the decisive role of such picture of the world in putting initial problems of quantum electrodynamics, if we take into consideration the following. The program of quantizing fields was based on extrapolation of methods of quantum mechanics of points to a new sphere — fields and their interactions. But, in order to realize such extrapolation, scientists first had to see resemblance of fields with already studied quantum mechanical systems. Such view of fields was not at all evident because known and familiar quantum systems, physics had dealt with before quantum electrodynamics was constructed, in classical limit could be regarded as systems of a finite number of particles (systems with a finite number of degrees of freedom). Here, in quantizing field, a classical analog was a continual medium which could be compared with a dynamic system with an infinite number of degrees of freedom. That is why extrapolation of quantum mechanical description to the new area required certain justification. It could be provided by the quantum mechanical picture of the world which fixed the most general features of discernment of quantum objects. Previously collected empirical and theoretical knowledge of microstructure of electromagnetic interactions revealed such features of electromagnetic field (dualism of wave-corpuscular qualities). On this basing electromagnetic field was considered as an integral system which had quantum nature. Then this type of consideration was extended to electron-positron field. But such transfer was as well connected with functioning of quantum mechanical picture of physical reality, as consideration of an electron system in the image of electromagnetic field stipulated non-standard vision of it. The electron system now acts not as a mere multitude of quantum mechanical particles, but as an integral object — field whose separate quanta are particles belonging to the system.

Such vision was unusual since there was no classical analog for such an object (unlike quantized electromagnetic field which has a classical analog, the idea of electron field is meaningless in classical physics: in classical language electrons are particle with a finite — in principle — number of degrees of freedom).

We may follow T. Kuhn and characterize such approach to new consideration of electron system as a sort of gestalt-switching caused by change of model of vision in investigational situations. It is important that the latter was prepared and happened due to already formed picture of the physical reality[29].

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28 The correspondence principle has two aspects. The first one can be defined as generally methodological. Here the correspondence principle plays a specific form of connection between old and new theories (see Kuznetsov (1948)). The other aspect of the correspondence principle marks peculiarities of quantum mechanical description: the quantum object theory cannot be constructed without the language of classical mechanics. This aspect, though tied with the first one, cannot be reduced to it. It expresses the special nature of quantum objects: their physical being, characterized by physical magnitudes, is determined by macroconditions, the way of interaction of a quantum object with a classical body (see Kuznetsov (ed.) (1967, p.105-109)).

29 We would like to remind the reader that, according to T. Kuhn' s views, the change of vision of investigation situations is always stipulated by changes of some models, as "patterns", which indicate how to consider the said situations. From this point of view, the transition from vision of the system of electrons as of a set of particles with quantum nature; their vision as of a field could be explained by choice of a new "pattern". The latter is understood as quantized electromagnetic radiation field, through which the investigator sees also other objects, for instance, he evaluates the system of electrons as a set of quanta of some field. Still, this approach, correct to some extent, leaves some important sides of the investigation process in the dark. It does not take into consideration the above mentioned difficulty of transfer of ideas about the system of photons as a field to a system of electrons (presence of a classical pattern in the first case and its

Just as the picture of the world identified field and set of quantum mechanical particles as objects of the same nature, having the same combination of qualities (wave-corpuscular dualism), so it was possible to choose any of these objects as a model for considering the other (possibility to consider field as a system of particles, or to define a system of quantum particles as field).

Thus, the picture of the world in physics contributed to the idea of fields as special quantum objects which are to be theoretically described. This was the foundation for formulating initial investigational problem, which led to creation of quantum electrodynamics. The picture of the world served as stimulus to put forward such a problem, and it also pointed out the ways to solve it. These ways were founded in transfer of mathematical structure of quantum mechanics of points to the new area (fields and their interactions). Field was to be quantized in the same way as non-relativist quantum mechanics did with systems of particles. On this base the method of secondary quantizing was developed. It provided transition from equations describing classical electromagnetic fields, and the ones describing quantum mechanical particles, to equations of quantized fields. Taking into consideration what was said about the role of physical picture of the world in forming mathematical apparatus of quantum electrodynamics, it would be interesting to compare the modern way of investigation and models of theoretical investigation in classical physics, for instance, method of constructing a theory used by Maxwell (described above). The comparison shows that, at least in initial points, there is no sharp rupture between traditional and modern ways constructing a theory, despite the fact that in 20th century physics theories are constructed by the method of mathematical extrapolation. In both cases the investigator first "guesses" new equations thanks to directing influence of the picture of the world, which defines the putting of theoretical problems and points at the sphere of mathematical means which would provide construction of a theory. The new element in modern investigation, along with explication of operational aspects of the picture of the world, is more active reverse influence of even early studies of mathematical synthesis upon the picture of the world. In the history of quantum electrodynamics we can see examples when the mathematical apparatus being created made scientists correct the quantum mechanical picture of the world from the point of view of relativist ideas. The need in such correcting was caused by the requirement of Lorentz-invariance of the equation created (Lorentz-invariance of classical electrodynamics equations, when synthesized with the formalism of quantum mechanics, should be transferred to the equations of quantized field). But after the general relativity theory had emerged, to require Lorentz-invariance meant to accept relativist notions of space-time. Consequently, such notions were to enter in hidden form the quantum picture of physical reality. Though the program of joining of quantum and relativist notions within the framework of an integral physical picture of the world was accepted by all investigators after quantum mechanics had been completed, the first real steps toward its realization were made only in the process of constructing relativist quantum mechanics and the quantized fields theory. In any case, it was stipulated by the very character of the mathematical formalism of the new theory, and that is why creation of the latter may be regarded as a considerable contribution to construction of the quantum-relativist picture of physical reality[30].

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absence in the second one). To carry out such transfer, we, previously, are to refer them to some general class and only then consider one object in the image, after the likeness of another. In other words, to compare, we are to have a base for comparison; to assimilate one image to another, we need a scheme of image distinguish. In this case the role of such a scheme belonged to the picture of physical reality which introduced an extremely general notion of the nature of quantum objects. Correlation of electromagnetic field and system of electrons with it was a base for further representation of one of the objects as a model of the other.

[30] The modern stage of quantum relativist picture of the world is connected with working out the program of Great

Idealized procedures of field measuring and interpretation of the apparatus of quantum electrodynamics (the initial idea of Bohr-Rosenfeld procedures)

Bohr-Rosenfeld measuring procedures occupy a special place in settling quantum electrodynamics, because it was thanks to them that non-contradictory interpretation of its mathematical apparatus was developed. At first Bohr and Rosenfeld interpreted the apparatus of quantized radiation field, and then revealed the physical meaning of the formalism which described interaction of the said field with quantized sources. We will try to show that Bohr-Rosenfeld procedures are a typical example of stage-by-stage shaping of a constructively justified theoretical scheme in modern epoch of theoretical investigation.

First we would like to describe the historical situation in which the said cognitive activity took place. After Landau and Pierles had proved that it was meaningless to apply the idea of field in a point in description of quantum processes, quantum electrodynamics entered period of crisis of its foundations.

First, it was entirely unclear, how to change the theory in order to get non-contradictory interpretation of the mathematical apparatus introduced. What is more, nobody knew if it was possible in principle. Only retrospectively (we retold Landau's and Pierles's work mainly from the point of view of its logically necessary contribution to construction of the new theory) can we see that the only right position in those circumstances was desire to reconstruct the initial theoretical scheme so that it could allow only to reject use of field quantities in a point but conserve the idea of classical observables (field strengths).

But this step was not at all easy. In any case, the investigators who had discovered paradoxes of impossibility to measure the field components failed to do the necessary work themselves. At that stage of development of electrodynamics Landau and Pierles regarded their results not as a proof of limitedness of the initial interpretation of the mathematical apparatus of the theory, but as an evidence that this apparatus was worthless and basically could not bear any physical meaning. It seemed their point of view laid on solid ground. The state of electromagnetic field in classical theory was characterized by strengths E and *H*. As to quantum mechanical description, it contained a well known principle: quantizing of a system limits simultaneous measurability of complementary (in Bohr's sense) pairs of quantities, but puts no limitations to measurability of a separate magnitude (classical observable). So, Landau and Pierles believed: it was impossible to get the exact value of strengths E and H taken separately, it meant that there are no ways to apply quantizing methods to such an object as radiation electromagnetic field.

Later Landau and Pierles extended this conclusion to quantizing field sources. They showed that determination of state of electrons, provided that they are measured by means of a point experimental particle during very short period of time, led to irremovable indeterminacies of each of separate quantities characterizing the state of electron[31]. It could be automatically concluded that it was impossible to create a quantum mechanical description of the field

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unification which is aimed at synthesis of the four main types of interaction: strong, weak, electromagnetic and gravitational. A considerable success of this program was construction of the electroweak interactions theory.

[31] To avoid analysis of disturbing effect of charged experimental particles on the electron, Landau and Pierles, treating photons as such particles, constructed their thought experiments in accordance with the scheme of experiments based on Compton's effect. In that case it was important that the impulse of photon, colliding with electron and transferring information of its state to the device, can be measured during time period Δt only with indeterminacy ΔP which cannot be made smaller than $\frac{\hbar}{c\Delta t}$ (according to the relationship $\Delta P\Delta t \geq \frac{\hbar}{\Delta t}$). If we take this circumstance into account, it means that a classical device can fix the magnitude, characterizing the state of the electron, with the corresponding indeterminacy.

sources, or, what is equivalent, to construct a quantized electron field theory[32].
Last, Landau and Pierles appealed to numerous difficulties which had emerged in quantum electrodynamics with efforts to find the physical meaning of its apparatus, extended through a series of mathematical extrapolations. They meant difficulties with interpretation of Dirac' s equations (they included solutions with negative energy values) and difficulties in search for sense of so called zero fluctuations of electromagnetic field. The former have already been discussed. We are only to remind the reader that though Dirac had already proposed an interpretation of his equations, a lot of investigators who worked on the quantum theory of field first took his model of "holes" as quite artificial33 (especially since at the early stages there existed a tendency to connect the "holes" with presence of proton, which led to contradictory conclusions in calculations of mass-energy of particles; only later there appeared the hypothesis of positron, empirically proved only in 1932). Under those circumstances Landau' s and Pierles' s thesis that quantum mechanical methods cannot be applied in the relativist area did not at all seem unconvincing nor illogical.
Besides, there were more difficulties connected with paradoxical corollaries of the mathematical apparatus describing quantized radiation field. According to them, the energy of zero energy level of the field was infinite[34].
Landau and Pierles linked those corollaries with the idea of fundamental incommensurability of the field components in a space-time point. They indicated that it follows from the expression for indeterminacy of each of the components E and H $\Delta E \geq \frac{\sqrt{\eta c}}{(c\Delta t)^2}$ and $\Delta H \geq \frac{\sqrt{\eta c}}{(c\Delta t)^2}$ (where ΔE — indeterminacy in the value of electrical intensity, ΔH — indeterminacy in the value of magnetic intensity, Δt — time of measuring, c — light speed, • -Planck' s constant) that if we decrease the time of measuring Δt to zero (to realize measurement of the field in time point t_1) correspondingly ΔE and ΔH will tend to infinity. From this position the conclusion of infinite values zero energy level of the quantized field was presented as a special type of incommensurability paradoxes[35].
Taking all this into consideration, we may understand why there appeared a tendency to preserve quantum mechanics methods only within the sphere of non-relativist processes[36].
The crisis of the early 1930s in quantum electrodynamics gives us one more proof that

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32 The quantum mechanical description of densities of the charge-current stipulates their representation as a set of separate electrons. The latter can be interpreted as quanta of electron field. According to a postulate of quantum mechanical description, classical quantities characterizing the system should be used also as observables in description of its quantum properties. Sources of the field were characterized in classical electrodynamics by vector of density of charge-current in a space-time point. When we determine this magnitude in the process of measuring it is taken that the time period, required for measuring, should be infinitely small. But in this case, quantum effects taken into account, it is impossible to get the exact value of this fundamental quantity, which contradicts to the quantum mechanical description postulate, which sets no limitations to exact measuring of one observable.

33 The evidence is W. Pauli' s skepticism expressed in 1932 (in. Collected Scientific Papers by W.Pauli, in Two Volumes. Ed. by R. Kronig and V.Weisskopf. New York-Sydney, Intersc. Publish., 1964. (.P. 284 — 286)).

34 We would like to remind the reader that the initial model for quantizing the field was the idea of it as of an infinite set of oscillators, each of them is subject to quantizing. The field energy was written down as sum of expression for energy of each oscillator. These expressions meant that the energy values of zero oscillations of all field oscillators are different from zero. At the same time, the said expressions showed that the state studied cannot include photons, i. e. physically it should be pure vacuum. As the number of the field oscillators was infinite (according to the number of the degrees of freedom), we had that, without photons, instead of the expected zero energy there emerged infinite energy which should be attributed to vacuum. That conclusion was so unexpected that initially it could well be regarded as evidence of profound defects of the theory created.

35 Landau and Pierles ‘Extension of uncertainty principle on relativistic quantum theory’, in: Landau, L. D., *Selected Works*, Vol.1, Moscow, pp.56-70. (in Russian) (1965, p.69).

36 Ibid.

fundamental theories of higher degree of generality are constructed differently from the way it seems when we use simplified approach to mathematical extrapolation. Usually for such theories it is impossible to build mathematical apparatus at once by means of a continuous series of mathematical hypotheses and then find interpretation of the ready formalism. Quite long progress in mathematical means enlarges the danger of hidden introduction and accumulation of non-constructive objects in the theory. So it is urgent that we should use special analysis of physical sense of already constructed links of the mathematical apparatus and their interpretation as early as at intermediate stages of forming of the theory' s fundamental laws.

In such periods the central point of the research passes to the area of search of theoretical models which could provide interpretation of the equations introduced.

Let us consider the logic of this search at the period of struggle against crisis in quantum electrodynamics.

First of all, to provide progress in the development of the theory, it was necessary to formulate the theorem correctly. To do this, the investigators had to see in the incommensurability paradoxes only limitations for classical idealizations of the field strengths, but not prohibition to use quantum mechanics methods for description of relativist processes.

Correspondingly, the investigation task was to be formulated as search of classical observable, which would be fit for characterizing wave properties of quantized electromagnetic field (without using field strengths in a point). But after Landau' s and Pierles' s work many investigators would have regarded such formula as inherently contradictory.

Here we have come to a very important aspect in evaluation of the crisis caused by incommensurability paradoxes. The fact is that Landau and Pierles, speculating on unsuitability of quantum mechanical description in relativist area, hiddenly accepted one ill-founded assumption which caused their too categorical conclusion. We mean the supposition that the test particle, used for measuring field quantities, is always a point particle and is of quantum mechanical nature. Such idealization of the test particle was legitimate when the problem dealt with measuring momentary value of E and H because of the problem itself. Indeed, if we measure the force which is to influence upon the test particle in a point of the field, it means that the particle should be located in that very point at the moment given. But for this the particle itself should be regarded as point. Naturally, in measurements in very small areas only microparticles which submitted quantum mechanics laws could satisfied these requirements. But then the idea of quantum mechanical test particle was hiddenly transferred to any situation of idealized measuring field magnitude in quantum area. Landau and Pierles concentrated on its interaction with the device and found out that here that increasing indeterminacy of the impulse of quantum test particle inevitably appears, if measurements take short periods of time.

In determination of the magnitudes characterizing state of quantum system in relativist area only short periods are necessary, because here the state of the system can change rapidly enough during the time of measuring. So, it would be easy to conclude: it is impossible to register the corresponding parameters of the test particle exactly, and, consequently, to determine classical observables characterizing quantum system in relativist area.

This conclusion would be logically immaculate only in one case: if we assume that the means of measurement is a point quantum test particle.

It just never occurred to the majority of scientists to throw doubt on that assumption. But its critical analysis led to decisive clearing on the situation. It was N. Bohr who carried out this analysis. Bohr put forward an idea which provided overcoming the crisis: he proposed to use in the intellectual experiments testing measurability of field quantities a classical experimental body instead of point quantum mechanical particle. Historians of quantum electrodynamics, including Bohr' s co-author L. Rosenfeld who brilliantly depicted that "heroic" (Rosenfeld' s word) period of the development of quantum physics, usually emphasize great productivity of Bohr' s idea, but they rarely reflect the logic of its emergence. Though, from methodological point of view, understanding of this logic is of extreme importance, because here Bohr' s idea is presented not only as a product of highly gifted intuition and a "spontaneous guess" but also as a logically necessary step of theoretical investigation. Probably, the main condition for this step was analysis of the notion of experimental body in the aspect of specificities of quantum mechanical measuring. Let us regard this point in more detailed way.

It is well known that the most part of investigations connected with experiment stipulate use of a special physical agent — a means to transfer the information about the state of the object measured to the observer. The role of such agent may be played by, for instance, a well charged body in experimental measuring of electrical field strengths, some volume of liquid in experimental measuring of temperature, a polarized beam in experiments with crystals etc. All agents of this kind are concrete variations of experimental bodies.

The construction of correspondence rules (operational definitions) is based on thought experiments which are just idealizations of real experimental-measuring activity. In this connection theoretical discourses of physics start using a special idealized object — experimental body. Its general features are derived from analysis of functions of concrete variations of experimental bodies in experiment. Such analysis lets us distinguish three basic and necessary features of experimental body: 1) it should interact with the physical system studied, changing its state in correlation with the state of this system: 2) it should translate the accepted state until interaction with the register device[37]; 3) its interaction with the register device should give the observer so good information about the state of the experimental body, that he could judge the state of the physical system studied (in this case the observer comes to conclusions about values of physical quantities characterizing the state of the system measured, basing on the data from the device).

The features mentioned of experimental bodies can be easily illustrated by simple examples. Suppose, we are measuring temperature with a mercury thermometer. The role of experimental body belongs to a volume of mercury in a glass vessel. The possibility to use it as an experimental body is conditioned by the following: 1) change of the volume of mercury (state of the experimental body) is correlated with the change of temperature of the bodies observed: 2) within certain limits we always can fulfill the requirement than, until observation of the scale (register device) which fixes the height of the mercury column, either the height will not change at all (volume of mercury) under external influences, or, if such change still takes place, it can be taken into account using corresponding equations (for instance, the heat balance equation); 3) when the height of the mercury column is registered by the observer, this act by itself does not change the state of the experimental body so, that it could prevent the body from transferring information about the temperature measured (this condition is practicable because we can, for instance, ignore the influence of light upon the mercury column, take into consideration in the very construction of the thermometer in graduation the change of the volume of mercury caused by its heat exchange with the scale etc.). In other words, really we can use a container with mercury as a means of temperature measuring because the criteria of correlation, translation and possibility to register the state of this experimental body got as the result of interaction with the object measured are observed. It is

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[37] Here the term "translation" means that the state of the experimental body during time $t_1 - t_2$ between interactions with the object measured, on the one hand, and the register device, on the other hand, either does not change, or changes in time in accordance with the known law, on base of which the observer can determine the initial state of the experimental body, which is an indicator of the studied state of the measured object.

easy to see that requirements of this kind are observed in any experiment concerning any experimental bodies. They are common and significant features of the whole class of experimental bodies, that is why they form the sense of the corresponding idea.

In experimental-measuring situations of classical, quantum and quantum relativist physics the indicated features are specified in several special assumptions.

For example, classical physics assumed that, first, the experimental body does not influence upon the state of the object studied during their interaction; second, that perturbing influences upon the experimental body from the register device at the moment of registering can be ignored. Of course, both assumptions are idealizations, but they take into account circumstances of real experiments and measuring in classical area. No doubt, perturbations caused by the experimental body always exist, and the experimental body itself also is object of influences from the register device during the period of time which is needed for measuring (it starts with interaction of the experimental body with the device and ends with finish of the device' s indication). But in such experimental-measuring situations, where elements of the system — experimental body and register device — are classical objects, it is always possible either to provide such conditions of experiment that these perturbations would be negligible, or to take these disturbances into account by means of calculations and corrections.

In the measurements of quantum objects all these assumptions lose their legitimacy. In such measurements the physical system whose state is measured is always a microsystem, while the device registering quantities which characterize the state of that system always belongs to macrolevel. The experimental body, as mediator between the microsystem measured and the experimental body should interact with the former as a microsystem. Existence of quantum of action prevents us from ignoring the reverse influence of the experimental body upon the object measured, so in quantum area we should avoid an idealized image of a register device which does not influence upon the object of measuring. This rejection means that in quantum mechanical measurements, unlike classical situations, we cannot identify the state of the system before and after measuring. Reproducing the same conditions and repeating the same measuring of the "prepared" state of the system, we will get different results every time. But each of them can be expected with a certain probability, if we characterize the state of the system before measuring by some wave function. Such connection between mathematical expectation of the results of measuring and characteristics of the state of the system measured allows us to predict (as we know the wave function) the results of measuring (measurements of quantum systems are not repeatable but predictable)[38].

Thus, quantum mechanical character of interaction of the experimental body with the object measured does not prevent the observer from receiving information about the state of the object. The experimental body takes part in quantum interactions and changes its state in correlation with the state of the system studied (though the characteristics of the state are different from those in classical physics). In this sense the first feature characterizing experimental bodies is still valid, when their interactions with the object measured submit quantum laws.

But there exists one more interaction: the experimental body transfers information about the object to the register device. If the experimental body interacts with the device also in accordance with quantum laws, how can it influence the functions of the experimental body? Can it, being a quantum particle, first, translate its state got in interaction with the system measured until interaction with the registering device, and, second, transfer without errors the information about the system measured to the device?

In non-relativist area, when the state of the quantum system is constant during period of time

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[38] Landau and Pierles (1965, p.57).

comparable with the period of measuring, it is possible to fit both conditions[39]. But in relativist area the situation is entirely different, as Landau — Pierles investigation proved. Here the function of experimental bodies belongs to quantum particles, and observation of one condition automatically excludes the other. The test particle enters interactions in which the state of systems changes during period of time comparable with the period of measuring. After interaction with the system measured the test particle — before it transfers information to the register device — may undergo new type of influence from the system, since interaction in relativist area is conjugated to birth of new particles, generated by both the system measured and the experimental point particle itself. The longer is the time of measuring, the harder is the influence of the particles mentioned upon the experimental particle whose state is being transformed. Hence, it is necessary to register the state of the experimental particle as soon after its interaction with the system measured as possible. But, as we have already mentioned, observance of this condition leads to irremovable increasing errors in determining magnitudes characterizing the state of the test particle. Thus, requirements of translation of the state transferring information about the system measures, and requirement of registration of this information without errors are mutually eliminating for a point quantum mechanical particle used as experimental body in measurements in relativist area. Measurements made through such particles resulted unpredictable.

Investigators saw that a point particle, when used in relativist area as experimental body, loses its features which could make it belong to the class of experimental bodies. This was the key moment in transition from Landau-Pierles analysis to Bohr-Rosenfeld procedures. From Landau-Pierles intellectual experiments the only conclusion could be drawn: a quantum mechanical particle cannot be experimental body in measuring quantized field, but from this it did not follow that methods of quantum mechanics are inapplicable in relativist area. Such conclusion considerably changed the situation. Now the task was: put into practice idealized procedures of measuring in quantum relativist area without quantum mechanical experimental bodies.

There was only one way to reach this goal: to return to classical experimental bodies. This approach automatically eliminated all problems connected with translation of state of the experimental particle and its interaction with classical device. If the experimental body is a classical object, in description of its interaction with the register device it is absolutely correct to apply classical idealizations which allow either to ignore the perturbing influence of the device or to take it into account by means of corresponding corrections. The only question to solve was that of interaction of the experimental body with the quantum object.

Evidently, such interaction should proceed in accordance with quantum laws. How can it be, when the experimental body is not a microparticle, but a classical object? The answer was

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[39] In this case we can always operate so that the experimental body, once having interacted with the measured quantum system, would move as a free particle, without any more influences (translation of its state would follow Schrödinger' s equation, and at any moment we could receive information about this state on base of the said equation). As to perturbing influence of the register device upon the state of the experimental particle during time Δt (time of registering this state), we can minimize emerging indeterminacies by means of corresponding choice of Δt. If we bear in mind values of energy ε or impulse P of the experimental particle as characteristics of its state, indeterminacies $\Delta\varepsilon$ and ΔP (caused by quantum effects which emerge with transmission of energy-impulse of the experimental particle to the device) can be reduced by increase in measuring time Δt (in accordance with correlations $\Delta\varepsilon\Delta t \geq \bullet$ and $|v''_x - v'_x|\Delta P_x\Delta t \geq \bullet$). All this makes measurements in the area of non-relativist quantum interactions quite predictable, even if the experimental particle interacts with the register device as a quantum object. Analysis of such measurements, when we get information about state of quantum systems not through their immediate interaction with the device (direct measurements), but through a number of intermediate links — quantum mechanical particles (indirect measurements), and justification of fundamental possibility of such measurement in non-relativist area can be found, for instance, in L. Mandelshtam' s lectures on quantum mechanics (Mandelshtam (1972)).

simple: quantum systems always include description in terms of macroscopic parameters, and quantum interactions by definition should have in their last stage interaction with a classical device. The latter can be accomplished as early as at the first step (Mandelshtam's words), when we deal with direct measurements, and through a series of further links, where the measurements are indirect.

Application of classical experimental bodies as means of obtaining information on quantum systems in relativist area may be carried out in two variations: 1) investigator abstracts himself from detailed examination and calculation of atomic structure of experimental bodies, considering the latter as a special part of a classical meter unit adjusted to measuring corresponding field quantities and 2) the said structure is taken into account, i. e. the experimental body is considered as a kind of aggregate of microparticles (for instance, distributions of electrons in certain volume forming experimental charge), which is set for interaction with the object and then interacts with the device, presenting itself as a classical object.

In the first case the measurements are direct, but, unlike direct measurements in non-relativist area, here we should bear in mind the measured quantum objects' ability to change their state during period of time comparable with the period of measuring. Because of this there are restrictions first marked by Landau and Pierles (but these restrictions now concern not experimental bodies, but the objects measured and are their immanent characteristic). The said restrictions consist in the following: to measure a separate classical quantity determining state of the system, we need time, not longer than period during which the state described by the quantity measured can be disturbed. If this is beyond our possibilities, measuring not pairs but a separate quantity will give a certain indeterminacy (for instance, for coordinate q and impulse p of a point particle in relativist area there emerge indeterminacies | $\Delta p \sim \frac{\hbar}{c\Delta t}$ | and | $\Delta q \sim \frac{\hbar}{mc}$ |).

In the second case, when atomic structure of the experimental bodies is taken into account, measurements are more like indirect ones. Here we can trace quantum effects of interaction of the object measured and the experimental body, say, some distribution of charge accounting microstructure of this distribution. Such interaction in relativity area causes birth of new particles, and that makes certain contribution to macroeffects fixed by the register device.

So, a classical experimental body used in quantum measurement has dual nature: at microlevel it interacts with the object measured, at macrolevel — with the register device. Thanks to this it transfers information about the object measured to the observer and works as means of measuring quantum systems.

The given analysis may be regarded as logical reconstruction of the cognitive activity which secured transition from Landau-Pierles conclusions to Bohr's fundamental idea.

We would like to draw the reader's attention to the fact that analysis of functions of experimental bodies in idealized measurements is a special investigation, which uses metatheoretical language as regards the language of quantum electrodynamics (or any other concrete physical discipline: classical mechanics, non-relativist quantum mechanics etc.). This is the language of logical-methodological analysis, an instrument of analysis of common features of experimental bodies and understanding of the very idea of "experimental body". The said peculiarity is important because it discovers exit (characteristic for investigation) to the area of methodological problems every time when science comes across seemingly unsolvable paradoxes. Solution of the paradoxes (or justification of impossibility to solve them with further reconstruction of previously suggested investigational program) is provided by metatheoretical investigations connected with analysis of the most general features of objects studied and comprehension of methods of theoretical cognition.

In this respect let us mark that analysis of function of experimental body was purposeful, on the one hand, by general methodological condition to link basic quantities of the equations with experiment by means of corresponding idealized measuring, on the other hand, by specificity of quantum mechanical objects which require that for their description classical idealizations should be applied. The fact that it was Niels Bohr who succeeded in this analysis has profound foundation. We should take into account Bohr's decisive part in revelation of conceptual foundations of quantum mechanics, his permanent attention to the key problems of quantum mechanics measurement theory, his methodological erudition which let him grasp the very core of such problems and find solutions. All this gave Bohr the opportunity to be the first who overcame the psychological obstacle which had appeared due to blind using a point quantum object as experimental particle[40]. But the said factors refer more to psychology of scientific creative work. In respect of logic of investigation, it is important that there existed logically necessary transition from Landau-Pierles thought experiments to the fundamental idea of Bohr-Rosenfeld procedures. From this point of view we may say that once the problem of quantizing of fields had been raised and difficulties in interpretation of the introduced equations were found, so if not Bohr, then somebody else had to make the described steps toward the program of idealized measurements by means of classical experimental bodies.[41]

Dropping the details we would like to emphasize that consistently moving from the most general shape of the thought experiment, dictated by the mathematical apparatus and hypothetical model of its interpretation, to empirical schemes of a possible experiment, Bohr and Rosenfeld gained that idealized field measurements gradually accumulated essential features of real experimental measuring activity. In the framework of such measurements they traced the process of interaction of device units (including experimental bodies) with the field measured and discovered its characteristics. The latter were compared with the characteristics postulated by the previously accepted theoretical scheme. Coincidence of the field tokens obtained in two described ways proved that the given scheme was an adequate reflection of quantum specificities of electromagnetic radiation.

Thus they solved the main problem of theoretical search at the stage of interpretation of the theory's mathematical formalism: features of the abstract objects got their empirical justification.

We would like to pay attention to one important feature of the described method of investigation: its application no longer requires that real experiments, which provides verification of constructive meaning of the theoretical scheme, should be realized in practice. Enough if they are basically possible and practicable. The investigator can make sure that the latter is true when he develops analysis of measurability of theoretical quantities to concrete empirical schemes of real experiment, when possibility to realize one or another device unit and its interaction with the object measured becomes evident at least because similar device units and methods of their functioning are familiar by previous practice.

So, Bohr's and Rosenfeld's procedure of measuring a field component did not leave place to doubts in fundamental practicability of the corresponding experiment, because in previous physical experiments similar measuring devices and methods of measuring had been used many

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[40] By the way, the discussions of incommensurability are very close in time to two Solvay congresses of 1927 and 1930, where the famous disputes on foundations of the quantum theory between Bohr and Einstein took place. The corner stone of these disputes was specificity of quantum mechanical measuring and clearing of special role of classical device in determination of states of the quantum system measured.

[41] Appearing psychological barrier and overcoming it is one of the characteristic features of the psychology of discovery in science. A detailed discussion of this aspect of scientific creative work can be found in B. M. Kedrov's writings.

times. There was no sense to especially prove that the measuring unit might contain, besides experimental charge, a body carrying compensating charge; that the field would cause polarization of charges in a neutral (as a whole) charge distribution: that it was possible to settle rigid connection between the carcass of the frame of reference and compensating charge etc. — similar device units and methods of their functioning could easily be found in previous practice.

Taking into consideration the fact that in creation of a theory by method of mathematical hypothesis the layer of real experiments, where specificity of new interactions is seen, may be developed insufficiently (sometimes there can be no such experiments at all), we may say that the described way of investigation is probably the only possible way of justification of the theory at the modern stage of evolution of physics. Using it, the investigator as if shortens the way of development of the theory. He does not have to wait until a vast enough set of local theoretical schemes and laws justified by real experiments is created. He reproduces in thought empirical schemes of basically practicable intellectual experiments and develops analysis to the foundations where the possibility to realize experiment of the given type is quite evident. The latter only means that such and such type of device unit and the principle of its interaction with the object studied has already been realized in previous practice, so it would be redundant to repeat what has been done.

The necessity to develop and refine procedures of idealized measuring until they accumulate essential specificities of real experiments, which provide studies of corresponding object, Bohr often expresses as a requirement of fundamental controllability of interactions of object and device.

Rationally this requirement can be reduced to the following: any real measuring indeed stipulates a special set of conditions under which the investigator could eliminate (or take into account) perturbing external influences which distort real values of the magnitude measured. The possibility to eliminate such influences or to take them into account introducing corresponding corrections means that the investigator controls the condition of measuring. Since thought experiments and measurements should be idealization of real experimental measuring activity, then the investigator also should completely discover in them the controllable conditions of measuring. From these positions he has to scrupulously check (basing on already known theoretical laws) consequences of every new detail in the mental scheme of the device unit and, at the same time, correlates the scheme with real possibilities of the experiment. Constructing idealized measuring procedures, the investigator step by step discovers those mentally fixed interactions of the object with the devices which could cause indeterminacies in values of magnitudes characterizing the object. Having revealed such interactions, he checks whether they refer to disturbing influences of the device unit which can be eliminated by its new refinement and application of compensatory devices.

Exhausting possibilities to control the conditions of measuring, the investigator makes sure that the idealized measuring corresponds as much as possible to the possibilities of real experimental measuring activity. If indeterminacies of magnitudes characterizing the object remain, it means that such indeterminacies should be considered as essential characteristics of the object itself.

In this respect everything what is fundamentally uncontrollable within the scope of idealized measuring, justified as scheme of a real experiment, should be included in the specificities of the object measured, since the measuring procedure itself is constructed in such a way that it reveals objective characteristics of the reality studied. Hence we cannot, of course, conclude that quantum characteristics appear due to uncontrolled interaction of the device and the microobject measured. The real structure of Bohr's cognitive activity and his method of construction of idealized measuring were not connected with the idea of uncontrollability in the sense above. They were based on entirely opposite approach, according to which idealized measurements, structured in concordance with real specificities of quantum mechanical and quantum relativist experiments, should reveal objective characteristics of the processes in atomic area.

Bohr's requirements of control over conditions of interaction of the object measured and the device were identical to requirements to construct idealized measuring drawing it as close as possible to real specificities of physical experiment. Then characteristics of a quantum object, which could be discovered within real experimental practice, undoubtedly should find expression in the results of idealized measurements.

Intermediate interpretations of apparatus of modern physical theory as a condition of its development

Constructive justification of the theoretical scheme of quantized radiation field automatically provided empirical interpretation of the formalism of the theory. Bohr-Rosenfeld procedures allowed to correlate field strengths from the equations of quantum electrodynamics with experiment indicating mechanism of such connection. This mechanism could be involved by means of description of Bohr-Rosenfeld procedures intellectual experiments. The description itself formed a system of operational definitions for corresponding physical quantities.

In this respect the process of construction of idealized measurements in quantum electrodynamics can be taken as some model of activity which provides introduction of operational definitions at today's stage of development of physical theories. But Bohr-Rosenfeld procedures not only formed empirical interpretation of the equations of quantum electrodynamics. They discovered new aspects in characteristic of such field and urged to introduce corresponding corrections also in the semantic interpretation of the formalism of the theory.

The idea of field resulted to be applicable only to finite space-time areas and inapplicable to a point. Thus the idea of quantized field as transfer of electric and magnetic forces from point to point was destroyed. Such idea, acceptable within classical electrodynamics, was inapplicable in quantum area.

Then it became clear that, because of field fluctuations caused by birth and annihilation of photons, the connection between the field and its sources is more complicated than classical theory used to believe. The latter ties sources and fields in a strictly determinate way. At the same time in quantum theory Laplace's determinism of classical electrodynamics is replaced by a wider form of statistical causality. Fields are casually connected with sources only from the point of view of statistical predictability of field magnitudes measured in the experiment. Strictly determined connection, characteristic for classical physics, restores only when the field in the measuring area "consists" of a large number of photons, which, in accordance with Poisson distribution, oscillate about some average number in every of the possible states forming the field. As the average number of photons is large enough, we can ignore their fluctuations and turn to classical description of the field. All these field characteristics were revealed thanks to measurability procedures, because it was here where investigators determined the physical meaning of influence of fluctuation field upon the magnitudes measured. The said fluctuations transformed traditional idea of radiation field determination by its sources.

Finally, in the process of idealized measurements unbreakable link between radiation field and vacuum was justified. This is probably the most important consequence of Bohr-Rosenfeld procedures.

It may seem at the first glance that the idea of connection between quantized radiation field and vacuum was born due to mathematical apparatus of the theory and did not depend on the proof of the field measurability, as application of methods of quantizing to electromagnetic field automatically led to notions of infinite field energy in absence of photons.

But the matter of fact is that before justification of the field measurability it was entirely unclear whether it was possible to provide vacuum with real physical meaning or it should be accepted only as an auxiliary theoretical construct lacking such direct meaning.

Paradoxes with infinities push physicists to the latter conclusion. They supported opinion that for non-contradictory interpretation of quantum electrodynamics in general it was necessary to exclude somehow "zero field" from the "body" of the theory. We should remember, then, that Landau and Pierles linked the idea of vacuum with paradoxes of incommensurability, and in their analysis energy was presented as one of evidences of fundamental inapplicability of quantum methods to description of electromagnetic field. Productively criticizing conclusions of Landau and Pierles, Bohr eliminated the last objection, but the question of physical sense of vacuum states still was not solved.

Only in the course of Bohr-Rosenfeld procedures was the problem clarified and connected with the discussion about the role of fluctuation of the field components in the measuring process. But there was one more aspect of the problem, which we have not yet touched for the sake of easiness of the account. Let us consider this aspect now.

Besides fluctuations connected with the presence of photons, there is one more variation of field fluctuations predicted by the apparatus of the theory. It is zero fluctuations which appear in absence of photons and connected with the zero energy level of the field. From the apparatus of the theory followed that these fluctuations have finite positive value (nothing to do with infinite energy of the field in zero state!).

As we have mentioned, Bohr and Rosenfeld proved that fluctuations connected with birth of photons should be included in values of the field components. They are discovered due to declinations of values of the field quantities predicted by the quantum theory, from the values calculated by methods of classical electrodynamics.

The empirical sense of fluctuations connected with birth of photons followed from the structure of idealized measuring of the field, since only taking them into account could the investigators determine exactly the averaged field component. But in that case fluctuations of zero field also got empirical justification, as they were fundamentally inseparable from fluctuations connected with presence of photons.

As zero fluctuations were display of "zero field", the latter as well got real physical sense. It resulted that, if vacuum and zero fluctuations caused by it were removed, the very idea of quantized radiation field would become physically empty, because the averaged field component could not be measured exactly[42].

As a result, Bohr-Rosenfeld idealized measuring procedures led to conclusion about real connection between the radiation field and vacuum and impossibility to obtain description of quantized radiation field without taking vacuum states into account.

In principle, the new vision of electromagnetic field caused by realization of the procedures of measurability is not something unusual of extraordinary in the development of theoretical knowledge. On the contrary, here we can see a certain pattern of epistemological nature; its manifestation we have already seen in the history of science (for instance, in analysis of the history of classical electrodynamics). The essence of it is the following: realizing constructive introduction of abstract objects of previously accepted theoretical model, investigator as if fills this model with new physical contents, because he organizes real experimental-research activity, revealing characteristics of the reality studied.

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[42] In this case we would have to consider the radiation, caused by displacement of the experimental body on Δx at measuring its impulse, and which cannot be compensate, as that perturbing influence, which basically prevents us from exact determination of the field component.

The obtained content is objectified due to mapping of the theoretical model on the picture of the world, and the result is new vision of the object studied, which fixes its essential properties and relations. The last procedure finishes construction of interpretation of the corresponding phenomena of the corresponding equations of the theory, which are presented now as description of new essential characteristics of the physical reality studied. At this stage the theory obtains new physical notions, and its conceptual apparatus gets further development. Due to this the preliminary accepted semantic interpretation is refined and developed. Thus, constructive justification of the theoretical scheme leads to decisive development of the contents of the scientific theory. This is an accomplishment of the process of formation of its conceptual structure, started at the stage of mathematical hypothesis. Bohr-Rosenfeld procedures can present us a characteristic example of the process developing at modern stage of evolution of theoretical knowledge. After measurability of quantized radiation field had been proved, fundamental possibility to apply quantum mechanical methods in description of relativist processes provoked no further doubts (unlike initial conclusions made by Landau and Pierles).

The foundation of quantum electrodynamics — the theory of free quantized electromagnetic field — became now a non-contradictory and empirically justified system of knowledge.

Now the researches only had to interpret the fragments of quantum electrodynamics which described interaction of quantized radiation field with quantized sources (measurability of electron-positron field).

This problem was solved by Bohr and Rosenfeld at the second stage of realization of their research program. It was connected with construction of idealized measurements for sources (distributions of charge-current) interacting with quantized radiation field43.

First, they proved measurability of classical sources interacting with quantized electromagnetic field, and then presented a proof of measurability of field sources with account of birth of electron-positron pairs. Thus they completed the interpretation of mathematical apparatus of quantum electrodynamics describing free quantized fields and their interactions in the first approximation of the perturbation theory.

At this stage they not only formulated the correspondence rules, which connected all physical magnitudes of the equations of quantum electrodynamics with experiment, but also discovered early unknown characteristics of quantized fields. In particular, the procedures of quantized measuring allowed to raise the question of space-time boundaries beyond which the field approach to description of quantum properties of charge-current losing its force.

From the mathematical apparatus of quantum electrodynamics it followed that, unlike fluctuations of electromagnetic field, the fluctuations of charge and current within any strictly limited space-time area are to be infinite. But the analysis of the situation of idealized measuring revealed new field specificities. It was found out that in areas related to shell of finite depth consisting of experimental bodies (which served to measure the field sources), averaged on the same areas fluctuations became finite. If we infinitely reduce the depth of the shell, the fluctuations infinitely grew tending to infinity. When they are equal to mathematical expectation of the field quantities predicted by the apparatus of the theory, it indicates the limits of applicability of quantum electrodynamics[44].

Thus, constructive justification of the theoretical scheme of interaction of quantized radiation field with quantum sources, providing empirical interpretation of the formalism of quantum electrodynamics, introduced new aspects into its semantic interpretation as well.

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43 Bohr (1970-1971, vol.2, pp.434-445).

44 Pauli ‘Exclusion Principle and Quantum Mechanics (Nobel Prize Lecture delivered December 13, 1946 in Stockholm)’, in: *Theoretical Physics of XXth Century*, Moscow. (in Russian) (ed.) (1956).

To sum up, we can now once more evaluate the way made by Bohr and Rosenfeld in construction of this interpretation.

Gradually justifying features of free quantized electromagnetic field, then interactions of this field with classical sources, and, lastly, with quantum sources, by means of idealized measurements, Bohr and Rosenfeld were creating a richer and richer theoretical model which took into account new and new aspects of electromagnetic interactions in atomic area. This way of construction of interpretation reproduced the basic steps of historical development of the mathematical apparatus of quantum electrodynamics at the level of conceptual analysis. No essential stage of its development was missed — the logic of construction of the interpretation mainly coincided with the logic of historical development of the mathematical apparatus of the theory.

In this respect, it is interesting to compare interactions of the mathematical apparatus and theoretical models in modern and classical situations in yielding of a scientific theory.

As we have shown above, in construction of classical electrodynamics every step toward the generalizing field equations (Maxwell' s equations) was supported by a corresponding theoretical model, which was constructively validated even at the intermediate stages of the theoretical synthesis.

While quantum electrodynamics was being formed, the situation changed. Here for a quite long time mathematical apparatus was built without constructive justification of the theoretical models; there were only hypothetical schemes which introduced preliminary semantic interpretation of the equations. As to procedures of their constructive justification, which provided empirical interpretation of the formalism created, and then its final semantic interpretation, they were carried out later and were separated in time from construction of the formalism as such. Nevertheless, in those procedures investigation as if repeated all the main stages of development of the apparatus of the theory in brief. Step by step does it reconstruct the developed hypothetical models and, through their constructive justification, introduces intermediate interpretation which correspond to the most important stages of development of the apparatus. The accomplishment of this way consisted in clearing of the physical meaning of the generalizing system of equations of quantum electrodynamics.

So, the method of mathematical hypothesis does not at all reject the necessity of content-physical analysis at intermediate stages of forming the mathematical apparatus of the theory. The specificity of modern investigations is not that intermediate interpretations become redundant, but that the activity aimed at their construction becomes a continuous transition from one intermediate interpretation to another in accordance with the logic of development of the apparatus, which reproduces the history of its development in brief. Classical theory was constructed according to scheme: equation$_1$ → intermediate interpretation1, equation$_2$ → intermediate interpretation$_2$ ... , generalizing system of equations → generalizing interpretation; in modern physics theory is constructed in a different manner: first equation1 → equation$_2$ → etc, then interpretation$_1$ → interpretation$_2$ → etc. (but not equation$_1$ → equation$_2$ → generalizing system of equation and immediately accomplishing interpretation!). Clear, the shift of interpretations in modern physics does not entirely reproduce analogue processes of the classical period. We should not believe that we have only discrete transition from one intermediate interpretation to another replaced by continuous transition, only the number of intermediate links is changed. In modern physics it is as if packed, and therefore the process of construction of interpretation and development of conceptual apparatus of the theory takes cumulative form. There are at least two reasons for that.

First, as we have already emphasized, the process of constructing theoretical models reproduces the history of development of mathematical formalism not entirely, but in brief. Search for adequate interpretation requires verification only of those links of its historical development, which were accomplished by creation of equations included in the theory (for example, Bohr and Rosenfeld, in their procedures of measurability of quantized radiation field, investigated the mathematical formalism created by Heisenberg, Jordan and Pauli on base of the initial variant, suggested by Dirac; this variant as such was not considered because it had been put away from further, more perfect mathematical apparatus).

Second, the mathematical hypothesis by itself reduces the number of intermediate links on the way to generalizing equations of the theory (since at once there are introduced equations of generalization of great enough level — as basic dependences subject to further synthesis and generalization). In its turn, it leads to reducing of the number of intermediate stages on the way to the final interpretation of the theory formalism.

All said lets us conclude that, in comparison with classical models, in modern theoretical investigation the procedures of constructive justification of theoretical models and construction of operational definitions, which connect the formalism of the theory with experiment, are somehow packed. So we may state that at the modern stage of evolution of physics some features of theoretical synthesis, distinctive only of the classical period, are reproduced, but in a packed and pressed form.

In principle, that should be this way — if we take into consideration dialectical way of development: in self-developing systems (and scientific cognition is one of them) higher stages of evolution always repeat in their functioning some features of historically preceding forms. It is important to remember that such features can be both transformed enough or reproduced comparatively purely. The latter variant allows to find new aspects of interaction of mathematical apparatus and interpretation in development of modern theory. As we understand, at some stages of this development it is possible to see sort of return to classical scheme of theoretical synthesis, according to which advance in mathematical formalism should not happen before its exhaustive interpretation is created.

But such return is not the same as absolute repetition of classical methods. It goes on new basis and requires usage of modern methods of theoretical search.

Breakthrough in mathematical extrapolations usually takes place, when they have already helped to build quite rich formalism able to be base of the future apparatus of the theory. But the theory itself is not accomplished yet. The necessity of its further development at this stage may be evident enough, at least because necessary problems are solved only partly (there are theories which should be solved, according to requirements of the theory, but which are unsolvable by means which exist).

But not at all always it is clear, how to find new mathematical means. Moreover, there are doubts if such search is possible on previous basis, as existence of unsolvable problems can be evidence of inner contradictions in the formalism already created. Then we need content analysis of the foundations of the theory, proofs of consistency of the created apparatus and construction of its interpretation.

Development of mathematical formalism is relatively independent from its interpretation (including empirical aspects) only to certain extent. In modern physics there always are periods when further perfection of mathematical apparatus of the fundamental theory created entirely depends on construction of its consistent interpretation, which gives a new impact for further mathematical synthesis and accomplishing of the theory.

In this respect the history of quantum electrodynamics can be a most eloquent example. Between the third and the forth stages of forming of its apparatus there emerged crisis of its foundation, caused by discovering of incommensurability paradoxes. Further generalization and elaboration of the formalism of quantum electrodynamics would have been impossible as the very principles of quantizing fields were doubted, if that crisis had not been overcome. Bohr and Rosenfeld laid the way out of the crisis when they constructed a consistent interpretation of the created apparatus, which described processes of interaction of quantized electromagnetic and electron-positron fields in the first approximation of the perturbation theory. Only after that did it become possible for quantum electrodynamics to recover in the 1950s. That recovery was connected with construction of renormalization theory. Firm belief in fundamental applicability of quantum electrodynamics methods of description in relativity area (shaken because of the crisis and restored thanks to success in solving the problem of measurability of quantized fields) was a necessary condition for search for theory of interaction of quantized fields with account of higher orders of the perturbation theory. The very setting of the problem was correct due to Bohr-Rosenfeld procedures which had previously proved that the description of interaction of quantized fields in the first approximation of the perturbation theory was consistent.

But Bohr-Rosenfeld procedures gave an impact to further development of quantum electrodynamics not in this generally theoretical aspect only. They exercised concrete influence upon further evolution of the theory, as they revealed such new characteristics of electromagnetic interactions, the information about which made it considerably easier to elaborate the basic physical idea of renormalization.

We usually pay little attention to this circumstance, but still it is extremely important for understanding patterns of evolution of theoretical knowledge.

The general idea of renormalization appeared, as it is well known, due to understanding limited nature of idealization of a free particle in respect to quantum relativist area. Any particle is not free, in strict sense of the world, because it interacts with vacuum, which corresponds to the lowest energy state of quantized fields. The result of such interaction is change of charge and mass of the particle, and then charge and mass of the particle observable in experiment become a summary of this interaction. For instance, if there are mass m_0 and charge e_0 of an electron not interacting with vacuum, in experiment we observe other mass and charge which are equal to $m = m_0 + \Delta m$ and $e = e_0 + \Delta e$. The magnitudes Δm and Δe express changes introduced in charge and mass of the electron by vacuum.

It seems possible to calculate charge and mass of the electron (observable in the experiment) by means of determining corrections Δm and Δe for interactions with vacuum. But such corrections turned out infinite expressions having the form of divergent integrals. All this caused enormous difficulties in description of interaction of particles (considered as quanta of the field) by methods of the perturbation theory.

Renormalizations, which allowed to eliminate these difficulties, were based on a quite simple physical idea. Magnitudes m_0 and e_0 representing mass and charge of non-interacting (or "bare" in modern physical terminology) electron, as well as corrections, were considered as auxiliary theoretical constructs which had no real physical meaning, because a real electron always is in interaction with vacuum and never exists beyond such interactions. Then mass and charge of a free electron were identified with expressions $m = m_0 + \Delta m$ and $e = e_0 + \Delta e$ which are really observed in experiment. But since these magnitudes have finite values, finite values m and e were to be got through special selection of divergent values for Δm and Δe. The method of such selection formed the essence of the renormalization method.

It means that the renormalization method was based on the idea of observable magnitudes characterizing particles, which are considered as quanta of some field, as display of total result of interaction of these particles with vacuum.

But this very idea firmly occupied its place in physics due to the procedures of idealized measuring.

Let us recall that Bohr and Rosenfeld justified measurability of quantized radiation field, and this fact lead to a conclusion: there is a contribution of vacuum in the field observable magnitudes characterizing the state with presence of particles (photons). Further analysis spread this conclusion also on magnitudes describing electron-positron fields (for instance, on such dynamic variable of the field as charge and mass).

Beyond the measurability procedures the initial idea of observables having a contribution of vacuum looked no more than a hypothesis. But idealized measurements got the status of a validated theoretical statement for that hypothesis.

Since works of Bohr and Rosenfeld containing the results mentioned above were well known among the physicists-theorists of the 1940s[45], we may quite naturally conclude that they prepared the necessary base for development of the idea of renormalization. In any case, we are to remember that the approach to observables, which became a necessary condition for the idea of renormalization, was prepared by Bohr-Rosenfeld procedures[46].

It is characteristic, that the said stage coincided with new development of mathematical apparatus of quantum electrodynamics. Here we can see the reverse influence of Bohr-Rosenfeld theoretical model upon the search for new mathematical structures characterizing quantized fields. By the way, such influence can be seen even at quite late stages of development of quantum relativist ideas. So, we would like to draw the reader' s attention to the following important circumstance.

In axiomatic quantum field theory the mathematical apparatus from the very beginning is constructed, meaning that physical sense can belong not to fields in a point, but to magnitudes of fields averaged on some finite space-time area. The modern theory characterizes field not by operator functions (as it was at the earliest stage of development of quantum electrodynamics), but operator functionals, whose description openly contains the operation of averaging on finite space-time area. Such apparatus allows to describe easily and briefly quantum processes in relativist area. For reaching this goal, it uses mathematical structures of higher “information capacity" than those which were in foundation of the mathematical formalism of quantum electrodynamics of the 1930s — 1940s.

It is obvious that the physical foundation for the application of new mathematical means were the specificities of fields uncovered by Bohr-Rosenfeld procedures. It means that the interpretation procedures prepare new development of the theory apparatus, encouraging search for more perfect mathematical structures.

To summarize all said above, we may formulate the following epistemological and methodological conclusions.

1. In modern physics the process of construction of a theory is even more autonomous in relation to new experimental data, than in classical physics. Mathematical hypothesis lets us move toward fundamental equations of developed theory even if the local theoretical laws which are to be synthesized and which are based on real experiments, are presented scarcely enough.
2. Still an important directing role in theoretical investigation belongs to the picture of physical reality. It provides base for choice of principles of mathematical description of new area of

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[45] The first Bohr' s and Rosenfeld' s publication dedicated to the problems of measurability of quantized electromagnetic field was made in 1934. The work referring to measurability of densities of current charge was published, in its final version, in 1952, but its first edition, as a review, was prepared in the mid 1930s and was quite well known for the majority of theorists who worked at the problem of field quantizing (see. L. Rosenfeld' s memories in Kuznetsov (ed.) *Niels Bohr. Life and Works*, Moscow. (in Russian) (1967, p.76)).

[46] In modern exposition, the need to consider the observables as summary of interaction of a bare charged particle with vacuum is often corroborated by references to vacuum polarization (interacting with vacuum, electron gets polarization "cover" made of virtual electrons and positrons, which an outside observer perceives as effective reduction of the electron charge). But we are to remember that the very discovery of vacuum polarization was a quite late achievement (compared to Bohr-Rosenfeld procedures) and, by itself, needed the preliminary idea of physical reality of vacuum and possibility to observe effects of its interaction with charged particles in an experiment. Such ideas were formed due to idealized measurements of quantized fields.

physical processes. But, unlike classical models, its operational structure is accentuated.

3. A mathematical hypothesis is able to provide working out a quite developed apparatus, but only to certain extent, because equations manipulation is linked with corresponding transformation of abstract objects of theoretical schemes. If a series of mathematical extrapolations is quite long, it can cause accumulation of non-constructive objects with mutually eliminating features. So, to the development of non-contradictory theoretical system of knowledge it is required interpretation of mathematical formalism at intermediate stages of construction of the theory.

Creation of a theory keeps going on as an alternate correlated movement in mathematical means and plain of physical contents. But, in comparison with classical models, the relatively independent "run" at each of this level grows, and the movement from equations to interpretation and vice versa goes on in larger steps.

4. Construction of intermediate interpretations in modern physics goes on as procedures of idealized measuring and often without preliminary real experiments. Nevertheless, due to consistent development of details of the thought experiment — up to reproduction of empirical schemes of possible future experiment, — the very idealized measuring procedures can be justified as schematized and idealized real experimental-measuring activity in the field of interactions. That is why they are capable of bringing to light objective characteristics of such interactions.

5. The idealized measurements not only verify characteristics hypothetically introduced in base of the specificities of the theory apparatus, but also discover new, unknown features of the physical processes studied. Hence the mathematical apparatus obtains new physical meaning, and the notion structure of the physical theory is reconstructed and presented as deeper and more adequate reflection of the object area investigated. In turn, it raises foundation for search for new, more perfect means of its mathematical description.

6. Stages of development of idealized measurements, which end at construction of an adequate scheme of new area of interactions, reproduce the main stages of construction of the mathematical apparatus, as if repeating its history, but in brief. At the same time, idealized measurements of modern physics shorten the way of constructing the theory as well because they do not require long forming of preliminary theoretical models and laws based on real experiment. In the very process of construction of idealized measurements the investigation briefly passes the stage of forming of such models.

Thus, the evolution of physics at modern stage conserves some basic operations of construction of the theory characteristic for its past forms (classical physics). But is develops the operations, partly modifying them, partly repeating — on a new base — some features of construction of mathematical apparatus and theoretical models, appropriate to the classical models.

In modern investigation the process of theoretical search characteristic for classical physics is reproduced in transformed and pressed form — as it should be at higher stages of the evolution in relation to the historically passed stages.

MUTUAL CONNECTION OF GENESIS AND FUNCTIONING OF A THEORY. THE CONSTRUCTIBILITY PRINCIPLE

If we compare specificities of development of a theory in classical and non-classical science, some common laws of the process of their development can be revealed.

Analysis of content aspects of the structure and genesis of a scientific theory demonstrates that in formation of its conceptual apparatus the key role belongs to procedures of constructing a theoretical scheme. Such construction is done as interaction between foundations of the science, mathematical apparatus, empirical and theoretical material generalized in the theory. First it stipulates transition from foundations of the science to a hypothetical variant of the theoretical scheme, and then — to empirical material. This is the first cycle of the process of constructing the theory, connected with the hypothesis put forward. But then we face reverse movement — from generalized empirical and theoretical material to theoretical scheme and again to the foundations of the science. This is the second stage connected with justification of the hypothesis. Here the initially introduced theoretical schemes are reconstructed, saturated with new contents and actively influence upon the foundations of the science, preparing new changes in them.

The hypothesis suggested marks only most general framework of the conceptual structure of the theory, which is formed — in its main features — with justification of the hypothesis. Methodological literature usually characterizes the very process of suggesting hypothesis in terms of "discovery context". It is urgent to emphasize that transition from the foundation of the science to analog model and then to a hypothetical scheme of the interaction area studied makes a certain rational outline of this process. It is often described in terms of the discovery psychology and creative intuition. But such description, if it is supposed to be constructive, should, for sure, be linked with clearing of the intuition "mechanisms". It is characteristic that here investigators at once came across the so-called mechanism of gestalt-switching which lies in the base of intellectual intuition[47].

Detailed analysis of this process shows that the intellectual intuition is considerably characterized by usage of some model ideas through which we examine the new situations. The model ideas stipulate the image of the structure (gestalt) which is transferred to new object area and organizes, in a new way, the before collected elements of knowledge of that sphere (notions, idealizations etc.)[48].

The result of such work of creative imagination is a hypothesis which allows to solve the problem offered.

Further consideration of mechanisms of intellectual intuition has marked clearly enough that the new vision of reality, corresponding to gestalt-switching, is formed due to substituting new elements — ideal objects — into the initial model-idea (gestalt), and it allows to construct a new model shaping new vision of the processes studied[49].

Here gestalt is a kind of "mould" according to which the "model is moulded"[50].

Such description of the procedures of generation of hypothesis corresponds to investigations of the discovery psychology. But the process of putting forward scientific hypotheses can be also described in terms of logical-methodological analysis. In this case its new important aspects will be uncovered.

First, let us emphasize once more the fact that the search for hypothesis cannot be reduced only to the method of trials and mistakes. In forming a hypothesis, a considerable role belongs to the investigator' s foundations (ideals of cognition and the picture of the world) which aim the creative search, generating investigation problems and indicating the field of the solution means.

Second, the operation of forming a hypothesis cannot be entirely transferred to the sphere of individual creative work of a scientist. They are obtained by an individual, just as his thinking

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[47] In Kuhn' s conception of paradigmatic models of solutions of problems, new non-standard solutions, leading to perspective hypotheses, are described in terms of gestalt-switching (see Kuhn *The Structure of Scientific Revolutions*, Chicago: Univ. of Chicago Press. (1962)).

[48] See Karmin and Khaikin *Creative Intuition in Science*, Moscow. (in Russian) (1971, pp.36-39).

[49] See Bransky *Philosophical Foundations of Problem of Synthesis of Quantum-Relativistic Principle* (1978, pp.40-41, 36-39).

[50] Ibid, p.40.

and imagination are formed in the cultural context absorbing samples of scientific knowledge and samples of their production activity. The search for a hypothesis, including choice of analogies and substituting new abstract objects, determined not only by historically developed means of theoretical investigation, into the analog model. This choice is also determined by translation in the culture of certain samples of the investigation activity (operations, procedures) which provide solution of the new problems. T. Kuhn is right when he mentions that such samples are included into scientific knowledge and mastered in the process of learning.

Translation of theoretical knowledge in the culture means also translation of samples of the problem solution activity. Such samples reflect procedures and operations of generating new hypotheses (foundations of the science — analog model — substitution of new abstract objects into the model). That is why in the process of adoption of already obtained knowledge (formation of a scientist as a specialist) also some quite general schemes of intellectual work, providing generation of new hypotheses, are mastered.

Translation of schemes of intellectual work in the culture, which provide solution of the problems, allows to consider the procedures of such generation, abstracting from personal qualities and abilities of a concrete investigator. From this point of view we can talk about logic of forming hypothetical models as a part of logic of forming a scientific theory.

Finally, third, summarizing specificities of the process of forming hypothetical models of science, it is important to emphasize that the base of this process is combination of abstract objects from one field of knowledge with the structure ("network of relations") taken from another field. In the new system of relations the abstract objects are provided with new features, which makes appear, in the hypothetical model, new contents, which can correspond to not yet studied connections and relations of the object area, for description and explanation of which the hypothesis putted forward is dedicated.

The said feature of hypothesis is universal. It can be marked at the stage of formation of local theoretical schemes, as well as in construction of a developed theory.

As to procedures of justification of the hypothesis, they also have quite complicated structure and internal logic. As it follows from reconstructions of development of classical and quantum electrodynamics, traced above, empirical justification of a hypothesis is not reduced to comparison of its corollaries with the results of experiments and observations. It includes procedures of constructive justification which is a condition and a premise of comparison of hypothetical models with experimental facts. Only after these procedures, does the theory get receipts of connections of its fundamental magnitudes with experiment — operational definitions, which guarantee efficiency of empirical verification of the theory. Further justification of hypothetical models and turning them into a theoretical scheme is connected with procedures of their correlation with disciplinary ontology (scientific picture of the world) and philosophical foundations of the science. When these procedures are completed, the ontological status of theoretical schemes as the core of the new theory is justified.

The process of justification of the hypothesis contributes to the construction of conceptual apparatus of the theory not less than the process of generation of the hypothesis. In the course of justification the contents of the basic notions of the theory are being developed. In turn, it creates premises for future theoretical search, as every new hypothesis stipulates usage of already developed notions and models as material for its construction.

If we take into consideration this specificity of development of scientific knowledge, it will be clear how incorrect were the positivists who strictly separated "the discovery context" and "the theory verification context"[51]. The logic of discovery and the logic of verification are two

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[51] Reichenbach *Experience and Predication*, Chicago. (1961, p.6-7).

aspects of one and the same process of the theory becoming, and there exists close mutual connection between them.

Historical approach to the problem of structure and genesis of the theory requires that we take into consideration not only mutual connections between different aspects of the theory genesis, but also the connection between the process of becoming and peculiarities of functioning of the theory.

Anti-historicism of the positivist analysis of scientific knowledge consists, for instance, in the fact that theory was considered only as given knowledge, without the peculiarities of its becoming. The result of such type of analysis was quite poor idea of the process of functioning of a formed theory. Positivism could mark only some formally logical aspects of deductive development of theory and the process of theoretical explanation and prediction of events. Informal aspects of theoretical investigation were lost by the positivist history of science.

The interest to these aspects of theory emerged in the Western philosophy of science in connection with formation of post-positivist branches, whose representatives referred to analysis of the history of science. Studying informal aspects of theoretical investigation, they came across the connection between functioning of theory and its genesis. Probably the most interesting results, revealing this connection, were contained in Kuhn' s conception of "model" problem solutions. Kuhn noted that operating models in the process of theoretical description and explanation of concrete events is analogous to the way of forming of new knowledge in the history of science[52]. Here in his analysis, Kuhn closely approached the question of reproduction of the peculiarities of theory' s genesis in its structure and functioning. Still, he failed to determine clearly this problem and logical-methodological approaches to its solution. He tried to answer, how the first model problem solutions are created in a theory, appealing to the psychology of perception of the investigator included into the scientific community. At the same time objective origins and premises of formation of the "models" remained outside Kuhn' s analysis.

Just as the problem of the "models" can be formulated as the problem of way of reduction of a fundamental theoretical scheme to local ones and transition from basic equations of the theory to their corollaries, so its solution is of greatest importance for understanding the laws of functioning of a theory. The key to the solution of this problem is to be sought in the logic of historical development of scientific knowledge.

Interaction of the operations of putting forward a hypothesis and its constructive justification is that key moment which allows to get the answer, how paradigmatic models of problem solutions appear in the theory.

Having raised the problem of getting models, the Western philosophy of science failed to find corresponding means to solve it, because it did not reveal and analyze, even in the first approximation, the procedure of constructive justification of hypotheses.

Discussing the problem of models, T. Kuhn and his followers emphasize only one side of the question: the role of analogies as basis of problem solving. The operations of forming and justification of meanwhile appearing theoretical schemes remain outside their analysis.

It is quite indicative that within such approach there emerge fundamental difficulties in trials to elucidate, what is the role of the correspondence rules and their origin. For instance, Kuhn believes that in the activity of scientific community these rules do not play such an important role as methodologists usually attribute to them. He especially emphasizes that the most important thing in solving problems is search for analogies between various physical situations and application of already found formulae on this basis. As to the correspondence rules, they, according to Kuhn, are a result of further methodological retrospective, when methodologist

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[52] Kuhn (1962).

tries to ascertain criteria used by the scientific community in application of different analogies[53]. Kuhn is consistent in his views, because the question of procedures of constructive justification of theoretical models is not brought up in his concept. To detect this procedure, we need a special approach to investigation of structure and dynamics of scientific knowledge. It is necessary that we should consider theoretical models included into the theory as reflection of object in the shape of activity. Referring to a concrete investigation of nature and genesis of theoretical models of physics, such approach orients us to special vision of them: theoretical models are considered as ontological scheme, which reflects essential characteristics of the reality studied, and at the same time as some kind of "closure" of object-practical procedures, within which in principle we can disclose the said characteristics. That vision allows to discover and describe operations of constructive justification of theoretical schemes.

With other theoretical-cognitive basis the mentioned operations remain outside methodologist's field of investigation.

But, as it is constructive justification that provides appearance of the correspondence rules in theory, defining their contents and meaning, it cannot surprise us that Kuhn came across difficulties in determining the ways of forming and functioning of these rules.

It is characteristic that in discussion of the problems of samples Kuhn refers to the history of Maxwell's electrodynamics. Analyzing it only in the plane of application of analog models, he believes that the main results of Maxwell's investigation were gained without any construction of correspondence rules[54]. But, as we have seen, this conclusion lies far from real facts of the history of science.

We think that the given above analysis of procedures of construction of a theory allows to get answer to the question: where from model situations appear in theory. Such model situations (examples of solution of theoretical problems) demonstrate methods of construction of local theoretical schemes on base of a fundamental one, and ways of transition from basic laws of theory to local theoretical ones. Forming and including such model situations into the theory take place in the course of its becoming.

In construction of a developed theory its fundamental theoretical scheme is created by means of consequent generalization of those theoretical schemes which either preceded the theory, or were constructed in the course of theoretical synthesis. This generalization is carried out by means of creation of several intermediate models, and each of them is aimed at representation of new, not considered before, characteristics of interactions studied, in the theory.

First the investigator introduces each of such models as a hypothesis and then gives its constructive justification. In the course of constructive justification of the model he works out two main proofs.

The first one determines that the model is able to express essential characteristics of situations being generalized. Such characteristics previously could be represented in cognition by local theoretical schemes. Now, when constructive justification of the model is done, the content of the mentioned schemes is included in the generalizing model.

During the second proof the investigator makes sure that in course of new generalization of the model its previous constructive content is not destroyed. This content corresponded to the local theoretical schemes which were assimilated by the generalizing model at previous stages of theoretical synthesis. To make sure this content is preserved, the investigator explicates it. From the generalizing model he derives corresponding local theoretical schemes which, in their

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[53] See Kuhn ‘Second Thoughts on Paradigms’, in: *The Structure of Scientific Theories*, Urbana, pp.459-482. (1974).

[54] Ibid.

content, are equivalent to the theoretical schemes assimilated in the theory.

Thus, in the course of the process of construction of a theory the investigator reduces the fundamental theoretical scheme being created to local theoretical schemes. The methods of such reduction reproduce, in their main features, the methods used for including of essential characteristics of concrete physical situations reflected in the theory, into generalizing model. Such including was executed by means of intellectual experiments based on real possibilities and peculiarities of the experiment. In the course of such experiments the investigator's thought traveled from model to experiment and from experiment to model, studying all main intermediate links between model and experiment. The same thought experiments in their main features are repeated in explication of constructive contents included into the model, when the latter is reduced to some local theoretical scheme. As in the process of justification of the model by new experiment, the investigator first considers concrete specificities of physical situations, and then imposes restricting conditions on the model and constructs a local theoretical scheme.

It is characteristic that at the final stage of theoretical synthesis, when the main equations of the theory are introduced and constructive justification of the fundamental theoretical scheme is accomplished, the investigator executes the last proof of correctness of the equation introduced and their interpretation: from the main equations he gets, in new form, all generalized local theoretical laws, and then, on base of the fundamental theoretical scheme, he constructs local theoretical schemes corresponding to the said laws. A typical example of such justification is the final stage of formation of Maxwell's theory of electromagnetic field, when it was proved that on base of the theoretical model of electromagnetic field it is possible to obtain, as particular cases, theoretical schemes of direct current electrostatics, electromagnetic induction etc., and from equations of electromagnetic field — to deduce Coulomb's, Ampere's, Biot-Savart's laws, laws of electrostatic and electromagnetic induction discovered by Faraday, etc.

Final justification of the main equations of the theory and the fundamental theoretical scheme at the same time presents as account of the "ready" theory. The process of its becoming is reproduced now in reverse order, in shape of deductive development of the theory, deriving corresponding theoretical corollaries from the main equations. Each conclusion here can be considered as account of some method and result of solution of a theoretical task.

Thus, the very process of constructing a theory forms and includes model situations of solving theoretical tasks.

Further functioning of the theory and expansion of its application area creates new examples of solving problems. They are included into the theory, along with those introduced in the beginning of its formation. With development of scientific knowledge and changes of previous form of the theory, the initial models are also modified. But, in their modified shape, they are normally preserved in all further accounts of the theory. Even the latest formulations of classical electrodynamics demonstrate methods of application of Maxwell's equations to concrete physical situation; the example used is deriving Coulomb's, Ampere's, Biot-Savart's, Faraday's laws from these equations. The theory, we may say, preserves in itself traces of its past history, reproduces — as typical problems and ways of their solution — the main specificities of the process of its forming.

Genesis of the theory is imprinted in its organization and determines its further existence. If we define genesis of the theory as intensive way of knowledge development, and functioning of the theory — as extensive way of such development, we will see that both ways are closely linked. Reproduction in a logic of unfolding the theory formed of the main specificities of its becoming is one of the sides of such mutual connection. But there is another side: active influence of the process of functioning of the formed theory upon future shapes of intensive development of theoretical knowledge.

After the theory is constructed, it enters the stage of explanation and prediction of new events. Here the empirical basis of the theory is extended, it being known that the new empirical material is not only mechanically absorbed by the theory, but has active reverse action. The theory is now changing in the course of application to new situations.

One of the main reasons of such changes is difficulties emerging with solving new problems by old methods. To work out methods which would provide solution of wide range of such problems, we have to change mathematical means and develop new theoretical models of the reality studied. As the result we have reformulating of the existent theory: new mathematical apparatus is created, and its conceptual structure is developed.

The history of science presents us a lot of evidences of such development of a theory already settled. For instance, Newton' s mechanics first was reformulated, on base of application of analytical methods, by Euler, and then reconstructed into Lagrange mechanics and Hamilton-Jacobi mechanics. Any such reconstruction was connected with application of mechanics to new physical situations and desire to work out general methods of solving various problems. Euler developed the analytical apparatus of mechanics to obtain universal methods of determining states of a material point or a system of such points under influence of forces. The new methods let him work out an absolutely new part of mechanics: solid body dynamics. Lagrange' s, and later Hamilton-Jacobi' s reformulatings of mechanics were — to a considerable degree — caused by needs in description and explanation of complicated mechanical systems. Analytical methods, based on the accelerating forces principle, could not be applied in the process of solving quite a number of problems, as the value of forces applied to each body, which was a part of a complicated system, is normally unknown in advance. Lagrange' s mechanics, and then Hamilton-Jacobi mechanics let solve such problems successfully. In this process of development of mechanics its new mathematical apparatus were formed, its new principles (for instance, the smallest effect principle) were introduced, its new fundamental notions (effect, energy etc.) were formulated.

This kind of specificities of development of already settled theory can be traced also in other historical examples. Thus, predictions of electromagnetic waves and further application of Maxwell' s theory to explanation of optical phenomena led to development of conceptual apparatus of electrodynamics (there appeared ideas of electromagnetic wave, electromagnetic radiation etc.). At the same time, as the sphere of empirical application of Maxwell' s equations expanded, so it required that the mathematical shape of the theory should be improved. In H. Hertz' s and O. Heaviside' s works Maxwell' s equations were expressed in a form close to modern one, and then electrodynamics was accounted with help of modern methods of vector analysis.

Finally, we can refer to one more example of reconstruction of a settled theory: historical development of quantum mechanics. After it had been created in its initial version (by W. Heisenberg, E. Schrödinger, N. Bohr and M. Born), its application for explanation and prediction of wider and wider set of processes in atomic sphere was accompanied by development of the apparatus and the conceptual structure of the theory. The stages of such development are, for example, Dirac' s strict operational formulation of the theory in terms of q-numbers, von Neumann' s axiomatic model of the quantum theory, Feynman' s formulation of quantum mechanics (path integrals).

Reconstruction of a theory in the process of its functioning not only forms new methods of solving problems but also creates means for building new fundamental theories. Mathematical apparatus and conceptual structures, which are developing in the process of application of the settled theory to new physical situation, might be precisely those means needed whose employment in a new area of theoretical search provide intensive development of scientific knowledge.

Electrodynamics could not have been worked out, if mechanics had not formed mathematical apparatus which provided solution of hydrodynamic problems. The development of quantum physics was carried out, in a great part, due to mathematical structures and notions formed in Lagrange's and Hamilton-Jacobi mechanics. The number of such examples can be increased. Thus, means for future theoretical search and construction of new theories are created not only at the stage of becoming of the theory, but also, at even a greater extent, at the stage of functioning of a developed theory. This side of mutual connection of genesis and functioning of a theory was missed in Kuhn's analysis. In his conception of development of science the stage of extensive increase of knowledge is sharply opposed to its intensive development. In the real history of science these two sides are closely connected: genesis of the theory determines its functioning, while functioning of developed theories prepares basis for new theoretical structures.

Forming of conceptual structure of a new theory is the result of interaction of mathematical apparatus, theoretical schemes and experiment. Dynamics of such interaction is mostly determined by procedures of constructive justification of theoretical scheme. These procedures have practically never been analyzed in methodological and philosophic literature[55]. Meantime, their disclosure opens new perspectives for getting concrete methodological conclusions and recommendations. First of all, we can present the idea of constructibility as a methodological rule, which indicates ways of construction of adequate interpretation of mathematical apparatus of the theory. This rule can be formulated in the following way: after a hypothetical model of explanation of empirical facts is introduced, new, hypothetical features of the abstract objects of the model are to be introduced as idealization based on a new layer of experiments and measurements, the layer which was intended to be explained with help of the model. Moreover, we have to make sure that the new features do not contradict to the features of the abstract objects justified by previous experience.

This rule does not mean the same as the requirement to verify theoretical knowledge by experiment. According to analysis of the historical material, verification of this kind stipulates (especially at modern stage) complicated activity connected with construction of adequate interpretation of the equations introduced. The core of such interpretation is constructive introduction of abstract objects. That is why the rule of constructibility not only says that empirical justification of a theory is necessary, but also indicates how, in what manner such justification is done.

From the requirement of constructive introduction of abstract objects there follow quite nontrivial methodological conclusions. One of them has already been discussed. It refers to connection between existence of non-constructive objects in the "body of the theory" and paradoxes emerging there. Since the presence of non-constructive objects can lead to paradoxes in a theoretical system (though not necessarily), then application of the constructibility rule allows to uncover contradictions inside knowledge before they are uncovered in the spontaneous course of the investigation. This, in turn, can be a means to reconstruct the theory effectively, and to form a conceptual structure which would adequately reflect the new object. To find such a criterion is especially important in respect to modern knowledge, which is quite complicated in its system organization and where is not always easily to find inconsistency.

The model of such activity aimed at analysis of inconsistency of knowledge by means of

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55 They were discovered and first described in Stepin and Tomilchik *Practical nature of cognition and methodological problems of modern physics*, Minsk. (in Russian) (1970), Stepin 'Genesis of Theoretical Models of Science', in: *Philosophy. Methodology. Science*, Moscow. (in Russian) (1972), (1976).

constructive justification of theoretical schemes may be Bohr-Rosenfeld procedures in quantum electrodynamics.

When we find non-constructive elements in a theoretical model, we can see weak points of the theory, which are — sooner or later — excluded through replacement of corresponding elements of the theoretical model and its constructive reorganization. This problem should be analyzed especially, as the requirement of elimination of non-constructive objects is close to the requirement of the observability principle. Here we are to discuss the question of relationship of ideas of constructibility and observability.

As we know, the observability principle meant that in construction of a theory the investigation should apply only magnitudes that have operational meaning, while ideas which cannot be verified in experiment should be eliminated from the theory.

Vast philosophical and physical literature gives us quite exhaustive analysis of the ideas of fundamental observability. It shows that the observability principle, applied along with other methods of physics, had quite an important heuristic role in its development, but its usage took place differently in different investigation situations. The strict requirement to eliminate non-observable quantities from the theory has never been applied in physics. This requirement, if understood literally, prohibits us at all to use non-observable magnitudes, while without them we fundamentally cannot construct any hypothesis, because at the stage of such construction the investigator uses mostly non-observable objects (when he supplies the objects of the model with hypothetical features, he, usually, does not know which of them would be justified by experiment, and which of them not). Besides, in a theory already developed there always can exist auxiliary constructs (like "bare electron" in quantum electrodynamics) which are important for development of the theoretical contents but which are fundamentally non-observable.

At the same time, in some investigational situations the ideas of observability unexpectedly turned out quite heuristic. For instance, in the period of construction of quantum mechanics elimination of non-observable electron orbits was a powerful impulse to development of the theory. A situation like this can be found in the period of construction of the special relativity theory, when elimination of non-observable absolute space allowed to develop new images of space and time.

All this is an evidence of certain part of rationality in the ideas of observability, but, at the same time, of inadequacy of the very formulation of the observability principle, which does not include concrete directions: where and when it can be applied in the investigation, how we can tell observable quantities from non-observable ones, and at what stage of construction of the theory we are to eliminate non-observable objects.

Consequently, the regulative role of the observability principle was reduced to a trivial claim: to construct the foundation of the theory on magnitudes, tried by experiment, and to base on the intuition of the investigator who should find out, which magnitudes are to be considered as observable, and which ones are to be rejected as fundamentally non-observable.

The inadequacy of the very formulation of the observability principle was, in a major part, connected with its genetic, theoretical-cognitive origins. One of the first its formulation was given by E. Mach, proceeded from false statements of his philosophy, that theory does not reflect the objective world, but experience and is not more than a brief reproduction of the facts observed. Later logical positivism tried to revive that idea in the form of the method of logical analysis. Positivism required that theory eliminated all metaphysical ideas which have not been verified (checked up on base of reduction of the concepts to the data of observation). But a theory cannot be reduced to a brief summary of observations, and its notions cannot be treated as just fixation of phenomena observable in the area described by the theory: the theory reflects not the events, but the essence of processes in the real world, while scientific concepts have meaning not only within a certain theory, but they accumulate all preceding history of cognition which uncovers — step by step — new and new characteristics of the objective world.

The positivist interpretation of theory and following "linear prescriptions" of elimination of all non-observable concepts from science led to conclusion that no scientific theory could survive if "purified" in accordance with prescriptions of methodology of logical analysis.

No surprise that inadequacy of such statements to real specificities of scientific cognition led to a deep crisis in positivist philosophy of science.

At the end, the very positivist interpretation of the observability principle was put away. But at the same time there emerged an urgent problem of right understanding of methods of empirical verification of a theory and discovering rational part of the observability principle, falsely interpreted by positivism.

In the course of this process investigators started gradually understand that the said abnormal hardness of the observability principle followed from the fact that theory is presented there as result of purely inductive generalization of the facts observed. Understanding real methods of construction of a theory caused efforts to make a less hard formulation of the observability principle. We were to indicate, at what particular stage of development of the theory it could play the role of a methodological regulator.

A great part in the right formulation of this goal belonged to methodological investigation of the problem of observability made by classics of modern natural science A. Einstein, M. Born et al. What is especially interesting is the analysis of A. Einstein' s comments of 1926 concerning W. Heisenberg' s understanding of the observability principle. Einstein indicated that the very idea of observability depends on the theory. Only the theory determines what is observable, and what is not[56]. Einstein' s criticism exercised influence upon Heisenberg' s works of the 1930s, where the latter postulated that a considerable number of new conceptions should be introduced into a theory, and only then the nature will decide, whether to revised them or not — in every point. In this respect M. E. Omelyanovsky told a truth saying that for concretization of the ideas of observability we are to add: introduction of new concepts into a theory should take place at the stage of creation of the theory, and their verification should be done basing on new experience[57].

Further investigation of the observability principle required analysis of the structure of the theory, methods of organizations of concepts inside the theory, distinguishing main and auxiliary abstract objects. Such analysis leads to ideas of constructive justification of the abstract objects of the theory.

After all above we can formulate the difference between requirements of constructibility and the observability principle.

1. "Observability" stipulated inductive construction of the theory, while the constructibility ideas are based on the opposite vision of genesis of the theory (from the very beginning they take into account that theoretical models are introduced from above, in respect to experiment, as hypotheses and only then are justified constructively).
2. The observability principle, at the best, only marks that at the stage of putting hypotheses forward we can use various notions, and only at the stage of justification of the hypothesis verify their empirical sense. The requirement of constructibility clearly differs these to stages from the very beginning, meaning that constructive introduction of abstract objects into "the body" of the theory starts only after introduction of the supposed hypothetical model.
3. In the observability principle there is no differentiation of ideal objects of the theory, so it is

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[56] Heisenberg *Der Teil und das Ganze*, München. (1969, S.91-92).

[57] Omelyanovsky *Dialectics in Contemporary Physics*, Moscow. (in Russian) (1973, p.99).

not clear which of them are to be considered as observable, and which are non-observable. Criteria of such differentiation are transferred to the sphere of the investigator' s intuition. In the requirement of constructibility we have an effort to introduce such differentiation (at least, in the first approximation). It is supposed that what should be constructively justified (i. e. introduced as an idealizations based on new experience) is abstract objects of the theoretical model which lies in foundation of the theory. Such model is pretty clearly indicated in any theory (so we can agree with Einstein that concrete structure of a concrete theory indicates what there should be observable and non-observable). Then, taking into account that a concrete theoretical scheme (model) and picture of the world should be distinguished, we may divide the problem into two parts: constructive justification of the theoretical scheme and constructive justification of the picture of the world. The latter can as well include non-constructive elements (visual auxiliary images which let us inscribe the created scientific knowledge into the culture of a certain period). These elements are eliminated from the picture of the world only in the long course of historical development. At the best, they can be fixed as non-observable essences, but "criticism of the pictures of the world" takes place only on the eve of their breach. As to abstract objects of concrete theoretical schemes, they are mandatory to be introduced constructively.

4. The observability principle, in its strict formulation, required that non-observable objects should be eliminated from the theory immediately after they are discovered. According to the ideas of constructibility, the process of replacement of such objects can be executed as long search for new constructive meaning of the theoretical model. But the very fact that a non-constructive object has been found allows us to develop a consistent investigation. In this case the process of construction of theoretical knowledge can be run not by means of immediate elimination of the non-constructive object from the theoretical scheme, but by its localization and use of the theoretical scheme in further cognitive movement so that it could "work" only with its constructive elements. A characteristic example of such investigation is the process of development of knowledge based on the atom model, offered by Bohr and developed by Sommerfeld. That model included electron orbit (a non-constructive element), but Bohr, knowing that it is a "non-observable" object, constructed the system of postulates describing basic relations among main elements of the model, so that they "localized" the main paradoxical corollaries of employing electron orbits (it was supposed that electron, in its stationary state, does not radiate).

Considering the chance of this way of development of knowledge, we may come to conclusion that the very fact of discovering non-constructive objects provides progress of the theory, even if they are eliminated much later than they are discovered.

Thus, the method of constructive justification of theoretical schemes, indicating a concrete procedure of discovering non-constructive objects in "the body" of the theory, can make it easier to solve many investigation problems.