Prolegomena 12 (2) 2013: 459–486

Husserl's Reconsideration of the Observation Process and Its Possible Connections with Quantum Mechanics: Supplementation of Informational Foundations of Quantum Theory

TINA BILBAN
Institute Nova revija, Cankarjeva cesta 10b, SI-1000 Ljubljana, Slovenia
tinabilban@gmail.com

ORIGINAL SCIENTIFIC ARTICLE / RECEIVED: 22–11–12 ACCEPTED: 23–07–13

ABSTRACT: In modern science, established by the scientific revolution in 16th and 17th century, the scientific observation process is understood as a process where *the observer* directly grasps Nature as *the observed* and scientific mathematical formulation is understood as a direct description of reality. Husserl criticized this lack of distinction between method and the object of investigation in modern science and emphasized the importance of phenomena in the observation process. A similar approach was used by Bohr in his interpretation of quantum experiments that seemed inexplicable from the modern science point of view. Many contemporary interpretations of quantum mechanics follow Bohr's opposition to the realism of modern science. Among them is informational foundations of quantum theory (IFQT) that connects parts of his interpretation with the latest quantum experiments, but due to the complexity and individuality of Bohr's interpretation, its philosophical consistency is mostly lost. In IFQT there is no direct connection between information and *the observed*. This ambiguous ontic status of information is often criticised, however, it can be solved by supplementation with Husserl's philosophical understanding of the observation process. If Husserl's definition of the relationship between the thing and the phenomenon is transmitted to the relationship between *the observed* and information in IFQT information can be understood as the direct answer to the question about *the observed* and thereby *the observer's* only knowledge about it. This helps to reject the main criticism of IFQT and to additionally support its explanations of quantum phenomena.

KEY WORDS: Edmund Husserl, information, informational foundations of quantum theory, modern science, Niels Bohr, observation process, perception process, phenomenon, quantum mechanics.

The observation process is generally defined as the complex relationships between its main agents: *the observer* is the one who is observing, *the observed* is the object of the observation process and *what someone observes* is *the observed* as has been given to *the observer*, *the observer's* information about it. In modern science[1] such a definition of the observation process is simplified. Mathematics is understood as the language of Nature (Galilei 1632), so Nature is considered equal to its mathematical description and *the observed* equal to *what someone observes*.

At first, mathematization of Nature only had the role of a scientific method, which enabled an abstract, objective and generalized description of Nature, and consequently exceptional progress of science. Newton, for instance, understood gravity solely as a "mathematical" and not as a "physical force". Later, this hypothetical character of mathematization of Nature was forgotten; already the first generation of Newton's students accepted gravity as an objectively real "physical force"(Koyre 1957). Because of the utility of mathematization, the need for its legitimacy and critical use was neglected. In time, it was no longer distinguished between the method and the object of investigation and Nature was regarded as a priori mathematical. Science was understood as the approach that most directly and thoroughly grasps *the observed*, without it being changed by *the observer* or by *the observed* being part of the observation process. This co-constituted the modern scientific concept of reality: Reality, defined as the world as it actually is, independent of *the observer*, was believed to be describable by science. Mathematical descriptions of natural phenomena were taken as *the observed*, as objectively real, e.g. forces were understood as physical forces, as *the observed*, not as *what someone observes* or as the way of describing it. Mathematized Nature as *the observed* seemed potentially completely explicable and all natural phenomena in principle determined by scientific laws.[2]

All these views formed the background of the philosophical understanding of Nature in classical physics. However, they were faced with

---

[1] Modern science has been established by the scientific revolution in 16th and 17th century. In that time the scientific method, its way of obtaining and interpreting information of the world around us, has evolved and later science itself has been understood as defined by this scientific method (Koyre 1957; Husserl 1976). As Kuhn has written in *The Structure of Scientific Revolutions*: "anyone examining a survey of physical optics before Newton may well conclude that, though the field's practitioners were scientists, the net result of their activity was something less than science" (1962: 13).

[2] The term *causal determinism* is used in philosophy of science to describe determinism as understood and applied in classical physics. It describes the idea that every event is determined by antecedent events and conditions together with the laws of nature.

a challenge at the beginning of the 20th century, when the first quantum experiments were performed.[3] A quantum system (QS) before measurement can be described by a wave function, which is a probability function; solving the equation does not give a particular result, but the probabilities of a result in the case of a measurement, e.g. it gives the probability of where a QS is if its position is measured, but not the position as a property of the QS. This lack of information about a particular property, called objective randomness[4], is not a consequence of *the observer's* ignorance or lack of knowledge; the information simply does not exist before the measurement. Objective randomness can be understood as an opposition to the determinism of classical physics. At this point, the modern scientific understanding of the observation process can be questioned—is *the observer's* description of *the observed* with the wave function really how *the observed* is?

When measured, a QS is entangled with the measurement apparatus.[5] It is no longer described by its own wave function but by the measured property. For *the classical observer,* the QS can be now described as a particle; the term 'collapse of the wave function' has often been used to describe this sudden change in the description of a QS. A quantum measurement not only emphasizes the problem of the relationship between *the observed* and *what someone observes* (e.g. has *the observed* been suddenly changed at the point of the measurement?), in QM the influence of *the observer*, or at least the influence of the observation process, caused by *the observer*, can clearly not be discounted as is the case in classical physics.

These characteristics of the quantum world seemed mystical, incomprehensible or even impossible for *the classical observer* (see Lurçat 2007:

---

[3] The most famous quantum experiment is the double slit experiment: A light source illuminates a plate pierced by two parallel slits and the light passing through the slits is observed on a screen behind the plate. If the path of the light is not detected (*the observer* does not follow this information), the light behaves as a wave: it goes through both slits, the waves interfere and they produce bright and dark bands on the screen. If the path of the light is detected, light behaves as a particle: it goes through a particular slit and lands on the corresponding place on the plate behind the slit.

[4] Randomness from our everyday life is not objective randomness—e.g. the result of a coin toss is not random in the objective way, if someone knew all the antecedent events, conditions and influences of all relevant forces, the final state would be determinate

[5] Entanglement is a type of relationship between QSs. After an interaction, two QSs can be described solely with a common wave function that presents one (common) QS, while each of the two QSs is now only a sub-QS. The relationship between the two entangled sub-QSs is completely determined; the sub-QSs are always entangled with respect to a particular property, e.g. spin or position. Thus, if the sub-QS_1 has spin up, the sub-QS_2 has spin down. Accordingly, the sub-QSs are fully determined, despite having no properties and only being described by the wave function before the measurement.

230). Nevertheless, they were confirmed by further experiments. It became clear that QM cannot be discredited as wrong, and that it should be taken seriously and be supplemented by a suitable philosophical interpretation. Although the need to connect QM and its mathematical description with a comprehensive philosophical interpretation has already been expressed by the "fathers" of QM, an interpretation, which would be acceptable for the whole scientific community, is still missing (Schlosshauer, Kofler & Zeilinger 2013; Carrol 2013).

Different interpretations of quantum data can be traced back to different understanding of the observation process of their protagonists. On the one hand, the so called realists have followed the view that the modern scientific concept of reality and its understanding of the observational process define science as such. This view was, for example, advocated by Einstein (Einstein, Podolsky & Rosen 1935) and later constituted new realistic interpretations that were formed in the second half of the 20th century, after the so called "shut up and calculate" era,[6] within which contemporary physics and philosophy were abruptly separated. The two most popular of those are the many worlds interpretation (Everett 1956) and the hidden-variables theory (Bohm 1952).[7]

On the other hand, characteristics of QM phenomena have set many physicists and philosophers of science off to rethink the observations process and approach it from a different angle. In his famous public dialogs with Einstein (Pais 1982), Bohr represented the view that the new knowledge provided by QM "has revealed the necessity of a closer consideration of the observation problem" (Bohr 1958: 69). On this basis, Bohr formed a complex personal interpretation of QM (the particulars of which we discuss later). Some parts of his interpretation were included in Copenhagen interpretation, a very complex non-realistic interpretation that combines

---

[6] Stenholm sees the reasons for estrangement between physics and philosophy in the fact that physics, blinded by the success of experimental technique and commercial applications, "overlooked the absurd world view offered by quantum theory," while philosophy "shunned the hard questions concerning reality and turned to logistic formalism, philosophy of everyday phenomena or pure linguistic pettiness". Consequently the "leading physicists have turned their back on all philosophy" (2011: 15).

[7] Both of them lack the distinction between *the observed* and *what someone observes*. Consequently, in many worlds interpretation the wave function, presenting mathematically described *observer's* knowledge of *the observed* is taken as objectively real, while its collapse is denied, thus implying the reality of all possible worlds. In the hidden variables theory, the mathematical descriptions of *the quantum observed,* before and after the measurement are equally objectively real; again this brings a plurality of as yet observed entities (hidden variables) that are supposed to be part of a completely new level of reality.

common views of different quantum physicists[8] gathered around Bohr's Institute of Theoretical Physics in Copenhagen and presents the basis for explanation of QM in most textbooks. Non-realistic interpretations, usually closely related with Copenhagen interpretation, have preserved their place within the field of QM, however, after the "shut up and calculate" era, they have lost a direct touch with philosophical standpoints on which they could build their opposition. They still offer comprehensive answers to some fundamental quantum questions connected with the latest technological applications of QM (e.g. IFQT), but their reconsiderations of the observation process are mostly only an opposition to established modern scientific realism. Consequently, the results of quantum experiments are often understood as mere representation of our knowledge and the connection between *the observed* and *what someone observes* remains lost.

A fresh approach that would connect contemporary quantum experiments, fundamental quantum questions and a suitable and rigorous philosophical methodology is needed. Since quantum reconsideration of the modern scientific description of Nature, the importance of a thorough description of the observation process and the fundamental quantum questions are all very close to contemporary steps taken within Husserl's phenomenology, a connection between Husserl and QM could provide the missing pieces. In this paper, the potential of this connection is shown in the case of informational foundations of quantum theory (IFQT), a contemporary anti-realistic interpretation of QM. IFQT is able to explain some fundamental quantum phenomena on the basis of the latest quantum experiments, but lacks philosophical consistency, which, as we aim to show, can be provided by supplementation with Husserl's understanding of the perception process.

The first section of this paper is dedicated to Husserl's phenomenological critique of modern science and reconsideration of the perception process and includes an explanation of the relationship between Husserl's

---

[8] Hans Primas (as quoted by Gregg Jaeger in *Entanglement, Information, and the Interpretation of Quantum Mechanics*) summed the Copenhagen interpretation in eight theses;

"(1) Quantum mechanics refers to individual objects.
(2) The probabilities of quantum mechanics are primary.
(3) The placement of the cut between observed object and the means of observation is left to the choice of the experimenter.
(4) The observation means are to be described in classical terms.
(5) The act of observation is irreversible and creates a document.
(6) The quantum jump is a transition from the potentially possible to actual.
(7) Complementary properties cannot be revealed simultaneously.
(8) Pure quantum states are objective but not real." (2009: 130)

understanding of the perception process and scientific understanding of the observation process. The second part describes how the “fathers” of QM, Bohr, Heisenberg, and Einstein, understood the observation process and science, and compares their views to those of Husserl. Finally, the last part analyses IFQT and its possible supplementation with Husserl’s phenomenology.

1. Husserl’s reconsideration of modern science based on the analysis of the perception process

The general separation between physics and philosophy during the “shut up and calculate” era and more personal “philosophical and political parting of the ways [between phenomenologists and predecessors of analytic philosophy] in pre-war Germany” (Heelan 2003) in great part caused a radical gulf of communication between phenomenology and human sciences on one side and analytic philosophy and natural sciences on the other. Consequently, “phenomenology and analytic philosophy live in different cultural and linguistic worlds and work from radically different platforms” (Heelan 2003). Thus, despite their similarities, QM’s and Husserl’s reconsiderations of modern science that reveal almost identical problems, have only rarely been considered together (Bilban 2011a; 2011b; Lurçat 2007; French 2002; London & Bauer 1983; Heelan 2004). From the point of view of contemporary analytic philosophy of science Husserl is mostly seen as only a critic of science and it is often overlooked that his critique is a constructive critique based on complex knowledge and appreciation of science and its results. Husserl’s phenomenological reconsideration of (modern) science is based on his understanding of phenomenology as “science of essence—as an ‘a priori’ or, as we also say, an eidetic science” (Hua III: 5). “It belongs to the sense of anything contingent to have an essence and therefore an Eidos which can be apprehended clearly.” (Hua III: 9) In *Experience and Judgement*, Husserl explains *eidos* with an example of *eidos* color:

> When the generic universal which is the essence, e.g. the eidos color, is exemplified in a number of colored objects, each of these objects has its own individual moment of coloring; we have many individual moments of color and, in contrast to them, the one eidos as generic universal. This eidos is capable of being envisioned only because, having been given several individual moments of color, we bring the colored objects into overlapping ‘coincidence’ by comparison then apprehend the universal, which is given in the coincidence as what is common to them – but not common in reell sense—and which we separate from what is irrelevant in the exemplifications. This is the intuitive process of abstraction of generic universal. (1973: 262)

The essence is a variable that in the particular perception process defines phenomena as what it is and differentiates it from something else. As such phenomenology is not only a science of essence, but also a science of phenomena. All sciences are sciences of particular phenomena, "psychology is designated as a science of psychological 'appearances' or phenomena and […] natural science is designated as a science of physical 'appearances' or phenomena." (Hua III: 1) However, phenomenology is a science of phenomena as such. Understanding of phenomena is thus crucial for any scientific investigation. Husserl's phenomenon can be described as the thing as has been given/shown to me by itself, but essentially to me, in my horizon, with the meaning it has to me (Hribar 1997: 509). It is always an intentional phenomenon, a phenomenon of something. Under intentionality, Husserl understands:

> the own peculiarity of mental processes 'to be conscious of something'. […] In every actional cogito a radiating 'regard' is directed from the pure Ego to the 'object' of the consciousness-correlate in question, to the physical thing, to the affair-complex, etc., and effects the very different kinds of consciousness of it. (Hua III: 168).

Husserl's phenomenon is based on his detailed analysis of the relationships between the main agents of the perception process. For those we will use the terms: *the perceiver* for the one who perceives, *the perceived* for the object of the perception process, the thing, and *what someone perceives/*phenomena for the perceived thing as has been given to me.

The perceived and *what someone perceives* are essentially connected on the basis of the concept of *Glaubengewissheit* (belief certainty). *Glaubengewissheit* is belief in the outer world and it is belief in itself, because the connection between *what someone perceives* and *the perceived* is based on certainty of reason, which is the foundation of any rational action in world:

> It is therefore fundamentally erroneous to believe that perception (and, after its own fashion, any other kind of intuition of a physical thing) does not reach the physical thing itself. The latter is not given to us in itself or in its being-in-itself. There belongs to any existent the essential possibility of being simply intuited as what it is and, more particularly, of being perceived as what it is in an adequate perception, one that is presentive of that existent 'in person', without any mediation by 'appearances'. (Hua III: 78)

Husserl distinguishes between *what someone perceives* and *the perceived* but keeps them connected and assures the reality of *the perceived*. Every *Seiende* (existent) can be perceived as what it is, but what someone perceives is always the phenomenon—the thing as has been given to someone by itself, but essentially to him, in his horizon, with the meaning it has to him (Hribar 1997). The core of what *the perceiver* perceives is *the perceived*, but always within the horizon of the perception process and according to *the perceiver's* own orientation. Husserl understands orientation as either orientation towards *the perceived thing itself* or a specific interest, e.g. admiration, esthetical contemplation, practical interest. Differences between the orientations are essential for the constitution of phenomena. If *what someone perceives* smells good or bad, this is not a property of *the perceived*. This is how *the perceived* is given to *the perceiver*, because of his specific physical/bodily interest. The role of orientation in Husserl's phenomenology is closely connected to the role of context in QM, as seen by non-realists. In their opinion, context is crucial; it defines the way the information is produced, gathered, described and understood.

While Husserl mostly uses the term perception (*die Wahrnehmung*), in science and in contemporary philosophy of science the term observation (*die Beobachtung*) is usually used. Husserl's perception describes the basic acquiring of information with the help of senses and is as such essentially connected with the primary openness to the world in Husserl's philosophy. The term observation describes a more contemplative, passive act. Most probably, the necessary use of measuring instruments that co-constitute the process of perception and are in-between the scientist and what he perceives, intuitively suggests the use of the more passive term in science. It can be argued that the choice of the term *observation* for scientific perception already includes the influence of the scientific orientation, a specific scientific interest in the object instead of the sole primary openness to the world. Phenomenology studies phenomena as such, while physics examines physical phenomena, the constitution of which is defined by the specific interest of physicists. The orientation of *the perceiver/observer* is changed, and not the relationship between the main agents of the perception/observation process—in both, phenomenology and physics, the exact understanding of the relationship between *the perceiver/observer*, *what someone perceives/observes* and *the perceived/observed* is needed to properly understand the nature of the object of investigation, describe it and understand its description.

Analysis of the perception process in phenomenology resulted in Husserl's complex reconsideration and critique of modern science. Husserl emphasized that the object of the scientific perception process, the thing explored and scientifically determined by *the scientific perceiver*, is always *the perceived thing itself* (Hua III: 99). However*, the scientifically perceived* is determined by a specific orientation, typical for the physical method. As such, *the perceived* is now "in the form of a constantly increasing approximation, beginning with what is empirically given to the geometrical ideal shape which functions as a guiding pole" (Hua VI: 29). Furthermore, it is subordinated to the principle of habit:

> The things of the intuited surrounding world (always taken as they are intuitively there for us in everyday life and count as actual) have, so to speak, their habits—they behave similarly under typically similar circumstances. If we take the intuitable world as a whole, in the flowing present in which it is straightforwardly there for us, it has even as a whole its habit i.e., that of continuing habitually as it has up to now. (Hua VI: 31)

According to Husserl, a physicist assumes that the world will follow the principle of habit and this assumption enables the formation of general scientific laws. *The scientifically perceived* is determined by a specific scientific orientation and can, as such, be abstracted, generalized and given in the language of mathematics. Perceptible spatiotemporal shapes and figures are mathematized and so become geometrical-ideal bodies. Perceptible shapes are "thinkable only in gradations: the more or less straight, flat, circular, etc." (Hua IV: 25), while the meaning of straight, flat, circular, etc. are determined by the axiomatic elementary laws of pure geometry. "What concretely exists in nature, and how this geometry is applied in experience is learned through the technical art of measuring. Measuring is the praxis that links the real to the ideal" (Heelan 1987).

Husserl believes the problem of modern science is that the roles of a specific scientific orientation, the hypothetical character of the approximation to the ideal geometrical forms and of the principal of habit, are forgotten. Science takes it not as a method to scientifically describe thing but as the way things are. The method and the object of investigation are not distinguished; Nature is regarded as a priori mathematical. Access to the full and proper understanding of *the observed* is closed. As science understands itself as self-sufficient, it misses the complexity of the relationship between *the observer* and *the observed* and thus their full understanding. Openness to the life-world is replaced by scientism.

2. Husserl and early interpretations of QM

That modern science does not distinguish between the method and the object of investigation, was not only relevant for philosophers, but has also revealed itself as highly important for understanding natural phenomena revealed by QM. If, as the realists do, we accept that the modern scientific concept of reality is necessary for science, how can we explain the collapse of the wave function and the properties of *the quantum perceived*? Either QM makes absolutely no sense or we need to supplement it by speculating about plurality of a priori unobservable or directly unobservable entities.

Husserl's critique of modern science included elements of modern scientific methodology that were also recognised as problematic within QM. Despite this, QM or "neue Atomphysik" (Hua VI: 57) was explicitly included in his critique, as one that still understands Nature as a priori mathematical. To some extent Husserl's inclusion of QM in his critique is justifiable, because the understanding of natural phenomena revealed by quantum experiments was (and still is) burdened by the modern scientific understanding of its object of investigation, of the observation process and of reality. At the time of formation of QM major part of the quantum community either understood mathematical description of *the perceived* as sufficient or based its interpretation of *the perceived* on the equivalence between Nature and its mathematical description.

a) Early interpretations of QM under the burden of the modern scientific realism

Einstein, who made some fundamental contributions to development of QM,[9] but never really accepted its description of nature and is known as one of its main critics (Pais 1982), understood the modern scientific concept of reality, connected with the simplified form of the observational process, as an essential element of science and rational thinking. In their famous paper "Can quantum-mechanical description of physical reality be considered complete?" Einstein, Petersen and Rosen write: "in a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system" (1935: 777) They a priori consider the un-simplified model of the observation process, which takes the influence of *the observer* and the observation process into account, as inappropriate for science and consequently consider QM as incomplete. However, they admit that one would not arrive at their conclusion, if one would regard two or more physical quantities as simultaneous elements of reality only when simultaneously measured or predicted (1935: 780). This would mean interpreting QM phenomena based on the un-simplified model of the observation process that takes the importance of context, influence of *the observer* and the differentiation between *the observed* (physical quantity) and *what someone observes* (measured/predicted physical quantity) in regard. Considering this possibility, the authors conclude: "No reasonable definition of reality could be expected to permit this" (1935: 780).

---

[9] He explained photoelectric effect by interpreting Planck's quantization of energy realistically.

Although not acting as critic but one of the main developers of QM, Heisenberg shared many of Einstein's realistic views. As Heelan writes: "for Einstein and Heisenberg […] scientific understanding is oriented towards ontology, the way things are and act; and this is intimately involved with mathematical representations of nature" (1975: 128).

Heisenberg's understanding of QM is based on the modern scientific understanding of Nature as a priori mathematical. In an interview in 1963, Heisenberg described his position as follows:

> we have a consistent mathematical scheme and this consistent mathematical scheme tells us everything that can be observed. Nothing is in nature that cannot be described by this mathematical scheme. […] When we get beyond this range of the classical theory, we must realize that our words don't fit. They don't really get a hold in the physical reality and therefore a new mathematical scheme is just as good as anything because the new mathematical scheme then tells what may be there and what may not be there. Nature just in some way follows the scheme. (Pais 1991: 309–310)

In Heisenberg's opinion, "as soon as one accepts that all quantum-theoretical quantities are in reality matrices, the quantitative laws follow without difficulty" (1927: 82). Lurçat sees Heisenberg as one that continues the Pythagorean and Galilean traditions. This approach has been adopted by many theoretical physicists before and after Heisenberg, however, Lurçat continues, "Bohr's interpretation breaks with these traditions; it has deep similarities to the Husserlian critique of the metaphysical foundations of classical physics" (2007: 244)

b) Bohr and Husserl: two complex reconsiderations of the observation/perception process

Bohr was one of the central figures, if not the central figure, in the formation of QM. As a leading theoretical physicist of the time he essentially contributed to its formalism[10] and, as the director of the Institute of Theoretical Physics, also mentored many of the top quantum physicists of the time. His persuasion that supplementation of mathematical formulation with philosophical interpretation is necessary encouraged discussions about philosophy and QM among his colleagues and students.

The interpretation presented here follows from Bohr's own texts. His views and concepts are paralleled to Husserl's phenomenological views. They prove extremely similar and some of their concepts are more easily

---

[10] E.g. the complementarity principle, which states that two complementary properties, e.g. position and momentum, of a QS cannot be precisely measured within the same measurement.

understood within the common context. As there is no evidence of Bohr ever studying Husserl, or vice versa, the similarity of their work has only rarely been recognised (Lurçat 2007; Bilban 2011a; 2011b).

Lurçat views Bohr's coherent interpretation of QM and Husserl's new conception of physics as two "convergent lines of thought" that might help to overcome the wrong basis of modern physics: "the universe is a book written in mathematical character". Lurçat's overview of QM and analysis of Bohr and Husserl is based on the consideration of the problem of mathematization of Nature, while other approaches and concepts used by Bohr and Husserl that are thoroughly examined in this text (e.g. the role of the reconsideration of the observation process, concept of reality, the role of context) are studied less closely (2007).

Similar to Lurçat, Heelan also closely studies Husserl's reconsideration of modern science and of the perception process and philosophical aspects of QM. However, to my best knowledge Heelan never directly connects Husserl's and Bohr's views. On the one hand, he analyses Husserl's position and describes it as anti(-theory) realism and scientific-(phenomena) realism (1987). On the other hand, he only touches upon Bohr's position within his comprehensive analysis of Heisenberg's interpretation of QM, and sees it as a complex interpretation that exceeds mere realism and antirealism (1975). Thus, though never stated as such, it seems that in regard to realism and antirealism Heelan understands Bohr's and Husserl's position to be similar and his views can be consequently regarded as indirectly supporting our argumentation.

Although he did not share all of Bohr's views, the complexity and philosophical deepness of Bohr's position was also recognized by Heisenberg:

> not a result of a mathematical analysis of the basic assumptions, but rather an intense occupation with the actual phenomena, such that it was possible for him to sense the relationship intuitively rather than formally. Thus I understood: knowledge of nature was primarily obtained in this way, and only as the next step can one succeed in fixing one's knowledge in mathematical form and subjecting it to complete rational analysis. Bohr was primarily a philosopher, not a physicist, but he understood that natural philosophy in our day and age carries weight only if its every detail can be subjected to the inexorable test of experiment (Heisenberg 1967: 94).

Bohr's complex personal interpretation of QM formed a basis for all his discussions, be it about its formalism, correctness of the results of quantum experiments or their possible understanding. The comprehensive and consistent philosophical interpretation provided him with an undefeatable position in debates (e.g. debates with Einstein (Pais 1982; Bohr 1935) and Heisenberg (Pais 1991)) that contributed to the establishment of QM. However, because of the complexity and individuality of his interpretation (it's impossible to connect Bohr's views with any single philosophical source), never gathered in one authoritative work, but spread across various texts and communications, it has been often labelled as ambiguous and since his time re-interpreted in many different ways.

Bohr was convinced that to understand QM the established modern scientific description of Nature and especially the understanding of the observation process have to be reconsidered (1934). Similar to Husserl's reconsideration of modern science, his reconsideration is connected with a critical analysis of the role of mathematics. Unlike the majority in the physical community, Bohr did not understand mathematics as a fundamental language of Nature, but as a language that is especially suitable for science, because of its preciseness and practicality. Mathematical formalism offers "rules of calculation for the deduction of expectations" about *what scientists observe* in the specific experimental context/scientific observation process and not about Nature in itself/*the observed* (1963: 60).

Bohr's and Husserl's analyses of the role of mathematics in modern science brought them to similar conclusions about the modern scientific description of Nature and the observation/perception process. They both recognised the undisputable achievements of physics in the era of modern science (Hua VI: 55; Bohr 1954), but were critical of the modern scientific description of its object of investigation, where the method and the object of investigation are not distinguished and Nature is regarded as mathematical or mechanical. How knowledge about *the observed* is obtained (e.g. the role of the observation/perception process and of context) is disregarded and thus access to the full and proper understanding of *the observed* is not possible:

> Mathematics and mathematical science [… encompasses everything which …] represents the life-world, dresses it up as 'objectively actual and true' nature. It is through the garb of ideas that we take for true being what is actually a method – a method which is designed for the purpose of progressively improving, in infinitum, through 'scientific' predictions, those rough predictions which are the only ones originally possible within the sphere of what is actually experienced and experienceable in the life-world. (Hua VI: 51–52)

> It is well known how a deterministic or causal account of this kind [Newtonian mechanics] led to the mechanical conception of nature and came to stand as an ideal of scientific explanation in all domains of knowledge, irrespective of the way knowledge is obtained. In this connection, therefore, it is important that the study of wider fields of physical experience has revealed the necessity of a closer consideration of the observation problem. (Bohr 1958: 69)

To exceed the modern scientific consideration of its objects of investigation, they both suggested “a reconsideration of the observation problem”. Bohr’s analysis of the observation problem was based on two main points: the problem of the lack of distinction between *the observed* and *what someone observes* and the problem of the deduction of the influence of *the observer*. In Bohr’s opinion, the modern scientific simplification of the observation process is not problematic by itself, but it is recognised as such when taken as an established assumption and faced with the results of quantum experiments. To properly describe and understand the results of quantum experiments, the observation process has to be understood as a complex relationship between *the observer, the observed* and *what someone observes.* When describing *the quantum observed*, one must not neglect the influence of *the observer.* On the one hand, this influence is caused by context of measurement, by inclusion of *the observed* in the observation process—because in QM *the observer* is “faced with an epistemological problem quite new in natural philosophy” that it is impossible “to distinguish sharply between the behaviour of objects and the means of observation” (1958: 25). On the other hand, the influence is caused by *the observer’s* orientation, by his understanding of *the observed*. Bohr emphasizes the need to use everyday language, based on experiences from our classical world, to describe the results of quantum experiments, “since by the word ‘experiment’ we can only mean a procedure regarding which we are able to communicate to others what we have done and what we have learnt” (1963: 3). For proper understanding of the relationships between the main agents of the observation process in QM the specific role of language and of the used concepts is crucial:

> While, however, in classical physics the distinction between object and measuring agencies does not entail any difference in the character of the description of the phenomena concerned, its fundamental importance in quantum theory […] has its root in the indispensable use of classical concepts in the interpretation of all proper measurements, even though classical theories do not suffice in accounting for the new types of regularities with which we are concerned in atomic physics. (1935: 701)

The specific importance of the use of classical concepts in QM is connected with two types of influences on *the observed*, caused by *the observer*.[11] When *the quantum observed* is measured, it entangles with the measuring apparatus, it becomes a sub-system of the entangled system:

---

[11] The presented description of both influences agrees with Bohr’s views, however, contemporary physical concepts (entanglement with measuring apparatus) and philosophical concepts (ontic, epistemic) that were not used by Bohr are used to make this description clearer within the context of contemporary QM and its philosophical interpretation.

measurement apparatus + the quantum observed and thus its ontic status is essentially changed. Consequently, the measuring apparatus becomes a mean to obtain a classical answer to the question about *the quantum observed*. This ontic change of *the observed* is caused by the inclusion of *the observed* in the observation process, while an epistemic change of *the observed* is caused by *the observer's* status of an a priori classical observer. All *the observer's* concepts are based on his everyday experiences. *The observer's* environment is a priori classical and as such defines his possible concepts; therefore, *the observer* cannot describe and understand anything, not the least a quantum observed, without classical concepts. The only answer about *any quantum observed* that *a classical observer* can get is a priori a classical answer. Since the property of the observed QS is a classical concept, with which *the quantum observed* in context of measurement is described, it makes no sense to transmit it to *the quantum observed* before the measurement, when it behaves otherwise, because of the ontic change at measurement.[12]

The recognition of both types of influences of *the observer* is the main part of Bohr's complex personal interpretation of QM. Reconsideration of the observation process is the basis for proper understanding of QM and at the same time a connection with fundamental philosophical problems:

> Since, in the observation of these phenomena, we cannot neglect the interaction between the object and the instrument of observation, the question of the possibilities of observation again comes to the foreground. Thus, we meet here, in a new light, the problem of the objectivity of phenomena which has always attracted much attention in philosophical discussion. (1934: 93)

For Bohr a crucial problem in QM is "the problem of the objectivity of phenomena". Not only are Bohr's reconsideration of the modern scientific description of Nature, the role of mathematics and the importance of the process of observation very similar to those of Husserl, he places the concept of phenomenon, Husserl's main philosophical concept, at the very top. Bohr most probably never studied Husserl's work and his use of the term *phenomenon* is not the same as Husserl's, however, the role of phenomenon in his understanding of the observation process is very

---

[12] This also explains why the wave function that describes *the quantum observed* before the measurement is a probability function. The concept of property is a classical concept and is used to describe *the quantum observed* when it is part of our classical system. Before (or after) the measurement *the quantum observed* has a different ontic status and is not part of our classical system, consequently, *the classical observer* can describe it only with respect to a potential measurement, an entanglement with our classical system. The wave function is a representation of *the observer's* knowledge about *the quantum observed* before the measurement; it describes only probability—potential results of the potential measurement of *the quantum observed*.

similar. Bohr understands phenomenon as "a complete description of the experimental arrangement as well as the observed results, and it is also the establishment of the statistical rules governing such results which is the only aim of quantum mechanics" (1998:130). His phenomenon can be understood as Husserl's phenomenon within the horizon of the quantum observation process and according to a specific orientation of a quantum physicist. In QM, *the quantum observed* is given to us in the form of the results of the experiment and according to the context of the experiment, which cannot be separated from the behaviour of *the observed*.

Bohr's (and Husserl's) phenomenon is influenced by *the observed* and by *the observer.* Faye and Folse describe this as Bohr's ontological realism and epistemological anti-realism:

> Bohr's insistence that the description of nature involves the description of interactions between measuring instruments and the objects whose properties they are designed to measure […] commits him to an ontological realism. […] Not only did Bohr deny that atomic objects were purely constructions, but also he [… distinguished] his view from those philosophers who regarded the measurement interaction as in some sense 'creating' the object of measurement. […] At the same time, however, Bohr […] argues strongly against those forms of realism which would attempt to describe an objectively existing, independent reality in terms of concepts which are well-defined only in relation to 'phenomena', as he uses that term. Bohr's ontological realism extends beyond the macro-realm to the atomic domain, nevertheless his epistemological anti- realism prohibits any attempt to carry the descriptive concepts of classical physics necessary for the description of phenomena beyond the phenomenal sphere to a world of things-in- themselves. (1998: 12–13)

Bohr's position of ontological realist and epistemological anti-realist is close to Heelan's description of Husserl as anti(-theory) realist, for his "critique of a certain notion of positive science the goal of which is the construction of an objective [mathematical] theory", and as scientific-(phenomena) realist, because of the ontic sense that the concept of phenomena gives to science (1987: 368). For Bohr (and Husserl) *the observed* is the core of *what someone observes*—therefore (ontological/phenomena) realism. But *what someone observes* is not *the observed* itself, but phenomenon, therefore its description cannot be transmitted to *the observed* as such, to *the observed* in other contexts—therefore (epistemological/theory) anti-realism.

Bohr claims that "no result of an experiment concerning a phenomenon which, in principle, lies outside the range of classical physics can be interpreted as giving information about independent properties of the objects". The result of a quantum experiment is always "inherently connected with a definite situation", defined by the used instruments and by *the observer's* way of understanding and describing the results. Therefore, the results of quantum experiments seem contradictory when considered outside the context as "a self-contained picture of the object" (1958: 26), as a priori properties of *the observed*. In QM the question "What is the polarization of that photon? Cannot be answered and has no meaning. A legitimate question is whether or not a photon has a specified polarization" (Peres 1995: 10). The polarisation (of that photon) per se makes no sense; it makes sense only to speak about the polarisation in a given context.

Heelan sees the importance of context as one of the most important differences between classical (universal and absolute) physics and post-classical physics, which is "contextual—or, to use phenomenological language, the 'horizontal'" (2011: 3). For Lurçat consideration of this difference presents one of the main elements of Bohr's interpretation of QM:

> "What is the value of the coordinate?" or "What is the value of the momentum component?" Asking such questions carelessly means going no further than Galileo's mathematical nature, with material points having definite values of their coordinates and momenta. […] Bohr's proposal is more fundamental: the meaning of any question has to be clarified by defining the experimental device that allows us to ask it concretely. (2007: 246)

Bohr's interpretation breaks with modern scientific tradition and has "deep similarities to the Husserlian critique of the metaphysical foundations of classical physics" (2007: 244). As such, Bohr's interpretation is comprehensive and undefeatable, it makes the results of quantum experiments understandable, connects them with broader philosophical understanding of the observation process and Nature and exceeds the oppositions between quantum interpretations, caused by historical development of modern science and physics:

> The classical physicist did not understand the nature of his science; the quantum physicist does not understand his very science, and, as we have seen, he is in many cases aware of this lack of understanding. Locked up in the Galilean prison, he does not see the key proposed by phenomenology, a key that Bohr, to a certain extent, rediscovered by himself. (2007: 257)

Bohr's way of constructing his interpretation shows that the phenomenological approach follows naturally from the reconsideration of the observation process and of the quantum object of investigation. Because he remained one of the central figures of QM, his interpretation has been integrated in many contemporary interpretations of QM, especially in the so called anti-realistic interpretations. However, because of his individuality and partition of his work in philosophy of QM, he is often misunderstood and philosophical consistency of his interpretation is mostly lost within these integrations. To exceed philosophical inconsistency of such theories Husserl's exact philosophical analysis of the perception process and of modern science can be of great help.

3. Husserl's philosophy as a philosophical support of contemporary QM interpretations: Husserl and informational foundations of quantum theory (IFQT)

Most quantum physicists agree about the basic mathematical formulations of QM and about the need for their supplementary interpretation. However, their interpretations depend on their philosophical and historical background. One of the most important contemporary interpretations of QM, grounded on direct analyses of the latest quantum experiments and their potential applications (e.g. quantum cryptography, quantum teleportation, quantum computers) is quantum information theory. Zeilinger's and Brukner's IFQT is one of the most important branches of quantum information theory that connects the knowledge pertained by the latest quantum results and the search for comprehensive philosophical interpretation of QM.

The philosophical background of IFQT is the Copenhagen interpretation with some crucial aspects of Bohr's personal interpretation (e.g. criticism of the modern scientific concept of reality, the importance of *the observer's* role and of context of the observation process) and some, although isolated and separately transmitted, elements from continental philosophy. The connection between Bohr and IFQT is widely recognised. Timpson, one of the most active critics of quantum information theory and a proponent of realistic quantum interpretations, finds that "immaterialism and instrumentalism", two crucial aspects of IFQT, are associated with "the Copenhagen school deriving from Bohr" (2010: 5). He believes that a quote famously attributed to Bohr—"It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature" (Petersen 1963: 8)—reveals that the problematic informational immaterialism of IFQT stems from the Copenhagen tradition:

> If quantum mechanics reveals that the true subject matter of physics is what can be said, rather than how things are, then this seems very close to saying that what is fundamental is the play of information across our psyches. (2010: 19)

As Timpson does not distinguish between *the observed* and *what someone observes*, the role of the latter escapes him; physics either describes *the observed* in itself, or its description is not connected with *the observed*.

IFQT, the philosophical side of which was constructed on the opposition to the established modern scientific realism, also understands its own and Bohr's position as anti-realistic. In their view, QM is only indirectly a science of reality and predominately a science of knowledge and thus of information (2005). However, this knowledge is not directly connected with *the observed*; *what someone observes* is not understood as essentially connected to both, *the observed* and *the observer*. Thus, *nature* in the quote attributed to Bohr is understood as only the inter-subjective agreement on the basis of information, as a mere construct for all practical purposes.[13]

IFQT is founded on the concept of information. Information, as purportedly used in quantum information theory, is defined by Timpson in *Quantum Information Theory and the Foundations of Quantum Mechanics* as a medium for meaning or message (2013). However, in IFQT information is understood as the smallest amount of knowledge, as a "yes" or "no" answer to the question about the object of investigation (Zeilinger 2003: 61). This places information in the system of the observation process as understood by Bohr and Husserl, where information has the role of *what someone observes*. In contrast to realistic interpretations, which are completely based on *the observed*, IFQT dismisses the role *the observed* has in the observation process and emphasizes that *the observer* only has information; therefore, information should be the basis to understand the results of quantum experiments. As a result, the foundational principle for QM should be based on the properties of information. The suggested foundational principle is that an elementary system has the information carrying capacity of at most one bit (Zeilinger 1999). On this basis, fundamental quantum phenomena that are regarded problematic from the modern scientific realistic point of view, e.g. objective randomness, collapse of the wave function, are explained by IFQT.

Objective randomness, the fact that information about a particular property of a QS does not exist before a measurement, becomes a fundamental property of the quantum world: one bit of information represents one possible answer to the question about a property of the QS. For example, to the question *Spin up?* (in a context of a particular measurement)

---

[13] There is another, not anti-realist, way to understand the quote, if one "uses the key proposed by phenomenology". (Lurçat introduces his article (2007) with this same quote, although he does not explicitly explain it, its position supports the possibility of understanding it by using the key proposed by phenomenology.) Physics cannot be seen only as a matter of language, because it concerns what we can say about nature/*the observed*. However, the way physics describes nature always depends on *the observer's* means of understanding and describing it, thus the task of physics cannot be only to simply find out how nature is.

there are two possible answers, either *yes* or *no* (*spin down*). One answer (*yes* or *no*) represents one property and gives one bit of information. Thus, the elementary system carries the answer to one question only (e.g., *What is the spin along the z-axis*). Answers to all other questions that one would also like to ask must contain an element of randomness (e.g., *What is the spin along the x- or y-axis for the particle with measured spin along the z-axis*) (1999).

The collapse of the wave function also contains no paradox if it is understood as:

> [J]ust an encoded mathematical representation of our knowledge of the system. […] When the state of a quantum system has a non-zero value at some position in space at some particular time, it does not mean that the system is physically present at that point, but only that our knowledge […] allows the particle the possibility of being present at that point at that instant. […] When a measurement is performed, our knowledge of the system changes, and therefore its representation, the quantum state, also changes. In agreement with the new knowledge, it instantaneously changes all its components, even those which describe our knowledge in the regions of space quite distant from the site of the measurement. (Brukner & Zeilinger 2003: 19)

Similar to Bohr and Husserl, IFQT understands the role of context, in which information is gathered, as crucial. However, in IFQT the role of context is connected only with *the observer* and his way of observing—*the observer* performs a measurement, his knowledge and thus information are changed. The connection between the context and *the observed* (the ontic change of *the observed*) and their influence on information are neglected, because there is no direct connection between *the observed* and *what someone observes*. If such an anti-realistic position is taken, the objectivity of information becomes problematic and it cannot be taken as self-evident on the basis of the common, from us independently existing outer world, as is the case in classical physics.

> Of course this does not imply that reality is no more than a pure subjective human construct. From our observations we are able to build up objects with a set of properties that do not change under variations of modes of observation or description. These are 'invariants' with respect to these variations. Predictions based on any such specific invariants may then be checked by anyone, and as a result we may arrive at an intersubjective agreement about the model, thus lending a sense of independent reality to the mentally constructed objects. (Brukner & Zeilinger 2003: 20)

On the basis of these invariants and of the inter-subjective agreement about the gained information, it is possible to exceed the solipsism and to conclude that a system of information, independent from us, forms something that we can call objective reality. In other words, it is possible to conclude that the outer world (in that sense) exists (Zeilinger 2003: 317).

The IFQT's answer to the question *What is real (in QM)?* can thus be "the inter-subjective system of information". However, there is no direct connection between this system of information and *the observed* and we cannot speak about an outer world (about objective reality of things outside us), which the information we possess is about and which is a basis for scientific objectivity. In IFQT the modern scientific realism is not replaced by a complex reconsideration of the observation/perception process, as by Bohr and Husserl, but is directly negated. The mathematical description is understood as mere representation of our knowledge, of *what someone observes*, without restoring the connection between *what someone observes* and *the observed*.

Such an understanding of the relationship between the main agents of the observation process in IFQT is a consequence of its philosophical and historical background. Much of the philosophical understanding of QM in IFQT is based on the work of Weizsäcker, a German philosopher and physicist. Weizsäcker was convinced that Kant's philosophy reveals and answers the same questions as QM (1985) and based his interpretation of the relationship between *the observation* and *what someone observes* in QM on Kant's distinction between *thing-for-me*/phenomenon and *thing-in-itself.* However, the relationship between the two is not causal, they are not directly connected. Weizsäcker transmitted Kant's definition of the relationship between *thing-in-itself* and phenomenon to the relationship between *the observed* and information in QM.[14] This has been later integrated into many anti-realistic interpretations of QM, among them into IFQT, although after Weizsäcker without full awareness of its source. Weizsäcker offered an understanding of the elements of the observation process in QM that exceeded the established modern scientific realism, but the transmitted lack of connection between both elements (*thing-in-itself* : phenomenon*; the observed* : information) was problematic. Kant himself acknowledged the problem in his *Critique of Pure Reason*: although we cannot know any objects as *things-in-themselves*, we have to think them as such, because otherwise we land in the absurd conclusion that there can be appearance without anything that appears (Kant 1787: B26–27). IFQT faces similar problems: Information is sensible only as long it is information about something, but if the existence of information is the only thing we are confident about, what is this information about?

---

[14] It is important to bear in mind that in Kant's philosophy the place of the physical object is solely on the side of phenomenon, so Kant's distinction between *thing-in-itself* and *phenomenon* is not directly applicable to QM, what is transmitted is Kant's method, his way of distinction between two concepts (Heisenberg 1986).

Husserl's phenomenological reconsideration of the perception process offers a solution to Kant's lack of connection between the two[15] (Blecha 2001). In Husserl's phenomenology the connection between the thing and phenomenon is assured, as phenomenon is essentially related to both, *the perceiver* (and his way of observing) and *the perceived*. If Husserl's definition of the relationship between the thing and the phenomenon is transmitted to the relationship between *the observed* and information in IFQT, the problem of the objectivity of information facing IFQT is solved. Information is the direct answer to the question about *the observed* and thereby *the observer's* only knowledge about it. The basis for this information is *the observed* itself, e.g., within a particular measurement, information is the value of the position or of the polarization of *the observed* photon. However, it is important to bear in mind that any concrete naming of *the observed* within the description of the measurement, e.g., the photon, is connected with *the observer's* understanding and knowledge and thereby with his information about *the observed*. The expression *photon* for *the observed* before and after the measurement (only) describes possible potential answers that *the observer* can get about *the observed* within a potential measurement (a sensible question for a photon is not necessarily the same as a sensible question for an electron) and not *the observer's* a priori knowledge about *the observed*. Based on our everyday experience, *Seiende* is always understood in the context of its properties. Therefore, with our classical concepts, which are, the only we (can) have, the quantum observed before and after the measurement can be described only as the potential to give an answer to classical questions, to have a property, which is a classical concept, to give/cause the result when measured. Furthermore, it is important not to talk about the/one photon, since this is already information dependent of the context of the particular measurement. Information is always the *observer's* information, dependent of his horizon/of given context, while the connection with *the observed* assures its objectivity.

As Husserl's philosophical solution is transmitted to IFQT, the complexity of Bohr's interpretation is regained; both, *the observer* and *the observed* have a significant influence on information. Physics concerns what we (*the observer*) can say about nature (*the observed*).

IFQT still exceeds the modern scientific realism, but the criticisms of the realists are now easier to reject, as its position is more philosophically consistent and comprehensive. The importance of the connection between *the observer* and *what someone observes* is preserved, while the connec-

---

[15] It can thus be argued that IFQT is not importantly connected with Husserl only through Bohr, but through Kant as well.

tion between *what someone observes* and *the observed* is established as well: All *the observer* has about *the quantum observed* is his information, gained within the context of the observation process. However, this is information about *the observed*. One can no longer claim that "what is fundamental is the play of information across our psyches" (Timpson 2010: 19). If Husserl's understanding of the perception process is used to supplement IFQT it is not only the inter-subjective system of information that can be taken as real. On the basis of *Glaubengewissheit,* not only the information, but the outer world, *the observed*, can be taken as real as well.

After the supplementation all IFQT's explanations of quantum phenomena remain valid. Objective randomness is now even easier to understand: One bit of information is one classical answer to one classical question posed to *the quantum observed*. The answer is given according to the particular entanglement with the measurement apparatus and is valid only within this particular context. To get another answer, another measurement is needed. This answer cannot be understood as the a priori property of *the observed*, because, as Bohr emphasized, we cannot transfer classical concepts to *the quantum observed* before or after the measurement. Also, the explanation of the collapse of the wave function remains valid and gains in complexity: *the observer's* knowledge about *the observed* is changed (epistemic change), as *the observed* itself is changed by the influence of the observation process (ontic change) and the relationship between *the observer* and *the observed* is essentially changed, thus *what someone observes* is naturally changed as well. However, to keep the connection with *the observed*, there is no need to understand the wave function as objectively real or in any other way than "just an encoded mathematical representation of our knowledge of the system".

4. Husserl's reconsideration of the observation process and its possible connections with QM

We argued in this manuscript that Husserl's critique of modern science and quantum experiments reveal similar problems with modern scientific thought. Husserl, from his meta-scientific philosophical point of view, and Bohr, from his inner-scientific quantum point of view, both recognize the need for reconsideration of the observation/perception process and on this basis reconsideration of science. As Bohr's personal interpretation of QM was not designed in a direct contact with Husserl's phenomenology, the similarities between their positions have so far only rarely been analysed. Some common aspects of their understandings of science in general and classical physics have been presented by Lurçat (2007), while Heelan's analysis of Husserl's philosophy and Heisenberg's interpretation of QM hints on possible similarities between Husserl and Bohr (1975, 1987).

In this article, Husserl's and Bohr's views are compared in detail. They both understand mathematics as (the optimal scientific) description of *what someone observes* and not of *the observed* itself, they emphasize the importance of the influence of *the observer* and context on *what someone observes* and they consider *what someone observes* as directly connected to *the observed*—it is how *the observed* is given to *the observer*. As Bohr's complex and unique interpretation is spread across various texts and communications and was never connected to any single philosophical source, it has often been misunderstood, re-interpreted and labelled as ambiguous. When analysed from the phenomenological point of view with the help of Husserl's rigorous philosophical system, some of Bohr's concepts are easier to understand and their philosophical consistency is much clearer. For example, one can see that the role of Bohr's phenomenon in the quantum observation process is equal to the role of Husserl's phenomenon in his model of the perception process; thus the complex relationships between the elements of the quantum observation process are clear and philosophically illuminated.

The insight into similarities between Husserl and Bohr not only illuminates Bohr's interpretation, but contributes to contemporary interpretations of QM as well. It is well known in the community of philosophy of QM that many of the contemporary quantum interpretations are based on Bohr's interpretation. However, it is often overlooked that within the transmission, some elements of Bohr's interpretation are critically simplified and that Bohr's position is unjustifiably reduced to simple anti-realism. Contemporary anti-realistic theories based on the simplified Bohr's view thus lack the necessary complexity and philosophical consistency. Here Husserl's phenomenology, within which the perception process and its role in science are rigorously defined and well known in philosophical community, can be of great help.

In this study we suggest a corresponding supplementation of one such anti-realistic theory, IFQT, one of the most promising contemporary interpretations of QM. IFQT is based on direct analyses of the latest quantum experiments and their potential applications, its informational vocabulary is clear and the refined system of information processing offers an understandable mean for the explanation of quantum phenomena and the observation process. However, the ontic status of information, the main concept of IFQT, is not clear and consequently IFQT is philosophically inconsistent. If Husserl's definition of the relationship between the thing and the phenomenon is transmitted to the relationship between *the observed* and information in IFQT, the problem of the ontic status of information is solved; now information has a clear position in the observation process—it is information about *the observed* as given to *the observer*. This philosophical supplementation helps reject the criticisms of IFQT and additionally support its explanations of quantum phenomena. In this way, IFQT becomes a direct successor of Bohr's interpretation; it rediscovers the key proposed by phenomenology and by Bohr and connects it with the latest discoveries in QM.[16]

References

Bilban, T. 2011a. "Prestopanje meja: Kaj si lahko povesta fenomenologija in sodobna fizika" ("The Transgression of Boundaries. What Phenomenology and Modern Physics Have to Say to Each Other?"), *Phainomena*, 76/77/78, 227−243.

——. 2011b. "Modeli opazovalnega procesa v kvantni in klasični fiziki" ("Models of the observational process in quantum and classical physics'), *Poligrafi*, 63/64, 119−142.

Blecha, I. 2001. "Kant, pragmatični antirealizem in Husserlova fenomenologija" ("Kant, Pragmatic Antirealism and Husserl's Phenomenology"), *Phainomena*, 37/38, 143.

Bohm, D. 1952. "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables", *Physical Review*, 85, 166–180.

Bohr, N. 1934. *The Philosophical Writings of Niels Bohr: Volume 1* (Woodbridge, Connecticut: Ox Bow Press).

——. 1935. "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?", *Physical Review* 48, 696−702.

——. 1958. *The Philosophical Writings of Niels Bohr: Volume II* (Woodbridge, Connecticut: Ox Bow Press).

——. 1963. *The Philosophical Writings of Niels Bohr: Volume III* (Woodbridge, Connecticut: Ox Bow Press).

——. 1998. *The Philosophical Writings of Niels Bohr: Volume IV* (Woodbridge, Connecticut: Ox Bow Press).

Brukner, Č. & A. Zeilinger. 2003. "Information and fundamental elements of the structure of quantum theory", in L.Castell, & O. Ischebeck (eds.). *Time, Quantum, Information*, 323−355 (Berlin, Heidelberg, New York: Springer).

---

[16] This work was supported by a grant from the John Templeton Foundation. I would like to thank Markus Aspelmeyer, Časlav Brukner, Johannes Kofler and Anton Zeilinger for inspiring discussions and helpful comments.

——. 2005. “Quantum Physics as a Science of Information”, in A. Elitzur, S. Dolev, & N. Kolenda (eds.), *Quo Vadis Quantum Mechanics?* (Berlin, Heidelberg, New York: Springer 2005), 47−63

Carrol, S. 2013. “*The most embarrassing graph in modern physics*”*,* 17.1.2013< http://www.preposterousuniverse.com/blog (accessed 11st May 2013).

Einstein, A., B. Podolsky, B. & N. Rosen. 1935. “Can quantum mechanical description of physical reality be considered complete?”, *Physical Review* 47, 777–780.

Everett, H., III. 1956. *Theory of the Universal Wavefunction* (unpublished doctoral thesis, Princeton: Princeton University)

Faye, J. & H. J. Folse. 1998. “Introduction”, in N. Bohr, *The Philosophical Writings of Niels Bohr: Volume IV* (Woodbridge, Connecticut: Ox Bow Press), 1–23.

French, S. 2002. “A phenomenological solution to the measurement problem: Husserl and the foundations of quantum mechanics”, *Studies in History and Philosophy of Modern Physics,* 22, 476−491.

Galilei, G. 1632. *Dialogo sopra i due massimi sistemi del mondo* (Florence)

Heelan, P. A. 1975. “Heisenberg and radical theoretic change”, *Zeitschrift für allgemeine Wissenschaftstheorie* 6, 113–138.

——. 1987. “Husserl’s Later Philosophy of Natural Sciences”, *Philosophy of Science* 54, 368– 390.

——. 2003. ‘Phenomenology and the Philosophy of Natural Sciences”, in A. T. Tymienicka (ed.), *Phenomenology World-Wide: A Guide for research and Study* (Dordrecht, Boston: Kluwer), 631–641.

——. 2004. “The Phenomenological Role of Consciousness in Measurement”, *Mind and Matter* 2, 61–84.

——. 2011. “Phenomenology, Ontology and Quantum Physics”, *Foundations of Science*.

Heisenberg, W. 1927. “Über des Anschaulichen Inhalt der Quantentheoretischen Kinematik und Mechanik”, *Zeitscrift für Physik* 43, 172–198. Translation in J. A. Wheeler, W. H. Zurek 1983. *Quantum Theory and Measurement* (Princeton: Princeton University Press).

——. 1967. “Quantum theory and its interpretation”, in S. Rozental (ed.), *Niels Bohr: His life and Work as seen by his Friends and Colleagues* (Amsterdam: North-Holland Publishing Company).

——. 1986. *Quantentheorie und Philosophie* (Stuttgart: Reclam)

Hribar, T. 1997. “Fenomen uma”, in E. Husserl, *Ideje za čisto fenomenologijo in fenomenološko filozofijo* (Ljubljana: Slovenska Matica), 498–522.

Husserl, E. 1939. *Erfahrung und Urteil* (Prag: L. Landgrebe, Academia). Translation: *Experience and Judgement*, transl. by F. Kersten (Dordrecht: Kluwer).

——. 1976. Hua III: *Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie (Hua III)*. K. Schuhmann (ed.) (Den Haag: Martinus Nijhoff). Translation: E. Husserl 1982, *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy*, transl. F. Kersten (Dordrecht: Kluwer).

——. 1976. *Die Krisis der europäischen Wissenschaften und dietranszendentale Phänomenologie. Eine Einleitung in die phänomenologische Philosophie (Hua IV)*. W. Biemel (ed.) (Den Haag: Martinus Nijhoff). Translation: E. Husserl 1970. *The Crisis of European Sciences and Transcendental Phenomenology. An Introduction to Phenomenological Philosophy*, transl. D. Carr (Evanston: Northwestern University Press).

Jaeger, G. 2009. *Entanglement, Information, and the Interpretation of Quantum Mechanics* (Berlin, Heidelberg: Springer).

Kant, I. 1787/1968. *Kritik der reinen Vernunft* (Berlin: Walter de Gruyter and Co.).

Kuhn, T. S. 1962. *The Structure of Scientific Revolutions* (Chicago, London: The University of Chicago Press).

Koyre, A. 1957. *From the Closed World to the Infinite Universe* (Baltimore: John Hopkins Press).

London, F. & E. Bauer 1983. “The theory of observation in quantum mechanics”, in J. A. Wheeler & W. H. Zurek (eds.), *Quantum Theory and Measurement* (Princeton: Princeton University Press), 217−259.

Lurçat, F. 2007. “Understanding Quantum Mechanics with Bohr and Husserl”, in L. Boi, et al. (eds.), *Rediscovering Phenomenology* (Berlin, Heidelberg: Springer), 229–258.

Pais, A. 1982. *“Subtle is the Lord . . .”: The Science and the Life of Albert Einstein* (New York: Oxford University Press).

——. 1991. *Niels Bohr’s Times, in Physics, Philosophy, and Polity* (Oxford: Clarendon Press).

Peres, A. 1995. *Quantum Theory: Concepts and Methods* (Dordrecht: Kluwer Academic Publishers).

Petersen, A. 1963. “The Philosophy of Niels Bohr’, *Bulletin of the Atomic Scientists* 19, 8–14.

Schlosshauer M., Kofler J. and A. Zeilinger 2013. “A Snapshot of Foundational Attitudes Towards Quantum Mechanics”, 6.1. 2013<http://arxiv.org/abs/1301.1069 (accessed 11st May 2013).

Stenholm, S. 2011. *The Quest for Reality. Bohr and Wittgenstein – Two Complementary Views* (Oxford: Oxford University Press).

Timpson, C. G. 2008. “Philosophical Aspects of Quantum Information Theory”, in D. Rickles (ed.). *The Ashgate Companion to the New Philosophy of Physics* (Hants, Burlington: Ashgate), 197−261.

——. 2010. “Information, Immaterialism, Instrumentalism: Old and New in Quantum Information”, in A. Bokulich & G. Jaeger (eds.), *Philosophy of Quantum Information and Entanglement* (Cambridge: Cambridge University Press), 208−228.

——. 2013. *Quantum Information Theory and the Foundations of Quantum Mechanics* (Oxford: Oxford University Press).

von Weizsäcker, C. A. 1985. *Aufbau der Physik* (München, Wien: Carl Hanser Verlag).

Zeilinger, A. 1999. “A foundational principle for quantum mechanics”, *Foundations of Physics* 29, 631.

——. 2003. *Einsteins Schleier* (München: Verlag C. H. Beck).