https://doi.org/10.21638/2226-5260-2020-9-1-216-234

THE PHENOMENOLOGICAL APPROACH TO QUANTUM MECHANICS: A BETTER UNDERSTANDING OF CONTEMPORARY PHILOSOPHY OF QUANTUM MECHANICS BY REVISITING BOHR AND HUSSERL

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Niels Bohr, considered one of the fathers of quantum mechanics, formulated a complex interpretation of quantum mechanics that guided his understanding of quantum experiments. The contemporary dispute between realism and anti-realism, the two main approaches to the interpretation of quantum mechanics, is often based on different attitudes towards or even readings of Bohr. We propose that a better understanding of Bohr's philosophical thought can contribute to the contemporary reconciliation of these opposing philosophical views and thus to a better understanding of the quantum world. Unfortunately, in many contemporary interpretations, Bohr's philosophical approach to quantum mechanics has been misunderstood, re-interpreted or labelled as ambiguous. This is mostly due to the dispersion of Bohr's complex and unique interpretation through different texts, never united in a single systematically conceptualized work. To comprehensively explain Bohr's philosophical approach and his main philosophical concepts, we consider the many similarities between Bohr's and Husserl's philosophical approach to science. Husserl developed his philosophical standpoint in a cultural context similar to Bohr's and shared Bohr's objects of philosophical consideration as well as his approach to these objects. Parallel reading of Bohr's and Husserl's texts reveals the closeness between Bohr's ontological realism—epistemological anti-realism standpoint and Husserl's phenomenological standpoint. This explains their similar views on the relationship between mathematical language, scientific method and Nature. While Bohr's use of the term phenomenon is not equal to Husserl's, Husserl's rigorous philosophical explanation of the term helps us to better understand Bohr's use. Furthermore, the parallel reading facilitates better understanding of one of Bohr's main philosophical theses, often labelled as ambiguous and interpreted in different ways, that it is necessary to use classical concepts to describe quantum phenomena. We claim that the thesis is connected with the advance of epistemological reconsideration of science at the time of Bohr's writing. Thus, Bohr considers some parts of argumentation as self-evident, while they are not evident to the contemporary reader. Husserl's analysis of the relationship between

science and the life-world offers a much-needed background for a comprehensive understanding of Bohr's thesis. The insight into the similarities between Bohr's and Husserl's philosophical approach to science and scientific phenomena enables a philosophically rigorous reading of Bohr's texts; it can eliminate some of the disagreements between realists and anti-realists and provide a firmer philosophical ground for a dialog between them.

Key words: Edmund Husserl, Niels Bohr, phenomenology, phenomena, classical concepts, quantum mechanics, life-world.

ФЕНОМЕНОЛОГИЧЕСКИЙ ПОДХОД В КВАНТОВОЙ МЕХАНИКЕ: ЛУЧШЕ ПОНИМАЕМ СОВРЕМЕННУЮ ФИЛОСОФИЮ КВАНТОВОЙ МЕХАНИКИ, ЗАНОВО ЧИТАЯ БОРА И ГУССЕРЛЯ

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Нильс Бор, который считается одним из отцов-основателей квантовой механики, сформулировал ряд положений о квантовой механики, в которых отражено его понимание квантовой механики. Современная дискуссия между реалистами и анти-реалистами, двумя основными направлениям интерпретаций квантовой механики, зачастую базируется на различном прочтении Бора. Мы полагаем, что лучшее понимание философии Бора может послужить примирению этих противоположных точек зрения и, как следствие, более адекватному пониманию квантового мира. К сожалению, во многих современных исследованиях философский подход Бора к квантовой механике понимается неправильно, интерпретируется или получает ярлык в качестве двусмысленного. Это зависит в большей степени от того факта, что сложная и уникальная интерпретация Бора раздроблена по различным текстам и никогда не была объединена в одной систематичной и концептуальной книге. Чтобы дать всестороннюю оценку философского подхода Бора и его основных философских воззрений, мы предлагаем проследить общие тенденции между философскими подходами к науке у Бора и Гуссерля. Гуссерль разрабатывал свою философскую позицию в общекультурном контексте, близком Бору, и разделял предмет философского рассмотрения Бора, равно как и его подход. Если параллельно читать тексты Бора и Гуссерля, то открывается схожесть между онтологическим реализмом — эпистемологическим антиреализмом Бора и феноменологической позицией Гуссерля. Это проясняет их схожие точки зрения на связь между математическим языком, научным методом и природой. Поскольку понятие феномен у Бора не эквивалентно гуссерлианскому, строгое философское объяснения данного понятия Гуссерля поможет нам лучше понять это употребление Бором. Кроме того, параллельное чтение способствует лучшему пониманию одного из главных тезисов Бора, часто определяемому как двусмысленный и интерпретируемому различным образом, который гласит, что для описания квантового феномена необходимо использовать классические понятия. Мы полагаем, что данный тезис связан с преимуществом эпистемологического подхода в науке во времена Бора. Так, Бор полагает некоторую часть аргументации в качестве самоочевидной, в то время как для современного читателя это не самоочевидно. Гуссерлианский анализ отношения между наукой и жизненным миром предоставляет исконный контекст

для более адекватного понимания тезиса Бора. Взгляд на схожесть между философскими подходами Бора и Гуссерля к науке и научным феноменам делает возможным строго философский подход к текстам Бора; это поможет избежать разногласия между реалистами и анти-реалистами и обеспечить более строгий философский базис для диалога между ними.

Ключевые слова: Эдмунд Гуссерль, Нильс Бор, феноменология, феномен, классические концепты, квантовая механика, жизненный мир.

1. INTRODUCTION

Niels Bohr was one of the central figures in the early formation of quantum mechanics. As a leading theoretical physicist of the time he essentially contributed to its formalism, while his supplementation of mathematical formulation with a philosophical interpretation co-determined the early relationship between philosophy and quantum mechanics. As Heisenberg remarked: "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, 95).

In his time, Bohr has been known as an excellent rhetorician, which was perhaps most clearly shown in his public disputes with Einstein about possible interpretation of quantum experiments, in which Bohr, in his defence of quantum theory, was widely considered the winner. Today his philosophical thought is available through his philosophical writings. It is dispersed through different texts, which were often described as more difficult to understand than his oral arguments. Due to Bohr's influence, his philosophical standpoint has been incorporated into different interpretations. Some parts were included in the Copenhagen interpretation, which at the time combined common views of different quantum physicists, gathered around the Institute of Theoretical Physics in Copenhagen, and presents the basis for explanation of quantum mechanics in most textbooks. Some parts of Bohr's philosophy have been adopted by his successors, incorporated in their personal interpretation systems and interpreted in the new context.

Today, quantum physicists and philosophers of physics are still far from reaching an agreement on how to understand the results of quantum experiments and their mathematical description. When they consider different explanations, they often revisit (or try to revisit) Bohr's philosophical position. It is, for example, characteristic of the ongoing dispute between realism and anti-realism, the two main approaches to the interpretation of quantum mechanics, that both sides build their philosophical position in regard to Bohr's. However, a careful examination reveals they interpret his texts differently and (therefore) form different attitudes towards it.

In the context of the dispute between realism and anti-realism, Bohr's complex philosophical standpoint is often simplified as merely anti-realistic and/or equated with the Copenhagen interpretation. Such a position is taken by some of the leading contemporary quantum physicists, e.g. Brukner & Zeilinger (2003), and philosophers of quantum mechanics, e.g. Timpson (2010), as well as by journalist and popular science writers in their presentation of quantum mechanics to the wider public, even in established media such as *Nature* (Merali, 2015).

To prove their standpoint in regard to the interpretation of quantum mechanics, physicists and philosophers have often used this simplified version of Bohr's position as basis of their own theory or as the basis of the theory they aim to dispute. Furthermore, they have often based their understandings of Bohr not (only) on Bohr's texts but mainly on statements attributed to Bohr by his successors, such as Petersen (Brukner & Zeilinger, 2003). As they interpret the Copenhagen interpretation as "a pattern of views centred around—and diverging in different ways from—Bohr's own" (Timpson, 2010), Bohr's position has been often mixed with philosophical standpoints not only deviating from Bohr's but sometimes directly opposite to Bohr's—from Heisenberg's instrumentalism to the so called *shut-up-and-calculate* attitude that evolved in the second half of the 20th century and considered philosophy of quantum mechanics mainly as a burden of the experimental and technological advancement (Merali, 2015).

Different interpretations of Bohr's philosophical standpoint often prevent philosophical opponents, such as realists and anti-realists, to either agree on the phenomena they describe and the concepts they utilize, or, to recognize Bohr's philosophical position as a complex additional philosophical option exceeding their extreme views.

I propose that better understanding of Bohr's philosophical thought can contribute to contemporary reconciliation of different philosophical views on quantum mechanics and thus to a better understanding of the quantum world. One of the more apparent problems with Bohr's philosophical thought is its dispersion through different texts, never united in a single systematically conceptualized work, in combination with its complexity and uniqueness. To provide a solid ground for the understanding of Bohr's philosophical thought and unambiguous interpretation of his main (philosophical concepts)—such as *phenomena* and *classical concepts*—we are going to consider the many similarities between Bohr's philosophical thought and that of Edmund Husserl. Husserl, who developed his philosophy in a cultural context similar to Bohr's, shared Bohr's objects of philosophical consideration as well as, as we shall see, his approach to these objects. We aim to employ his rigorous philosophical system as guidance when interpreting Bohr's philosophical thought.

2. REVISITING BOHR IN HUSSERL'S COMPANY

In his philosophical texts, Bohr constantly refers to the *observation problem,* which he describes as a new problem for natural sciences or even "natural philosophy" (Bohr, 1938, 25), but, at the same time, a problem, "which has always attracted so much attention in philosophical discussion" (Bohr, 1929, 119), a problem "as old as physical science itself" (Bohr, 1958, 59).

The epistemic question of how the means of observation change the observed object itself, has been constantly present in philosophy. However, natural sciences as well as our everyday understanding of the world have been based on the assumption "that it is possible to distinguish sharply between the behaviour of objects and the means of observation" (Bohr, 1938, 25). In Bohr's opinion, classical physics has been justified to presuppose such a position, which enabled its progress and understanding of the experimental results. It was not until the first quantum experiments that such a position became (too) simple and inappropriate for further examination of the world around us:

> As soon as we are dealing, however, with phenomena like individual atomic processes which, due to their nature, are essentially determined by interactions between the objects in question and the measuring instruments necessary for the definition of experimental arrangements, we are, therefore, forced to examine more closely the question of what kind of knowledge can be obtained concerning the objects. In this respect we must, on the one hand, realize that the aim of every physical experiment—to gain knowledge under reproducible and communicable conditions—leaves us no choice but to use everyday concepts, perhaps refined by the terminology of classical physics, not only in all accounts of the construction and manipulation of the measuring instruments but also in the description of the actual experimental results. On the other hand, it is equally important to understand that just this circumstance implies that no result of an experiment concerning a phenomena which, in principle, lie outside the range of classical physics can be interpreted as giving information about independent properties of the objects, but is inherently connected with a definite situation in the description of which the measuring instruments interacting with the objects also enter essentially. (Bohr, 1938, 25–26)

While a classical physicist could make sense of his/her own experimental results and description of the world without considering foundational epistemic questions, such as *how the observer influences the world he observes*, a quantum physicist is forced to consider them and apply them to the interpretation of the quantum experiments, since "individual atomic processes […] are essentially determined by interactions between the objects in question and the measuring instruments necessary for the definition of experimental arrangements" (Bohr, 1938, 25). Before a measurement the quantum system in question can be considered coherent and can be mathematically described by

a wave function, which no longer holds within the context of a measurement within which the quantum system can be described by a measured property. Thus, the quantum physicist has to factor his role in the observation of the quantum phenomena, a role of the one who decides what to measure and sets the experiment, as Bohr puts it: a role of both an onlooker and an actor. His observation of quantum phenomena always depends on the measuring devices and the context of the measurement.

What Bohr presents as epistemic questions raised in physics by quantum experiments, are, as he remarks, old philosophical questions already raised by Buddha, Lao Tse and many Greek philosophers, "who based the explanation of the specific properties of substances on the limited divisibility of all matter, took it for granted that the coarseness of our sense organs would forever prevent the direct observations of individual atoms" (Bohr, 1958, 59).

These epistemic questions also represent the foreground of Husserl's phenomenology. In phenomenology the person examining the world—whether as a scientist, a philosopher, an artist or merely a curious mind—is always an onlooker as well as an actor. His perception of the world around him depends on his modes of cognition. These determine his understanding of the world and thus his world as such. However, it is this world, where he meets with others. He accepts their and his own surrounding world "objectively as one and the same world of which we all are conscious, only in different modes. Each has his place from which he sees the physical things present; and accordingly, each has different physical-thing appearances" (Husserl, 1998, 56). Consequently, "we come to an understanding with our fellow human beings and in common with them posit an Objective spatiotemporal actuality as our factually existent surrounding world to which we ourselves nonetheless belong" (Husserl, 1998, 56).

Husserl describes a perception of a chosen object—e.g. a sheet of paper—as singling it out and seizing upon it. However, we can only single the perceived object out, because we acknowledge its background: "…anything perceived has an experimental background. Around the sheet of paper lie books, pencils, an inkstand, etc." (Husserl, 1998, 70). They appear, but they are not seized upon. However, this background does not consist of "all the physical occurrences which valid and progressing experience may ascertain there" (Husserl, 1998, 94). The formation of the background as well as the perception of the object we seize upon, depend on our modes of perception—on our intentions, abilities, previous knowledge. As we seize upon the chosen object, it is always "given only 'one-sidedly',"

> in mere "modes of appearance" […] It points ahead to possible perceptual multiplicities which, merging continuously into one another, join together to make up the unity of one

> perception in which the continuously enduring physical thing is always showing some new "sides" (or else an old "side" as returning) in a new series of adumbrations. (Husserl, 1998, 94)

At the given moment, some of the sides become clearer, while others fade away. "To be in infinitum imperfect in this manner is part of the unanullable essence of the correlation between 'physical thing' and perception of a physical thing" (Husserl, 1998, 94).

Both, Husserl and Bohr, unveil the important role of context and means of observation (measuring devices/modes of cognition) on the provided information about our object of interest. However, this does not commit them to subjectivism. Such a position is explicitly refuted by Husserl: "The perception of a physical thing does not presentiate something non-present, as though it were a memory or a phantasy; perception makes present, seizes upon an it-itself in its presence 'in person'." (Husserl, 1998, 93). The world around us can be given to us in different modes, we can seize upon it from different sides. However, these perceptions are our world; they are the world where we meet others. This is our factually existing surrounding world and we have all the reasons for the belief-certainty in its existence independent from us. This is fundamental belief "that my perceptual experiences have unquestioned validity (certainty) for me and the objects of experiences have the character of existent actuality" (Moran & Cohen, 2012, 132). This is the most fundamental belief, a basis for all the interaction between me and the world.

In a comprehensive introduction to the forth volume of *The Philosophical Writings of Niels Bohr*, Jan Faye and Henry J. Folse, two distinguished scholars of Bohr's philosophical thought, discuss the question of Bohr being realist or anti-realist, a question over which, they write, philosophers who have studied Bohr's position often disagreed. Faye and Folse describe the comprehensive Bohr's philosophical standpoint as ontological realism and epistemological anti-realism. As I consider their insight into the complexity of Bohr' philosophical thought of high importance for the present comparison between Bohr's and Husserl's position, I quote it in full length:

> On the one hand every scholar would agree that Bohr was not a realist in the sense of holding that theories are designed to provide literal representations of nature. Nevertheless, on the other hand, it is clear that Bohr does want to insist that the atomic objects which are the subject matter of quantum physics exist independently of our theorizing.
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> Bohr's insistence that we recognize that the description of nature involves the description of interactions between measuring instruments and the objects whose properties they are designed to measure—and which indeed are necessary for such properties to be well-defined—commits him to an ontological realism that he intends to distinguish his

> view from the phenomenalism of philosophers such as Mach, who denied the 'reality' of atoms. Not only did Bohr deny that atomic objects were purely constructions, but also he always endeavoured to distinguish his view from those philosophers who regarded the measurement interaction as in some sense 'creating' the object of measurement. He clearly argued that the description of reality physics seeks to provide is an objective description that does not require the presence of a cognizing object, thereby differentiating his position from that of numerous physicists who have seen the quantum revolution as introducing a subjectivistic element in the physicists' description of nature.
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> At the same time, however, Bohr's repeated statements that the epistemological lesson of complementarity was a lesson about the limitations for the unambiguous use of descriptive concepts 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… (Faye & Folse, 1998, 12–13)

A concept that compounds Bohr's epistemological anti-realism and ontological realism is quantum phenomenon. Bohr explained his understanding of quantum phenomenon at various places in his philosophical texts, however, his explanation, never connected with a particular philosophical school or system, has been often labelled as ambiguous. On the other hand, the concept of phenomenon presents the corner stone of Husserl's philosophy; it is a part of his rigorous philosophical system and has been comprehensively explained by Husserl as well as by scholars of Husserl's phenomenology.

Tine Hribar describes Husserl's phenomenon as the thing as has been given to me by itself, but essentially to me, in my horizon and with the meaning it has for me (Hribar, 1997, 509). A phenomenon is always an intentional phenomenon, a phenomenon of something. Under intentionality, Husserl understands

> the own peculiarity of mental processes "to be consciousness 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. (Husserl, 1998, 200)

On the other hand, Bohr describes quantum phenomena as "a complete description of the experimental arrangements 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" (Bohr, 1946, 130). For Bohr, the context, in which we perceive the object of interest as well as our measuring devices, comprises the phe-

nomenon. It makes no sense to use such utterances as "disturbance of phenomena by their observation, a phrase equally irreconcilable with any unambigious meaning of the very words 'observation' and 'phenomenon' " (Bohr, 1946, 130). The observation cannot disturb the phenomenon, as it co-defines the phenomenon. While Husserl defines a phenomenon as such, Bohr defines specific—quantum—phenomena, from the point of view of a physicist in the context of discussion on quantum mechanics. He seizes upon it within a specific horizon and with a specific orientation. Taking this into account, we can conclude that Husserl and Bohr share their philosophical understanding of the concept of phenomena.

The convergence of Husserl's and Bohr's line of thought has been closely studied by physicist and philosopher of science François Lurçat. In his opinion, quantum mechanics is incomprehensible only as long as someone ignores or misinterprets Bohr's interpretation of quantum mechanics. The underlying question is thus not why quantum mechanics is incomprehensible, but why "Bohr is understood to be an incomprehensible author" (Lurçat, 2007, 232). The answer, Lurçat presupposes, is presented by Husserl in his *Crisis of European Sciences and Transcendental Phenomenology (Crisis)*.

The main constitute of Husserl's *Crisis* is a critique of contemporary science, not of its remarkable advancement but of its self-comprehension, the fact that a scientist disregards his specific orientation towards the objects of interest and considers his mathematical description as their objectively actual and true nature, as the distinguished truth about them. The scientific method—idealization and mathematization of the world—is taken for a true being. "It is because of the disguise of ideas that the true meaning of the method, the formulae, the theories, remained unintelligible and, in the naïve formation of the method, was never understood" (Husserl, 1970, 52). There is nothing wrong with the method as such, which enabled the advance of science, however as we forget about its character—the fact that it is an approximation, a specific orientation—the world itself is perceived as mathematical.

> Believing that the trouble started with the advent of quantum physics would be an illusion. Both the obscurity of quantum physics and the clarity of classical physics are grounded in the same initial mistaking of mathematized nature for the world we live in… (Lurçat, 2007, 233)

However, while classical physics made sense despite general acceptance of "substitution of mathematical abstractions for the real world" (Lurçat, 2007, 233), quantum physics forces us to reconsider the observation problem.

Bohr's criticism of scientific attitude towards the scientific method and the need for its reconsideration is very similar to that of Husserl:

> It is well known how a deterministic or causal account of this kind [classical physics based on Galileo's pioneering work and Newton's mastery] 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 observational problem. (Bohr, 1954, 69)

The reconsideration "of the way knowledge is obtained" underpins Bohr's interpretation of quantum mechanics. Any question set by a quantum physicist within his research of the quantum world, "has to be clarified by defining the experimental device that allows us to ask it concretely" (Lurçat, 2007, 245), while the concepts necessary for description of what the scientists observes and communicates to scientific community

> cannot be found in nature as one finds a character on a page; rather, the fact that they play an essential role suggests that they are built by physicists to allow an understanding of physical processes. Their privileged role stems, inseparably, both from the features of human knowledge and the nature of physical phenomena. (Lurçat, 2007, 245)

In the conclusion to Lurçat's text we can read:

> 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. (Lurçat, 2007, 257)

It seems the lack of generally accepted interpretation of quantum mechanics and the perception of quantum mechanics as weird and counterintuitive are not primarily connected with the subject matter itself. Foremost, they are connected with the foreground of classical physics and its (lack of) consideration of the scientific method, which physicists and philosophers of physics are unwilling to question, refine and to some extend abandon. The same goes for Bohr's philosophical thought based on comprehensive reconsideration of "the metaphysical foundations of classical physics" (Lurçat, 2007, 245). It seems many contemporary physicists and philosophers find it less troublesome to misinterpret or even discredit Bohr's interpretation than to follow his path and reconsider the foreground of classical physics.

3. THE NEED TO USE CLASSICAL CONCEPTS

Until now, we have discussed Bohr's view on the observation problem, the main points of his epistemological anti-realism and ontological realism and his understanding of the scientific method. Closely connected with all these is Bohr's claim that it is necessary to use classical concepts to describe the results of quantum experiments. It is one of the most important and most comprehensive parts of Bohr's philosophical thought, however, at the same time it is also one of the most troublesome. It has been often misunderstood, misinterpreted or opposed, not only by his opponents, but by his successors as well. Because of the importance and troublesome character of Bohr's claim about the indispensible use of classical concepts, we will closely examine it in this chapter.

Bohr often returns to the indispensable use of classical concepts throughout his philosophical texts, however, the most well-known formulation is the one from his answer to the supposed EPR paradox[1] and it is a crucial part of his refusal of the EPR thesis about the incompleteness of the quantum mechanical description of reality:

> 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, as we have seen, has its root in the indispensable use of classical concepts in the interpretation of all proper measurements, even though the classical theories do not suffice in accounting for the new types of regularities with which we are concerned in atomic physics. (Bohr, 1935, 81)

Bohr's claim that the use of classical concepts is indispensable, and that it is, thus, not possible to form something regarded quantum concepts, is often distrusted by contemporary physicists and philosophers, including those considering themselves Bohr's successors. They interpret Bohr's claim as a consequence of a restricted insight into the possible advancement of quantum mechanics. They see it to be in a very contrast with the logic of the system of science, where it is inadequate to label any kind of potential knowledge as a priori unattainable.

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[1] In paper *Can quantum mechanical description of reality be considered complete?* Einstein, Podolsky and Rosen (Einstein, Podolsky, & Rosen, 1935) proposed a thought experiment describing two entangled particles. Based on the results of the thought experiment they concluded that the description of reality as given by a wave function is not complete. Some decades later with Bell's inequality theorem that offered a theoretical basis to test EPR claim and quantum experiments with entanglement, entanglement was recognized as one of the fundamental characteristics of the 'quantum world,' while EPR paper became one of the most discussed papers in the field of philosophy of quantum mechanics.

However, Bohr's claim is not avouched from the point of view of a scientist, but from the point of view of a philosopher. It is a part of Bohr's answer to the epistemic question *what can we know and how*, a question urged by the results of quantum experiments, but provided by philosophical reconsideration of the observation process.

Bohr often returns to this claim about the indispensible use of classical concepts, but he never explains it comprehensively and most often presents it as a clear fact. Today the claim is thus often regarded ambiguous. It seems Bohr's reflection on indispensible use of classical concepts is very much connected with the advance of epistemological reconsideration of science at the time of Bohr's writing. For example similar insights can be found in the philosophy of science of Ludwik Fleck (1935), published in the same year as Bohr's answer to Einstein, Podolsky and Rosen, and, as I aim to demonstrate in the following lines, in Husserl's *Crisis*, where Husserl not only criticizes contemporary science, but also unveils the role of "the life-world as the forgotten meaning-fundament of natural sciences" (Husserl, 1970).

It is the concept of life-world that will help us better understand Bohr's claim about the indispensible use of classical concepts for description of quantum phenomena. Husserl describes the concept of life-world as always pregiven to us. The life-world always has only the sense given to it by ourselves. It is our immediately given ground, while its content changes dynamically in relation to ourselves—to what we build upon it. Our life-world is always unique, defined by our specific orientation, knowledge, modes of cognition; but it is, at the same time, the world where we meet others. It is a ground for our objective discoveries, which we can share with others, based on common recognition of the life-world.

As observed by Dagfinn Føllesdal, "according to Husserl, the life-world and the sciences are intimately connected" (Føllesdal, 2010, 43). The world of science is part of the life-world and the sciences are justified through the life-world. Furthermore and most important for our discussion on Bohr's philosophical thought: "Scientific statements get their meaning by being embedded in the life-world" (Føllesdal, 2010, 43). Such a standpoint can be already found in Husserl's manuscript from 1915:

> Alle Meinungen, rechtmässige oder unrechtmässige, populäre, abergläubische, wissenschaftliche, alle beziehen sich auf die schon vorgegebene Welt. […] Alle Theorie bezieht sich auf diese unmittellbare Gegebenheit, und sie kann einen berechtigen Sinn nur haben, wenn sie Gedanken bildet, die den allgemeinen Sinn der unmittelbaren Gegebenheit nicht verletzen. Keine Theoretisierung kann diesen Sinn verletzen. (Husserl, 1973, 196)

And in *Crisis*:

> And what also comes under consideration here is precisely the scientists' repeated recourse, in different general manners, to the life-world with its ever available intuited

> data; to this we can immediately add the scientists' statements, in each case simply adapted to this world, statements made purely descriptively in the same prescientific manner of judging which is proper to the "occasional" statements of practical, everyday life. (Husserl, 1970, 122)

All our statements have meaning for us and for others because they relate to our life-world, to the world as we perceive it, to the world where we meet with others. We understand our new perceptions on the basis of their context, our past perceptions, the common knowledge, all of these being contents of our life-world.

This line of thinking is present in Bohr's reconsideration of the knowledge we can obtain about the atomic processes and the need to describe quantum phenomena with classical concepts: As we measure a quantum system, we change it: previously coherent quantum system, which can be mathematically described with a wave function, now interacts with our measuring apparatus and can be, within this context, described with a measured property, which is a classical concept. We, the observers, ground our understanding of the new knowledge on our life-world, which consists of our everyday perceptions of macroscopic objects describable with classical physics. As we proceed to research the quantum world, we set the measuring apparatus to provide a classical answer to a classical question, such as what is the position of the observed quantum system, or what is its polarization. "[T]he meaning of any question has to be clarified by defining the experimental device that allows us to ask it concretely" (Lurçat, 2007, 247). We perceive a quantum phenomenon—"a complete description of the experimental arrangements 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" (Bohr, 1946, 130)—and get an answer to our question.

In his text from 1938, Bohr clarifies his claim about the indispensable use of classical concepts from an additional perspective:

> …we must, on the one hand, realize that the aim of every physical experiment—to gain knowledge under reproducible and communicable conditions—leaves us no choice but *to use everyday concepts, perhaps refined by the terminology of classical physics*[2], not only in all accounts of the construction and manipulation of the measuring instruments but also in the description of the actual experimental results. (Bohr, 1938, 25–26)

Here, Bohr speaks about the indispensible use of everyday concepts, perhaps refined by classical concepts. He understands classical concepts as the specific terminology of a physicist, with which he describes the perceived objects of interest. Classical concepts are the only expert terminology a physicist can have, as quantum concepts

[2] Emphasis added.

cannot exist. Our concepts in each case ground in our life-world and are adapted to it. Otherwise, they bear no meaning and thus do not exist as concepts.

4. RECAPITULATION OF THE JOURNEY

The revisit of Bohr in Husserl's company clarified some of Bohr's philosophical concepts, crucial for his philosophical thought, but often labelled as ambiguous. Bohr explains his view of quantum phenomenon; however, he does not offer an explanation of the concept of phenomenon itself. The same goes for a comprehensive explanation of his claim that the use of classical concepts is indispensable, when we describe quantum phenomena. Bohr often presents these concepts and claims as facts, which is, I argue, closely connected to the cultural context of his discussion on quantum mechanics. At his time contemporary science was closely connected to philosophy (of science) and the concepts and claims that constitute Bohr's philosophical thought were widely present within debates among philosophers and scientists. As today Bohr's line of thought is considered less self-evident and often labelled ambiguous, Husserl's rigorous philosophical system can be of much help as a firm philosophical foreground to understand Bohr's philosophical claims and concepts.

Furthermore, as proposed above, Husserl's company did not only facilitate better understanding of Bohr, but also better understanding of wide spread misinterpretations, misreadings and disregard of Bohr's philosophy. If we put our effort in understanding Bohr's philosophical standpoint, we have to unveil the ideological dress from the life-world, we have to undertake the reconsideration of science and its method, we have to return to the old observation problem, disregarded by modern science, as it is deceived by its success. This is, as it seems, often too much, even for those physicists and philosophers of quantum mechanics motivated to explain the quantum phenomena and provide an interpretation to the results of quantum experiments.

This is often a case in the ongoing dispute between quantum realism and anti-realism. Though it is characteristic of both sides to build their philosophical position in regard to Bohr's, comprehensive research of Bohr's thought and reconsideration of the observation process in Bohr's spirit is missing from the debate. Often, Bohr is presented by statements attributed to him by his successors, such as Petersen, as we will see in an exemplary case in the following pages. This is not only problematic since the quotes are not authorised by Bohr and their full meaning might be lost or transformed through the messenger, the main problem is, I believe, the lack of context—single statements (in contrast to Bohr's comprehensive philosophical texts) are taken from a dialog with Bohr, which determined their full meaning. Consequently, they are easier subjected to manipulation.

An eloquent example of this is the well known statement attributed to Bohr in Petersen's contribution for Bulletin of the Atomic Scientists *Philosophy of Niels Bohr*:

> When asked whether the algorism of quantum mechanics could be considered as somehow mirroring an underlying quantum world, Bohr would answer, "There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find how nature is. Physics concerns what we can say about nature." (Petersen, 1963, 12)

In Petersen's contribution, the quoted statement is indeed presented as Bohr's own, however, it is part of a contribution that starts with the following remark:

> For me, Niels Bohr's philosophy also fell into three parts: one which I thought I grasped; one which I did not understand, but I felt was clear to Bohr; and finally, one that Bohr himself saw only dimly. Thus my description can be only a weak reflection of his wonderfully rich thought, and I am sure he would have expressed many points differently. (Petersen, 1963, 9)

Yet, the statement attributed to Bohr in Petersen's contribution is often quoted as Bohr's, leaving the information about the mediator aside (Mermin, 2004). Such a use of Bohr's figure can be seen as characteristic for the debate between realists and antirealists. In the following pages, I aim to display the nature and problems of such debates, in case of philosophical consideration of quantum information theory as potential foundation for interpretation of quantum theory.

In the last decades, quantum information theories have been one of the most important mind teasers in the field of quantum physics. This also holds for Brukner's and Zeilinger's informational foundations of quantum theory, a theory based on Zeilinger's foundational principle for quantum mechanics: the most elementary system represents the truth value of one proposition, i.e., it carries just one bit of information (Zeilinger, 1999). It has a simple theoretical framework, with a promising explanation potential and is extremely well connected with the latest quantum experiments, since Brukner's and Zeilinger's groups have been co-defining state of the art science in the field of quantum physics for quite some time. As a philosophical framework of their theory, they often use Bohr's philosophical stand, which they interpret as more or less anti-realistic, in accordance to their point of view, that reality is not mere "pure subjective construction," however:

> 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*[3]. (Brukner & Zeilinger, 2003)

Brukner and Zeilinger try to avoid pure subjectivism, which could be connected to their interpretation based on the character of information. However, what they offer is "a sense of independent reality," something we can all agree that exists and can be used as our objective ground, however, it is based on our agreement and does not (have to) exceed it.

In this manner, they start the abstract of the quoted paper with the statement attributed to Bohr by Petersen, presented as follows:

> Niels Bohr wrote: "There is no quantum world. There is only an abstract quantum physical description. 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." (Brukner & Zeilinger, 2003)

It is fair to say that throughout the article, Bohr is primarily presented in the light of his epistemological anti-realism, while the authors do not comprehensively discuss his position in regard to the ontology of the quantum world. They do not, however, distance themselves from Bohr, whose ideas are presented as their main groundwork, beside Weizsäcker and Wheeler, as they present their view about the ontological status of the independent reality of the outer world.

Timpson, one of the main critics of their theory, reads Bohr (or at least the Bohr in the statement attributed to Bohr by Petersen) as an ontological antirealist, whose point of view is in accordance to the, as Timpson claims, untenable position of Brukner and Zeilinger:

> The last sentence is particularly pertinent: 'Physics concerns what we can say about nature.' Compare again, another statement of Zeilinger's, "…what can be said about Nature has a constitutive contribution on what can be 'real'." (Reported in Fuchs (2003, 615)). […] If quantum mechanics reveals that the true subject matter of physics is what can be said, rather than how things are, it seems but a small step from there to the view that what is fundamental is the play of information. However, there is a very obvious difficulty with the thought that what can be said provides a constitutive contribution to what can be real and that physics correspondingly concerns what we can say about nature. Simply reflect that some explanation needs to be given of where the relevant constraints on what can be said come from. Surely there could be no other source for these constraints than the way the world actually is—it can't merely be a matter of language. […] Zeilinger and Bohr (in the quotation above) would thus seem to be putting the cart before the horse, to at least some degree. Schematically, it's the way the world is (independently of our attempted description or systematisation of it) that determines what can usefully be said about it,

[3] Emphasis added.

> and that ultimately determines what sets of concepts will prove most appropriate in our scientific theorising. (Timpson, 2010, 158)

Such an interpretation of Bohr's thought is obviously not in tune with Bohr's position presented in this article. But what is the cause for such a discrepancy? Is it due to the problematic statement, which is (completely) inconsistent with Bohr's comprehensive philosophical position, or is it due to a misinterpretation of Bohr's thought (made easier by the fact that it is based on a single statement, missing a context of Bohr's more comprehensive explanation)?

Interesting enough, François Lurçat also introduces his article *Understanding quantum mechanics with Bohr and Husserl* with the famous statement attributed to Bohr by Petersen. Thus, we can assume, the statement in question is still in tune with Husserl's phenomenological approach and thus with the explanation of Bohr's philosophical standpoint as presented in the present article. We propose that Bohr's statement can be interpreted form the point of view of phenomenology as follows:

There is no quantum world just as there cannot be any quantum concepts. There is, however, our life-world, and there are classical concepts, with which we can describe quantum phenomena as given to us in the context of a measurement. We do not create quantum phenomena, but we do create their conditions, as we make the measuring arrangements in order to get a specific classical answer to our classical question—the only kind of question we can have or grasp. Bohr's philosophical standpoint is compatible with Timpson's claim that "the way the world is […] determines [or better to say co-determines] what can usefully be said about it," (Timpson, 2010, 158) this claim is actually present in the statement Timpson finds so problematic: "Physics concerns what we can say *about nature*[4]" (Petersen, 1963, 12). This claim is, however, not equal to Zeilinger's statement (attributed to Zeilinger by Fuchs) that: "… what can be said about Nature has a constitutive contribution on what can be 'real' " (Timpson, 2010, 158). All of them, Zeilinger and Brukner on one side and Timpson on the other, miss an important detail of Bohr's philosophical approach described by Faye and Folse as ontological realism and epistemological anti-realism. Bohr believed, in accordance to philosophy of science of his time, that "what we can say about nature" (Petersen, 1963, 12), is co-determined by our modes of cognition, by our life-world, by our orientation, our horizons, limits of our communication, etc. However, it is also co-defined by how nature/world is[5]. The reconsideration of the observation process

[4] Emphasis added.

[5] This does not mean, however, that we know, "how nature is," compare this to Fuch's and Peres' statement: "*If the world is such* that we can never identify a reality independent of our experimental

forced by the results of quantum experiments, displays the impossibility to apply our knowledge about a certain phenomenon on our object of interest outside the context of this specific observation. A physicist, aware of these limits, cannot consider the task of physics as simply "to find out how nature is" (Petersen, 1963, 12). His knowledge is, however, crucially knowledge about nature—co-defined by the observer and the observed. It is not the observer that defines what is real. It is, however, the observer (his concepts, abilities, interests, etc.) and the observed who co-define what can be perceived as real by the observer.

Bohr's path, converging with Husserl's, demands from a scientist or a philosopher (of science) to reconsider his very approach to science and scientific method. It is a path that exceeds mere realism and antirealism and offers a more comprehensive approach towards philosophy of physics. It "invites us to enlarge our horizons" (Lurçat, 2007, 258), a fearful proposition for those scared of restricted pathways, persuaded that phenomenology and contemporary physics do not have much to tell to each other.

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activity, then we must be prepared for that, too." (Fuchs & Peres, 2000) (Emphasis added).

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