Complementary Descriptions (PART I)
A Set of Ideas Regarding the Interpretation of Quantum Mechanics

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Abstract
Niels Bohr introduced the concept of complementarity in order to give a general account of quantum mechanics, however he stressed that the idea of complementarity is related to the general difficulty in the formation of human ideas, inherent in the distinction between subject and object. The complementary descriptions approach is a framework for the interpretation of quantum mechanics, more specifically, it focuses in the development of the idea of complementarity and the concept of potentiality in the orthodox quantum formulation. In PART I of this article, we analyze the ideas of Bohr and present the principle of complementary description which takes into account Einstein’s ontological position. We argue, in PART II, that this development allows a better understanding of some of the paradigmatic interpretational problems in quantum mechanics, such as the measurement problem and the quantum to classical limit. We conclude that one should further develop complementarity in order to elaborate a consistent worldview.

Introduction
I believe that scientific thought is intrinsically related with desire and passion. Desire to create new ways to “understand” reality, passion to follow the path. This article is a compendium of ideas and intuitions regarding the interpretation of quantum mechanics, it should work as a “road sign”. It is certainly not a closed system, but rather the opposite, a framework that can allow for ‘new ideas’ regarding the interpretation of the quantum theory. I warn the reader he will not find closed statements nor conclusions, rather, he might find some thoughts which he is free to judge as interesting or not. Many of the statements in this article are still to be worked out, my only aim is to produce a suitable atmosphere where these ideas can be developed, this is what I call the complementary descriptions approach.

In this first part of the paper\(^1\), I would like to present the principle of complementary descriptions as mentioned in [34] and [35]. To some extent I take this principle to be an extension of (my reading of) Niels Bohr and Wolfgang Pauli. It constitutes a general framework and a philosophical worldview. We have learned many new insights in quantum mechanics since the early discussions of Bohr and Einstein. Thus, I believe the philosophy of complementarity first introduced by Bohr in his ‘Como lecture’ in 1927 should be also further developed in order to interpret and understand the problems still present in the quantum theory.

The article is organized in four main sections. In section 1, I present the principle of complementary descriptions. In section 2, I give some general definitions of what is meant by a description, a perspective, and a context. Section 3 deals with the concept of ‘complementarity’. Firstly, I analyze Bohr’s concept of complementarity; secondly, Pauli’s view on complementarity; thirdly, I give an account of the concept of complementarity within the complementary descriptions approach. In section 4, I study the idea of convergence in science. Finally, I present the conclusions.

\(^1\)The second part of this paper, [36], is a more technical development of the ideas presented in this article.
1 Complementary Descriptions

During the last centuries, there has been a tough struggle between two main philosophical views of the world. On one side stands the empiricist view of the world: the world is only a conjunction of perceptions and phenomena. There is no sense in looking for an external reality, outside of my own perceptions. The only thing I have is experience. In the 20th century, instrumentalism inherited many tenets of the traditional empiricism: according to the instrumentalistic view, a physical theory should link measurable phenomena without being concerned with what happens to nature when it is not measured. The theory does not seek to describe what nature is, but rather it is a mere instrument of prediction, and only in that sense it is an instrument of knowledge. Following Mach, the function of a physical theory is to provide a simple and economical synopsis of observable phenomena. It can be used to make predictions of future phenomena, but it must not be thought as providing a description of the world behind the phenomena. The theory is an instrument and not a description. Opposite to this position, we have the realistic view of the world: this view stands for the independent and objective reality of the world. The article you have at this moment in your hands, would be in front of you, even if you would not be reading it, even if you would close your eyes, even if you would not be able to experience it in any way. There is an external world whose existence does not depend on the presence of observers. Consciousness is a contingent creation of nature and it does not determine the physical existence of the world. Thus, a physical theory must be regarded as the enterprise of discovering and describing the basic structure of the world behind the phenomena. This point of view has been the guide for the physical discovery of the world since Tales tried to explain, without the use of mythical tales, how the world was one of many rocks in the universe.

In quantum mechanics the realist-antirealist debate was exposed by two of the most important figures of the quantum revolution: Albert Einstein and Niels Bohr. The first regarded science from an ontological basis and stressed that: “it is the purpose of theoretical physics to achieve understanding of physical reality which exists independently of the observer, and for which the distinction between “direct observable” and “not directly observable” has no ontological significance; this aim furnishes the physicist at least part of the motivation for his work; but the only decisive factor for the question whether or not to accept a particular physical theory is its empirical success.” On the other hand, Niels Bohr regarded science from an epistemological point of view. According to his long time assistant, Aage Petersen, Bohr once declared when asked whether the quantum world could be considered as somehow mirroring an underlying quantum reality:

“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” N. Bohr quoted from A. Petersen (p.8)

I would like to avoid endless discussions about what Bohr ‘really’ meant to say, or if he did actually say something like this. Rather, I would like to present here my own position and extend this as follows: There is no quantum world, nor is there a classical world. There is only an abstract quantum description as there is an abstract classical description. With respect to the latter I want to take a middle path between the epistemological restrictions imposed by our means of expression and the ontological commitment which Einstein so vividly defended. Physics not only concerns what we can say about nature but also about what nature is.

Methodological reductionism states that the understanding of a complex system is best sought at the level of the structure and behavior of its component parts. Hans Primas wrote with respect to this matter: “In spite of the obvious plurality of scientific explanations on various levels of descriptions, there still exists a bias toward theoretical monism. Neglecting the possibility to view nature from different perspectives and ignoring the fact that the decomposition of nature into parts is not God-given, traditional reductionism treats the various theories and models as, to be sure, incompletely articulated but ultimately reducible to an all embracing fundamental theory.” Opposite to methodological reductionism stands methodological holism, which states that the understanding of a complex system is

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2This position has two main views, an ontological one, which was presented by Berkley and Locke; and an epistemological view, which is defended by Van Fraassen.

3Einstein quoted from [10], p.175.

4In a talk in Buenos Aires David Mermin (September 29, 2003) presented this same quotation after which he mentioned that some physicists (who had known Bohr personally) agreed and disagreed about whether Bohr could have said something like this.
best sought at the level of principles governing the behavior of the whole system, and not at the level of the structure and behavior of its component parts (155, p.2). Half way between these positions, stands complementarity5. Niels Bohr introduced the concept of complementarity in order to describe situations in which two different conditions of observation yield conclusions that are conceptually incompatible. However, Bohr 5 made it clear that complementarity is not restricted to quantum physics. He stressed that the idea of complementarity is related “to the general difficulty in the formation of human ideas, inherent in the distinction between subject and object”. Hans Primas makes a clear statement of the importance of such a concept:

“A new style in science began with quantum mechanics when Niels Bohr initiated a spiritual renewal by introducing his concept of complementarity. It turned out that complementarity is far more important than quantum mechanics, it has led to a development of science that encourages a holistic vision.” H. Primas ([30], p.349)

I want to develop complementarity in order to take into account not only complementary contexts (phenomena in Bohr’s terminology) but also complementary descriptions such as the classical description (which stresses the reductionistic character of the being) and the quantum description (which stresses the holistic character of the being). For this purpose I will follow a middle path between ontology (a certain form of the being) and epistemology (the theoretic preconditions of the description which determine a certain access to the being). I take complementarity as a philosophical term, connected with the “limitations of our means of expression”6. In this sense special attention should be paid to the observer as precondition of the physical reasoning and not as object of the theory. Immanuel Kant expressed the idea that the conditions of possibility for knowledge are given by a definite group of categories which together with the forms of sensible intuition (space and time) constitute the object, however, we do not have access to ‘the thing in itself’ which remains forbidden to us:

“Not only are the drops of rain mere appearances, but even their round shape, and even the space in which they fall, are nothing in themselves, but merely modifications of fundamental forms of our sensible intuition, and the transcendental object remains unknown to us” I. Kant ([22], p.85)

Kant critically analyzed the “metaphysical foundation of science” which was based in classical logic and classical mechanics; he patterned the categories after the table of judgements and the synthetic principles after Newton’s laws of gravitation. All genuine science requires a ‘pure part’ which must be worked out separately “so that we may strictly determine what reason can accomplish by itself and where it begins to need the aid of principles of experience”7. I would like to analyze in the following sections the problem of the limitations in the framework presented by Kant: “We know today why this pure part could not fulfill the task that Kant put to it. It was too closely bound to a specific form of science, which classical rationalism held to be the plainly rational form.”8 Regarding this particular criticism of the program developed by Kant, Wolfgang Pauli makes the following remark:

“We agree with P. Bernays in no longer regarding the special ideas, which Kant calls synthetic judgements a priori, generally as the pre-conditions of human understanding, but merely as the special pre-conditions of the exact science (and mathematics) of his age.” W. Pauli ([25], p.126)

To go beyond Kant we must take new concepts into play and not only regard fixed categories in the synthesis. The first step is thus, to develop these new concepts. I don’t take for granted the justification over the condition of objectivity, however in order to apply such a procedure we must first have the new

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5I should clearly stress that however, I do not try to present the complementary descriptions approach as a closed method; rather, it supports Feyerabend’s [11] critic: “The idea that science can, and should, be run according to fixed and universal rules, is both unrealistic and pernicious. [...] All methodologies have their limitations and the only ‘rule’ that survives is ‘anything goes’.” I will develop the meaning of complementarity within this approach in Sect. 3.3.

6See for example von Weiszacker ([43], p.282) or Heisenberg (quoted in [45], p.86) for an equivalent statement of the concept of complementarity; also Bohr’s quotations in ([12], pp.68, 72 and 121) and in ([12], p.88).

7Kant, quoted from [8].

8Furthermore Cassirer ([8], p.74) also expresses with respect to the specific problem in quantum mechanics: “When in the face of the new factual material and new theoretical tasks which it was facing, physics extended and transformed its conceptual apparatus, it did not simultaneously give up its general character and structure. It only made evident the fact that this structure is to be thought of not as rigid but as dynamic, that its significance and efficacy do not rest upon substantial rigidity established once and for all but precisely upon its plasticity and flexibility.”
concepts at hand. In our schema there is no complete cut between ‘the thing in itself’ and that which we regard as the real. There is access to the real as an expression of a certain description exposed to the experimental observation. Reality comes together from the synthesis of the creative element of our description and the discovery character of the empirical data. ‘The thing in itself’ is not the description nor the experimental observation, it is not accessible as a whole and in this sense it remains veiled.

Ontology is the study of the being, it is not the real itself but rather its study, thus, always of a specific form, a restricted aspect of the being. I will take a position which will take into account the distinction of different complementary descriptions. Within this approach ontology only arises from the synthesis between our conceptual scheme and the noumenal realm as exposed in the experimental observation. Different conceptual schemes (descriptions) define different ontologies through their ‘imprint’ in the experimental observation. It is important to stress the idea that different descriptions define different, in principle incompatible, ontologies. Ontology is description dependent, so “objective” does not mean independent of the subject, but rather the opposite, it results from applying our different frameworks (descriptions); the more possibilities and abstract conceptual schemes one is able to apply to describe/create reality the more “objective” one gets. Within the position taken by the complementary descriptions approach different levels of discourse can define equally “objective” ontologies, each of which makes possible the creation of a certain experience. I want to stress the importance of knowing from which descriptive level one is talking from, because it might happen that the same sentence can have only significance in a certain level while it is meaningless in a different one (Sect. 9.3). I will argue that only together, different complementary descriptions allow a resolution of the quantum paradoxes and a better ‘understanding’ of the quantum theory of measurement.

Bohr explains that for the description of certain atomic phenomena we need a particle picture while for others we need the wave picture. Using both pictures simultaneously leads to contradictions; it is the concept of phenomenon which allows to avoid such controversies. According to Bohr one never needs complementary views in the same phenomenon and objectivity is regained.

“On the lines of objective description I advocate using the word phenomenon to refer only to observations under circumstances whose description includes an account of the whole experimental arrangement. In such terminology, the observational problem in quantum physics is deprived of any special intricacy and we are, moreover, directly reminded that every atomic phenomenon is closed in the sense that its observation is based on registrations obtained by means of suitable amplification devices with irreversible functioning such as, for example, permanent marks on a photographic plate, caused by the penetration of electrons into the emulsion. In this connection, it is important to realize that the quantum-mechanical formalism permits well defined applications referring only to such closed phenomena.” N. Bohr (p.73, quoted from p.3)

The definition of phenomenon relied for Bohr in the use of classical language. We want to extend this definition by allowing the possibility of expressing a phenomenon with non-classical descriptions, the concepts of which are still to be developed. In our approach there are no ‘naked facts’. This goes against a naive empiricist position which would identify reality with experience. A phenomenon is thus the synthesis between the description (which determine the conditions of possibility to access a certain aspect of the being) and experimental observation (the noumenon as exposed by the description). Quantum theory should be developed in order to extreme it’s own concepts, we need to help quantum mechanics find its own interpretation. This can be pursued by a careful analysis of its historical development, taking special attention to the ideas developed by the founding fathers of the theory.

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9 This term was introduced by Bernard D’Espagnat.
10 This is in close analogy to the internalist position developed by Hilary Putnam and also by Hans Primas.

11 The noumenon is taken by Kant to be that which is not accessible by the senses, which remains completely unknown to us: “das Ding an sich”. As we expressed above we will not follow this cut but rather state there is a certain access to the real.

12 I am grateful to Pablo Vitalich for discussing this idea with me.

13 This goes clearly against the conception of Bohr (p.7) who stated: “it would be a misconception to believe that the difficulties of the atomic theory may be evaded by eventually replacing the concepts of classical physics by new conceptual forms.”

14 This positivist position renders objectivity to facts, the limitations of such position will be discussed in Sect. 1.5.
2 Descriptions, Perspectives and Contexts

I consider descriptions to be a general framework in which concepts are related. Descriptions express the precondition to access a certain character of reality. Descriptions are closed systems, they interrelate but they are not necessarily complete\(^\text{15}\). A description is defined by a specific set of concepts, this definition precludes, at a later stage, the possibility of applying different (incompatible) concepts. Quantum mechanics is a description as well as classical mechanics or relativity theory are, each of them relating concepts which are not necessarily compatible with the ones present in a different description. Objects are already part of a particular description with strong presuppositions. As a matter fact, we will argue that the quantum description is incompatible with the preconceptions needed to define an object in the classical sense (I will go more deeply into this matter in \(^\text{36}\), Sect. 1.1). This goes against a naive realist position which would identify reality with the objects around us. Articles, tables and Stern-Gerlach apparatus are not fundamental blocks of reality, they are conceptual creations we are forced to make in order to approach a certain character of reality\(^\text{16}\). The main characterization of a description is then by means of the concepts applied which deal with the irreducible limitation and incompleteness in the means of expression that must be acknowledged in every description. For example, the concepts of mass, space and time in classical mechanics are not the same concepts of mass, space and time in general relativity theory; we are dealing with different concepts which have developed historically and are determined by different descriptions. The fact that we, as physicists, use the same words is quite misleading\(^\text{17}\). It is relevant to state at this point that I do not take physics to be the only possible description. Philosophical thought, psychology, biology or economy can be viewed as general descriptions which, in the same way as physics, try to grasp certain ‘knowledge’, certain ‘understanding’. The idea of encapsulating this knowledge into different ‘boxes’ should not be pushed to the extent it is done today.

I take a perspective to be a faculty. It expresses the potentiality of an action which makes possible a definite consistent view within a certain description. A perspective is the condition of possibility for a definite representation to take place, it deals with the choice between mutually incompatible contexts. The importance of defining this level of description (which can be regarded as superfluous in the classical realm) will become clear in \(^\text{36}\).

The context is a definite representation of the entity. Contexts are determined by the conceptual scheme of the description; i.e. they are description dependent. This leaves open the possibility of representing experiments with ‘new’ non-classical concepts.

The distinction between perspective and context was introduced in \(^\text{32}\) in order to distinguish between the holistic properties and the reductionistic properties in the Bene-Dieks perspectival interpretation \(^\text{4}\) (this will be further analyzed in \(^\text{36}\); Sect. 1.4). In special relativity theory a context is given by a definite inertial frame of reference. There is no necessity of defining the perspective because the invariance principle allows us to think of these contexts as existing in actuality, as events which pertain to physical reality. In quantum mechanics a context is given by a definite experimental setup; i.e. a Complete Set of Commuting Observables (C.S.C.O.) which is defined equivalently by a Schrödinger wave function in a definite basis/representation. It is only at this stage that we can talk of a quantum-entity (a set of mutually compatible properties\(^\text{18}\)). Different contexts, due to the commutation relations as expressed in the standard formulation, can be mutually incompatible; thus, the quantum contexts cannot be thought as existing in actuality. In classical mechanics (and relativity theory) this problem does not arise because of the relation of contexts through the Galilean (and Lorentz) transformations.

The main difference between quantum mechanics and the rest of the theories created by man is that the quantum wave function expresses explicitly a level in the description of nature which has been neglected from a mechanistic idea of a clock-type-world. It presents us with the concept of choice within knowledge itself. This character is expressed by the perspective which lies in the indeterminate level (that which has to be chosen) while the context\(^\text{19}\) lies in the determined level (that which has been chosen). However, in the quantum context there is still certain indetermination regarding the properties in the

\(^{15}\)I will discuss in more detail the idea of completeness and incompleteness in Sect. 3.3

\(^{16}\)In this sense my position is close to that of a critical realism.

\(^{17}\)On this respect see also the quotation of Wittgenstein on p.10 of this article.

\(^{18}\)We refer to the meaning of compatibility in \(^\text{3}\).

\(^{19}\)The perspective can be regarded in this sense as the wave function without any definite basis (or factorization in a scheme with a preferred basis), it is an expression of the possible contexts. The context can be seen as the explicit election of the ‘representation’; i.e. the basis or factorization. In quantum mechanics this choice determines explicitly the entity under study (this character will be further discussed in \(^\text{36}\); Sect. 1.2 and 1.3).
sense that a superposition expresses still the potential, and in this sense is and is not. Concepts are lacking in the development of these levels. I will introduce the concept of ontological potentiality as an attempt to escape the limits of classical thought (this will be analyzed in more detail in Sect. 1.2 of [36]).

3 The Concept of ‘Complementarity’

In this section I will go through several views regarding the concept of complementarity. Firstly, I will give an account of complementarity as introduced by Bohr, secondly, I will present the ideas of Wolfgang Pauli with respect to complementarity, finally, I will present the meaning of complementarity within our approach.

3.1 Bohr’s Concept of ‘Complementarity’

The incompatibility of different views is expressed by the commutativity relations of Heisenberg which show that the position-context and the momentum-context are mutually incompatible:

\[ [x, p] \neq 0 \] (1)

The great achievement of Bohr was to bring together these mutually excluding contexts by means of the concept of complementarity. As John Hendry ([18] p.119) expresses: “Of all those actively involved in the search for a new quantum mechanics in the 1920s, Bohr was at once the most radical and the most conservative. He had been initially responsible for the idea that classical mechanics and kinematical concepts were incapable of describing quantum phenomena, and he had continued to believe this throughout. But he had also held fast to the belief that these concepts, and especially those of the classical wave theory of light could not be replaced.” Heisenberg had always emphasized the discreteness of quantum theory. This conception brought him to the uncertainty relations in February 1927 when Bohr left Copenhagen for a holiday. At his return, the priority of the particle picture over the wave particle in the scheme presented by Heisenberg was not taken by Bohr very enthusiastically and discussions followed in which Pauli had to defend his young fellow. The objections raised by Bohr, which would later be expressed in [5], can be tracked to an “Addition in Proof” at the end of Heisenberg’s paper:

“After the conclusion of the forgoing paper, more recent investigations of Bohr have led to a point of view which permits an essential deepening and sharpening of the analysis of quantum-mechanical correlations attempted in this work. In this connection Bohr has brought to my attention that I have overlooked essential points in the course of several discussions in this paper. Above all, the uncertainty in our observation does not arise exclusively from the occurrence of discontinuities, but is tied directly to the demand that we ascribe equal validity to the quite different experiments which show up in corpuscular theory in the one hand, and in the wave theory in the other hand. […] I owe great thanks to Professor Bohr for sharing with me at an early stage the results of these more recent investigations of his-to appear soon in a paper on the conceptual structure of quantum theory-and for discussing them with me.” W. Heisenberg ([16] quoted from [45], p.83)

One can see the importance (and pressure) of Bohr’s figure upon the young Heisenberg in one of the foundational articles of quantum mechanics. Bohr’s own search of a consistent interpretation was later explained by Leon Rosenfeld:

“Bohr wanted to pursue the epistemological analysis one step further, and in particular to understand the logical nature of the mutual exclusion of the aspects opposed in the particle-wave dualism. From this point of view the indeterminacy relations appear in a new light. […] The indeterminacy relations are therefore essential to ensure the consistency of the theory, by assigning the limits within which the use of classical concepts belonging to the two extreme pictures may be applied without contradiction. For this novel logical relationship, which called in Bohr’s mind echoes of his philosophical meditations over the duality of our mental activity, he proposed the name “complementarity”, conscious that he was here breaking new ground in epistemology.” L. Rosenfeld (quoted from [15], p.59)

20This is the expression that experimental arrangements which show particle properties preclude the possibility of showing wave properties and vice versa.
As we already know, there are as many definitions of complementarity as physicists attempting to define it\textsuperscript{21}. What Bohr expressed by ‘complementarity’ remains foggy to me. I was to some extent released when I found out other people shared my problem. The most weird example I found was the case of Carl Friedrich von Weizsäcker who wrote an article named: “Komplementarität und naturwissenschaft” \textsuperscript{41} for the 70th birthday of Niels Bohr. In this article he explained the concept of complementarity in two different forms, namely, \textit{parallel complementarity} and \textit{circular complementarity}\textsuperscript{22}, the second of which was attributed to Bohr himself. The article ends with a rectification of von Weizsäcker in which he explains that he received a letter from Bohr (\textsuperscript{42}, p.338) expressing that complementarity can be only defined with respect to phenomena\textsuperscript{23}, and as the Schrödinger wave equation is just an \textit{abstract magnitude of calculus} and it does not designate in itself any phenomena, such circular complementarity is by no means possible and only parallel complementarity should be taken into account\textsuperscript{24}. Even von Weizsäcker, who was an active player in the discussions that took place during the development of quantum theory, all together with Bohr himself, Pauli and Heisenberg, had a misleading idea of what Bohr meant with complementarity.

Only a few thinkers are able to develop themselves trough history, to discuss with non-contemporary people. I think the common attitude nowadays is to read Bohr and then try to convince others that if Bohr would not be dead he would sit at the same side at the discussion table. I believe that on the contrary, Bohr himself is still quite alive and if one tries enough, it even is possible to discuss with him.

### 3.2 Pauli’s Concept of ‘Complementarity’

Wolfgang Pauli was one of the most brilliant and creative minds of the last century, he was called by his colleagues “the consciousness of science.” He discussed deeply the implications of complementarity with Bohr himself and he saw in its philosophy a more general way of approaching science as is expressed in the following quotation:

“...in the hope of furthering by this small contribution those major efforts which have the general aim once more bringing into closer contact the various partial disciplines into which our intellectual life (Geistigkeit) has fallen apart. The splitting off of the exact sciences and mathematics as independent partial disciplines from an originally unified but pre-scientific natural philosophy, which began in the 17th century, was of course a necessary condition for the subsequent intellectual development of the western world (Abendland). At the present time, however, the conditions for a renewed understanding between physicists and philosophers on the epistemological foundations of the scientific description of nature seem to be satisfied. As a result of the development of atomistics and quantum theory since 1910 physics has gradually been compelled to abandon its proud claim that it can, in principle, understand the whole universe. All physicists who accept the development that reached a provisional conclusion in 1927 in the systematic construction of the mathematical formalism of wave mechanics, must admit that while at present we have exact sciences, we no longer have a scientific picture of the universe (Weltbild). It is just this circumstance that may contain in itself, as a corrective to the earlier one sided view, the germ of progress towards a unified total world-picture, of which the exact sciences are only part. In this I would like to see the more general significance of the idea of complementarity, an idea that has grown out of the soil of physics, as a result of the work of the Danish physicist Niels Bohr.” W. Pauli (\textsuperscript{25}, p.36)

I think Pauli could see the deeper meaning of complementarity even more clear than Bohr himself, he extended the principle to knowledge itself, seeking for a new type of science. For example, he repeatedly stressed the idea of complementarity between physics and psychology, a problem which he called “the most important problem of our time”.

\textsuperscript{21}See for example the analysis of complementarity and Bohr’s philosophy in \textsuperscript{20} and \textsuperscript{35}.

\textsuperscript{22}Parallel complementarity is defined by von Weizsäcker as the complementary relation which takes place between, for example, \textit{position} and \textit{momentum} or \textit{particles} and \textit{waves}; this is very close to what I call \textit{complementarity between contexts}. On the other hand circular complementarity was defined by von Weizsäcker as complementarity between \textit{classical concepts} and the description given by the Schrödinger wave function; this is very close to what I call \textit{complementarity between the quantum and the classical descriptions}.

\textsuperscript{23}A clear expression of this insight in Bohr’s concept of complementarity can be found in (\textsuperscript{44}, p.3): “Complementarity: any given application of classical concepts precludes the simultaneous use of other classical concepts which in a different connection are equally necessary for the elucidation of the phenomena.”

\textsuperscript{24}See also Jammer’s remarks on this episode in \textsuperscript{21}. 
It actually seems to me that in the complementarity in physics, with its resolution of the wave-particle opposites, there is a sort of role model or example of that other, more comprehensive coniunctio. For the smaller coniunctio in the context of physics, completely unintentionally on the part of its discoverers, has certain characteristics that can also be used to resolve the other pairs of opposites listed on p. 3. [...psychology-physics...]

W. Pauli (26, p.91)

Pauli was aware of the importance of a true development of the concept of reality, a concept which is at the main core of the ontological problems raised by quantum mechanics. He writes:

“When the layman says “reality” he usually thinks that he is speaking about something which is self-evidently known; while to me it appears to be specifically the most important and extremely difficult task of our time to work on the elaboration of a new idea of reality.” W. Pauli (quoted from 26, p.193)

The quotations I have chosen express a small part of Pauli’s thought. The path created by Pauli’s deep thinking is the one I will try follow in the sections to come.

3.3 ‘Complementarity’ within the Complementary Descriptions Approach

The idea that reality can be captured by an objective system has been to great extent the motor of knowledge in its different forms. The acknowledgment of the impossibilities for such a project, should not be regarded as a defeat but rather as a new insight of reality itself. In this same sense I don’t take complementarity as describing an encompassing whole, on the contrary, I think complementarity obliges us to face the incompleteness and paradoxical character of reality. “Complementarity is no system, no doctrine with ready-made precepts. There is no via regia to it; no formal definition of it can be found in Bohr’s writings, and this worries many people. [...] Bohr was content to teach by example. He often evoked the thinkers of the past who had intuitively recognized dialectical aspects of existence and endeavored to give them poetical or philosophical expression.” Complementarity goes with paradox, it allows us to stress the limits of knowledge and at the same time it presents us with the incommensurability of reality. Descriptions, perspectives, contexts and concepts are then taken as complementary in this same sense.

With the complementary descriptions approach I try to find a middle path between ontology and epistemology between realism and empiricism. The main difficulty of this approach is to stand in between, to not be dragged by any specific description, each of which should be regarded only as a ‘partial description’, and complementary to a different one.

I regard quantum mechanics, on the one hand, as a complete theory; in the sense of Pauli (25, p.96): “that no new laws can be added to the system of natural laws of the domain connected without partly altering the content of those already contained in it.” On the other hand, the EPR argument, as Aerts (1) correctly points out, is an ad absurdum proof of the incompleteness of the quantum theory. In what sense quantum mechanics is incomplete, I argue, relates to the complementarity of the classical and quantum concepts involved. Every description is incomplete in the following: it has to choose a certain structure, a certain group of concepts which define it. In their turn these concepts expose the limit within which the description is ‘useful’; but a limit is always in itself a definition of something which lies ‘outside’. “Insofar as it is measured against and prohibits the classical models of completeness, complementary entails incompleteness –structural, irreducible incompleteness.” This incompleteness deals explicitly with the complementarity of descriptions, every description expressing in itself a limit in our means of expression and understanding. The incompleteness of quantum mechanics presents us with its limit; for example with the impossibility of describing separated entities (as it is presupposed in classical mechanics/relativity theory). One should be aware that in this sense classical mechanics is also incomplete as it cannot by any means take into account the ‘non-separability’ present in the quantum formulation.

According to the received view our language presupposes individuality, it is an expression of the metaphysical choice inherited from Aristotle, Plato and the parmenidean ‘One’. These presuppositions

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25 Rosenfeld quoted from (40, p.85).
26 This is the same sense in which Heisenberg regarded quantum mechanics as a complete theory and which many times has been badly characterized as meaning that quantum mechanics is the fundamental theory of nature. As expressed in 38 by von Weizsacker: “For Heisenberg, “closed” was not to identical with “final”, but the sequence of closed theories rather hinted at the idea of physics as an open-ended enterprise.” See also 37.
27 Plotnitsky quoted from (29, p.128).
expressed by classical logic go together with classical mechanics. Quantum mechanics, on the other hand is closer to the heraclitean ‘Many’\textsuperscript{28}. Classical and quantum mechanics are definite descriptions with definite concepts. Both theories approach reality, the result of which is to a large extent, partially determined by the description itself: they are mutually incompatible, and at the same time they are expressions of the preconceptions involved presenting complementary views of reality. It is in this general sense that I take the quantum mechanical description to be complementary to the classical description.

As Folse (\cite{14}, p.163) argues: “Bohr persistently evades any direct engagement with the question of ‘reality’.” I will not argue for or against the ‘realist-antirealist’ position of which a lot of bibliography can be found\textsuperscript{29} but rather, as I expressed above, try to move towards a new conception of reality (of which this article might be considered as a micro step). Reality should not be a pre-established concept nor a prejudice in observing and relating empirical data, but rather a goal concept which should be transformed and developed. We should not expect reality to be... as we would like it to be; we must constantly revise the conceptual framework with which such a description is expressed. Following the main idea, which led Einstein to the special theory of relativity, we should not conclude experiments from reality; however, the opposite should be neither pursued; Carlo Rovelli (\cite{37}, p.2) proposed the following: “I have a methodological suggestion for the problem of the interpretation of quantum mechanics: Finding the set of physical facts from which the quantum mechanics’s formalism can be derived.” The problem is: there are no facts without a description\textsuperscript{30} Experimental observation and ontology are intricately related without supremacy of one over the other, both being the reflection of the former like two mirrors with nothing in between.

It must be clear at this point that I do not mean to take as a standpoint, like Bohr did (\cite{45}, p.7), the importance of classical (physical) concepts in the definition of experience. Bohr relied in a concept of complementarity which was a consistent explanation of these phenomena. My approach is a development of the concept of complementarity stressing the importance of descriptions which make possible the preconditions of experimental observation encouraging the creation and development of new concepts within physics. These descriptions develop a plurality of ontologies which capture different forms of the being. To a great extent every new theory that has been developed, from Aristotelian mechanics to general relativity, has been grounded in new concepts. The physicist should be a creator of physical concepts. Concepts which, within a theory, make possible to grasp certain character of nature. This however should not be regarded as some kind of solipsism, it is not only the description shaping reality but also reality hitting our descriptions. It is through this interaction, namely, our descriptions and the experimental observation that we create and discover a certain character of the being. It is in this way that we can develop that which we consider to be reality.

My standpoint is that experience is defined by description, and vice versa, description is defined by experience, they intricate themselves with no preponderance of the one over the other. In order to regain objectivity, we must acknowledge that the classical description has no supremacy over different descriptions, that it is not given to us a priori, and that it develops through the different descriptions with which we choose to express ourselves. The phrase of Bohr (quoted from \cite{45}, p.7) stating that “…the unambiguous interpretation of any measurement must be essentially framed in terms of the classical physical theories, and we may say that in this sense the language of Newton and Maxwell will remain the language of physics for all time.” gives way to a quite strong conclusion, this is, that we have come to the limits in the pre-conditions of human understanding. By having to confront Einstein’s realism and ontological position Bohr was dragged to the other extreme, namely, an empiricist and epistemological position. I hope to go back to the middle path, just in between experience and description, between creation and discovery\textsuperscript{31}.

4 Convergence of Descriptions?

There is a quite tacit assumption which goes against the ideas I have been presenting, namely, the idea that science is converging towards the ultimate truth, the theory of everything, that our knowledge increases with every article that is published. I think the concept of what is understanding has been severely damaged by a radical positivistic attitude science has taken in the last centuries. I point this out

\textsuperscript{28}See for example David Finkelstein’s article: “All is Flux” \cite{12} and \cite{39} for a related analysis.

\textsuperscript{29}See for example \cite{13}, \cite{19} and references therein.

\textsuperscript{30}As Einstein himself pointed out to Heisenberg: “It is only the theory which decides what can be observed.”

\textsuperscript{31}A related position, namely, the creation discovery view was introduced by Diederik Aerts in \cite{2}. 
because the idea that more production is equal to more knowledge is at stake. One should, as a scientist wonder over the very deep meaning of “understanding”\textsuperscript{32}. This maybe the core problem for many in reaching the concept of complementarity, which tackles our tacit presuppositions \textsuperscript{14} in the traditional positivist epistemological framework; i.e. that a theory provides knowledge about an object if and only if it justifies making \textit{true descriptive statements} predicating properties of some substantial entity. This idea rests on imagining that science has reached the \textit{a priori} conditions of human understanding itself while it has in fact succeeded only in setting up the \textit{a priori} conditions of the systems of mathematics and the exact sciences of a particular epoch (\textsuperscript{25}, p.95).

The idea of a convergent reality presupposes the idea that one can reduce concepts of one theory to the next; i.e. that there is a fundamental theory which can reach the fundamental ‘concepts of nature’. Richard Feynman is a proponent of such view, in his BBC television lectures he argued:

“\textit{The age in which we live is the age in which we are discovering the fundamental laws of nature, and that day will never come again. It is very exciting, it is marvellous, but this excitement will have to go.}” R. Feynman (quoted from \textsuperscript{30}, p.347).

Reductionism goes together with convergence. In this sense, classical mechanics is worse than relativity theory, because, the last is able to see the concepts of the first as a limit, and at the same time it produces new insights. Contrary to this position, it is quite clear that when one studies the problem in a deeper way, one finds that such concepts are no limits, rather, they can be found as approximations within certain very specific conditions; however, when these conditions are extended to the general frameworks from which the concepts acquire meaning incompatibilities and inconsistencies appear as much as in between the classical and quantum descriptions. In other words, I think that trying to find a limit between relativity theory and classical mechanics is to some extent equivalent to trying to find a limit between physics and psychology. Although concepts like space and time can be used in the physical framework as well as in the Freudian theory of psychology, once we generalize the concepts to the general framework of either description we find out the concepts generalize as well in both directions making impossible to retain the consistency presented in the beginning. Quantum mechanics is full of these type of mistakes which appear in most cases by using concepts and symbols which are not part of the \textit{quantum language} (which make no sense in it). Through mixing symbols and words which pertain to different languages in many cases we end up in weird paradoxes. In order to get closer to the mystery one first needs to demystify and clarify the limits and the usage of the different languages. Wittgenstein was certainly aware of this important fact as he points out in his \textit{Tractatus} (\textsuperscript{46}, pp.18-19):

\textbf{3.323.} In everyday language it very frequently happens that the same word has different modes of signification–and so belongs to different symbols–or that two words that have different modes of signification are employed in propositions in what is superficially the same way.

Thus the world ‘is’ figures as the copula, as a sign for identity, and as an expression for existence; ‘exist’ figures as an intransitive verb like ‘go’, and ‘identical’ as an adjective; we speak of \textit{something}, but also of \textit{something’s} happening.

(In the proposition ‘Green is green’–where the first word is the proper name of a person and the last an adjective–these words do not merely have different meanings: they are \textit{different symbols}.)

\textbf{3.324.} In this way the most fundamental confusions are easily produced (the whole philosophy is full of them).

\textbf{3.325.} In order to avoid such errors we must make use of a sign-language that excludes them by not using the same sign for different symbols and by not using in a superficially similar way signs that have different modes of signification: that is to say, a sign-language that is governed by \textit{logical} grammar–by logical syntax.

The idea that quantum mechanics is a fundamental theory of nature (as describing the fundamental blocks of reality from which everything else can be derived), even the idea that there might exist a true story about the world\textsuperscript{33} goes completely against the spirit of what I am proposing here. My approach goes together with Heisenberg’s conception of \textit{closed theories} as a relation of tight interconnected concepts, definitions and laws whereby a large field of phenomena can be described \textsuperscript{7}. Heisenberg states that

\textsuperscript{32}See for example the very interesting Chap. 6 of \textsuperscript{17} about the concept of ‘understanding’ in a discussion between Heisenberg and Pauli.

\textsuperscript{33}See for example \textsuperscript{14}.
theories come up through “intelectual jumps” with the theories that have come before. In this point he confronted the ideas of P.A.M. Dirac who states that theories are continuously revised and straightened \[.\]

My approach goes just in between; the composite (discrete and continuous) development makes possible to take into account both, holistic and reductionistic conceptions of science; this is where complementarity remains a fundamental position in order to find new paths\[34\].

In this sense we will argue it is wrong to follow the orthodox reductionistic conception: that everything is “quantum” and that it is necessary to find a limit-process between quantum mechanics and our classical conception of the world (the quantum to classical limit); rather one should be able to acknowledge the possibility of describing the world from different (incompatible but complementary) view points. Wolfgang Pauli imagined a future in which the quantum conceptions would not be regarded as ‘weird.’ This conceptual jump in the way we see the world has not yet taken place with respect to quantum mechanics\[35\].

We believe this is due to the lack of new concepts in the quantum domain and to a ‘reductionistic conception’ which presupposes that ‘understanding’ is reducible to ‘classical understanding’, to a single view point. My aim in \[36\] will be to show that quantum mechanics is \textit{not} an open theory, in the sense of convergence\[36\], that it is not necessary to find a reduction between classical mechanics and quantum mechanics. Rather, that the quantum and classical descriptions are complementary with respect to the concepts involved, thus, that quantum mechanics, nor classical mechanics, can be regarded as a fundamental theories in this reductionistic sense. The classical description is complementary to the quantum description and even though they can make contact in some definite situations, one should acknowledge the structural and conceptual impossibility of the quantum theory to explain the classical world (this will be further analyzed in \[36\], Sect. 1).

Scientific realism is the position that theory construction aims to give us a literally true story of what the world is like, and that acceptance of a scientific theory involves the belief that it is true. The idea of truth as a closed enterprise is responsible to great extent for the development of the ‘fabric of science’. Reductionism allows a single truth, it is hostile to every conception which is outside its own limits. But truth is nothing but a concept created by man. Max Planck expressed this point in a very bright way: “A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.” Quantum mechanics presents us a new truth, with new concepts which up to the present have not been further developed. In \[36\] I will present a new way of ‘reading’ quantum mechanics through the distinction of different complementary levels of description. I will discriminate between different levels in order to clarify the discussion and show that different, mutually incompatible concepts are taken into account in the discussion of the interpretational problems of the quantum theory.

Conclusions

I have presented a development of the concept of complementarity following the road shown (specially) by Niels Bohr, Werner Heisenberg and Wolfgang Pauli. I see this as a starting point in the development of the interpretation of the quantum theory and a return to the philosophical attitude which was brought by the founding fathers of the quantum theory. To return we must take into account the very deep philosophical understanding of the time, and go still further in this forgotten path.

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\[34\]I am grateful to Leonardo Levinas for explaining this important point to me.
\[35\]See also Constantin Piron \[28\].
\[36\]It is important to point out that the view of Dirac is read as implying convergence of theories.
References

[1] Aerts, D., 1985, “The physical origin of the EPR paradox and how to violate Bell inequalities by macroscopical systems” In On the Foundations of Modern Physics, P. Lathi, and P. Mittelstaedt (eds.), World Scientific, Singapore, pp.305-320.

[2] Aerts, D., 1988, “The entity and modern physics: the creation-discovery view of reality” In Interpreting Bodies: Classical and Quantum Objects in Modern Physics, E. Castellani (ed.), Princeton University Press, Princeton.

[3] Aerts, D., de Ronde, C. and D’Hooghe B., 2005, “Compatibility and Separability for Classical and Quantum Entanglement” submitted to International Journal of Theoretical Physics.

[4] Bene, G. and Dieks, D., 2002, “A Perspectival Version of the Modal Interpretation of Quantum Mechanics and the Origin of Macroscopic Behavior”, Foundations of Physics, 32, No 5, May 2002, also in archive ref and link: quant-ph/0112134.

[5] Bohr, N., 1928, “The Quantum Postulate and the recent development of atomic theory”, Nature, 121, pp.580-590.

[6] Bohr, N., 1958, Atomic, Physics and Human Knowledge, Wiley, New York.

[7] Bokulich, A., 2004, “Open or Closed? Dirac, Heisenberg, and the relation between classical and quantum mechanics”, Studies in History and Philosophy of Modern Physics, 35, pp.377-396.

[8] Cassirer, E., 1956, Determinism and Indeterminism in Modern Physics, Yale University Press.

[9] D’Espagnat, B., 1995, Veiled Reality. An Analysis of Present Day Quantum Mechanical Concepts, Addison-Wesley, Reading MA.

[10] Dieks, D., 1988, “The Formalism of Quantum Theory: An Objective description of reality”, Annalen der Physik, 7, Band 45, Heft 3, pp.174-190.

[11] Feyerabend, P., 1993, Against Method, Third Edition, London: Verso.

[12] Finkelstein, D., 1987, “All is flux” In Quantum Implications: Essays in honour of David Bohm, pp.289-94, B.J. Hiley and F.D. Peat (eds.), London: Routledge and Kegan Paul.

[13] Folse, H.J., 1985, The Philosophy of Niels Bohr: The Framework of Complementarity, North Holland Physics Publishing, Amsterdam.

[14] Folse, H.J., 1987, “Niels Bohr’s Concept of Reality”, In Symposium on the foundations of Modern Physics 1987, pp.161-179, P. Lathi and P. Mittelstaedt (eds.), World Scientific, Singapore.

[15] Healey, R.A., 1999, “Holism and Non Separability in Physics”, The Stanford Encyclopedia of Philosophy (Winter 2004 Edition), Edward N. Zalta (ed.), URL = http://plato.stanford.edu/archives/win2004/entries/physics-holism/

[16] Heisenberg, W., 1927, “Uber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechan” Zeitschrift fur Physik, 43, pp.172-98; reprinted as “The Physical Content of Quantum Kinematics and Mechanics”, translation by J.A. Wheeler and W.H. Zurek, in Quantum Theory and Measurement, J.A. Wheeler and W.H. Zurek (eds.).

[17] Heisenberg, W., 1972, Dialogos sobre la Física Atómica, Biblioteca de Autores Cristianos de la Editorial Católica, Madrid.

[18] Hendry, J., 1984, The Creation of Quantum Mechanics and the Bohr-Pauli Dialogue, D. Reidel Publishing Company, Dordrecht.

[19] Howard, D., 1989, “Holism, Separability and the Metaphysical implications of the Bell inequalities”, In Philosophical Consequences of Quantum Theory: Reflections on Bell’s Theorem, pp.224-253, Cushing and McMullin (eds.), University of Notre Dame Press, Notre Dame, Indiana.
Howard, D., 1994, “What makes a classical concept classical? Towards a reconstruction of Niels Bohr’s philosophy of physics” In Niels Bohr and Contemporary Philosophy, J. Faye and H. Folse (eds.), Kluwer, Boston.

Jammer, M., 1974, The Philosophy of Quantum Mechanics, Wiley, New York.

Kant, I., 1973, Critique of Pure Reason, Trans. Norman Kemp Smith. London: Macmillan.

Laurikainen, K.V., 1998, The Message of the Atoms, Essays on Wolfgang Pauli and the Unspeakable, Springer Verlag, Berlin.

Lombardi, O., 2002, “Determinism, Internalism and Objectivity”, In Between Chance and Choice, pp.75-87, H. Atmanspacher and R. Bishop (eds.), Imprint Academic, Exeter.

Pauli, W., 1994, Writings on Physics and Philosophy, Enz, C. and von Meyenn, K. (eds.), Springer Verlag.

Pauli, W. and Jung, C.G., 2001, Atom and Archetype, The Pauli/Jung Letters 1932-1958, Princeton University Press, New Jersey.

Petersen, A., 1963, “The philosophy of Niels Bohr”, The Bulletin of the Atomic Scientists, September 1963.

Piron, C., 1999, “Quanta and Relativity: Two Failed Revolutions”, In The White Book of Einstein Meets Magritte, pp.107-112, D. Aerts J. Broekaert and E. Mathijs (eds.), Kluwer Academic Publishers.

Plotnitsky, A., 1994, Complementarity, Duke University Press, Durham and London.

Primas, H., 1983, Chemistry, Quantum Mechanics and Reductionism, Springer Verlag, Berlin.

Primas, H. 1987, “Contextual Quantum Objects and their Ontic Interpretation”, In Symposium on the foundations of Modern Physics 1987, pp.251-275, P.Lathi and P. Mittelstaedt (eds.), World Scientific, Singapore.

Primas, H., 1994, “Hierarchical Quantum Descriptions and their Associated Ontologies” In Symposia on the Foundations of Modern Physics 1994, pp.201-220, Laurikainen, K.V., Montonen C. and Sunnarborg K. (eds.), Frontiers, Gif-sur-Yvette Cedex.

Putnam, H., 1981, Reason, Truth and History, Cambridge University Press, Cambridge.

de Ronde, C., 2003, Master Thesis: Perspectival Interpretation of Quantum Mechanics (a story about correlations and holism), Institute for History and Foundations of Mathematical and the Natural Sciences, Utrecht University and University of Buenos Aires, URL = http://www.vub.ac.be/CLEA/people/deronde/.

de Ronde, C., 2004, “Interpretación perspectival de la mecánica cuántica y descripciones complementarias” In Volumen 10 de Epistemología e Historia de la Ciencia, pp.161-167, García, P. and Morey, P. (eds.), Universidad Nacional de Cordoba, Cordoba. URL = http://www.vub.ac.be/CLEA/people/deronde/.

de Ronde, C., 2005, “Complementary Descriptions (PART II): A Set of Ideas Regarding the Interpretation of Quantum Mechanics”, Preprint.

Rovelli, C., 1996, “Relational Quantum Mechanics”, archive ref and link: quant-ph/9609002

Saunders, S., 2005, “Complementarity and Scientific Rationality”, Foundations of Physics, forthcoming.

Schrödinger, E., 1935, “The Present Situation in Quantum Mechanics”, Naturwiss, 23, 807, translated to english in Quantum Theory and Measurement, J.A. Wheeler and W.H. Zurek (eds.), Princeton University Press 1983.
[40] Verelst, K. and Coecke, B., 1999, “Early Greek Thought and perspectives for the Interpretation of Quantum Mechanics: Preliminaries to an Ontological Approach” In The Blue Book of Einstein Meets Magritte, pp.163-196, D. Aerts (eds.), Kluwer Academic Publishers.

[41] Von Weizsäcker, C.F., 1955, “Komplementarität und Natuurwissenschaft”, Die Natuurwissenschaften, p.42, n.19-20. Translated as “Complementariedad y Lógica” in La Imagen Física del Mundo, 1974, Biblioteca de Autores Cristianos, Madrid.

[42] Von Weizsäcker, C.F., 1974, La Imagen Física del Mundo, Biblioteca de Autores Cristianos, Madrid.

[43] Von Weizsäcker, C.F., 1985, “Heisenberg’s philosophy” In Symposium on the Foundations of Modern Physics 1985, pp.277-293, P. Lathi and P. Mittelstaedt (eds.), World Scientific, Singapore.

[44] Weinberg, 1993, Dreams of a final theory, Vintage, London.

[45] Wheeler, J.A. and Zurek, W.H., 1983, Quantum Theory and Measurement, J.A. Wheeler and W.H. Zurek (eds.), Princeton University Press, New Jersey.

[46] Wittgenstein, L., 1974, Tractatus Logico Philosophicus, Routledge Classics, London.