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TRANSCENDENTAL PHILOSOPHY AND QUANTUM PHYSICS

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Abstract: In the *Critique of Pure Reason* Kant argues that the empirical knowledge of the world depends on *a priori* conditions of human sensibility and understanding, i. e., our capacities of sense experience and concept formation. The objective knowledge presupposes, on one hand, space and time as *a priori* conditions of sensibility and, on another hand, *a priori* judgments, like the principle of causality, as constitutive conditions of understanding. The problem is that in the XX century the physical science completely changed how we conceive our knowledge of the world. Face to this new situation, what was changed in our classical reason? However, if the transcendental point of view is adopted, in the specific case of quantum mechanics, we have to wonder about the general conditions of this theory that make possible such knowledge, which predictive value is much more accurate than the classical physics. The aim of this work is firstly to show the Kantian implications on Bohr's interpretation of quantum phenomena and secondly to provide an overview of the key elements for understanding the transcendental locus of ordinary language in the quantum mechanics context, in order to give support to a transcendental pragmatic position in the analysis of science.

Keywords: Transcendental pragmatics. Bohr's interpretation. Quantum theory.

FILOSOFIA TRANSCENDENTAL E FÍSICA QUÂNTICA

Resumo: Na *Crítica da Razão Pura*, Kant sustenta que nosso conhecimento do mundo empírico depende das condições *a priori* da sensibilidade e do entendimento humano. O conhecimento objetivo pressupõe assim o espaço e o tempo como condições *a priori* da sensibilidade e os princípios do entendimento, como é o caso do princípio de causalidade, como condições constitutivas do conhecimento. No entanto, a física do século XX, em particular a mecânica quântica, mudou completamente nosso modo de compreensão do conhecimento do mundo físico. Se uma perspectiva transcendental de análise do conhecimento é adotada, torna-se legítimo indagar pelas condições gerais que tornam possível o conhecimento da teoria quântica. O objetivo desse trabalho é mostrar em primeiro lugar as implicações kantianas da interpretação de Niels Bohr do fenômeno quântico, e, em segundo lugar, oferecer os elementos chaves para a defesa de uma posição pragmático-transcendental de análise da ciência.

Palavras chave: Pragmática transcendental. Interpretação de Bohr. Teoria quântica.

Literature published in the past few years has begun again to emphasize the transcendental conditions of physical theories and, more particularly, the *a priori* conditions of quantum mechanics. It represents a welcome change of perspective from the view of logical empiricists and scientific realists who, for decades, rejected the transcendental method, as a potential tool for providing new insights on the epistemic basis of scientific knowledge.

In the1930's, efforts to extend transcendental analysis to the field of contemporary physics were made by Neo-Kantian philosophers, such as Grete Hermann, Ernst Cassirer and even Heisenberg himself. More recently, new approaches began more exhaustively to explore the potential of transcendental philosophy, anchored on current debates about the fundaments of quantum mechanics[1].

This paper supports a transcendental pragmatic position in the philosophy of science, beginning with an overview of the key elements necessary to understand the transcendental locus of ordinary language in quantum mechanics context.

A controversial issue is whether or not the Copenhagen Interpretation of quantum mechanics can be understood in terms of Kantian philosophy. Heisenberg, in several of his essays, takes a clear

[1] See, for instance, Carl Friedrich von Weizsäcker (1971/1979), Peter Mittelstaedt (1976, 1994), Erhard Scheibe (1988), Brigitte Falkenburg (1998, 2000, 2004), Gordon Brittain (1994), Jean Petitot (1991) and Michel Bitbol (1996, 1998, 2000).

stand in regards to the limits of Kantian epistemology in relation to quantum theory. There is even a chapter entitled “Quantum Mechanics and Kantian Philosophy” in his book “Physics and Beyond: Encounters and Conversations”, whereas Bohr makes no explicit references to Kantian philosophy[2], even though he received an education during a period strongly influenced by Neo-Kantianism.

This absence of philosophical references may in part explain the divergences between Bohr’s interpreters’ characterization of his philosophical affiliation. For Peter Mittelstaedt, Bohr is the first to bring the empiricism of David Hume into the field of quantum mechanics:

> In principle, there are two possible ways to react to this discrepancy between transcendental arguments and quantum mechanics. First, one could restrict the physical/to the observed data and measuring results thus avoiding the inconsistencies mentioned. This approach corresponds *both* to the empiricism /of David Hume or to the positivism of Ernst Mach and was first applied to quantum mechanics by Niels Bohr. (Peter Mittelstaedt, 1994: 119-120)

On the other hand, scholars like Clifford A. Hooker (1972), John Honner (1982), Catherine Chevalley (1994) and Steen Brock (2003) establish a parallelism between Kant and Bohr’s thought. Although no explicit reference to Kant can be found in Bohr’s texts, these authors claim that implicit Kantian elements can undeniably be found therein.

Clifford A. Hooker (1972) was one of those who carried out a detailed study in support of this claim. According to him, it is only in the light of Kantian philosophy that we can grasp the full extent and depth of Bohr’s doctrine. In fact, Kantian vocabulary pervades Bohr’s writings. The following sentence, contained in the introduction to his book *Atomic Theory and the Description of Nature*, might well have been lifted from the *Critique of Pure Reason*: “all new experience makes its appearance within

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[2] See, for instance, Henry Folse (1978), John Honner (1982) and Catherine Chevalley (1991).

the frame of our customary points of view and forms of perception" (Bohr, 1934:1). We can see that the Kantian formula of synthesizing intuitions and concepts is clearly present in this statement. Chevalley recognizes that "the occurrence of terms stemming from *Anschauung* [intuition], used by Bohr or by other founders of quantum mechanics, always presupposes the presence of Kantian issues, even if not directly referred to". (1991: 459-0)

The principle of complementarity is, doubtlessly, one of the most original contributions of Bohr's contextual interpretation of quantum theory. It is introduced in very different ways in his many articles. It is sometimes defined in terms of the complementary and mutually exclusive aspects of atomic phenomena descriptions: the corpuscular and the wave. In the light of uncertainty relations, he also presented his principle as an expression of the complementary use of classical concepts, such as position and momentum. However, I would like to draw attention to yet a third expression, one that is formulated in strictly Kantian terms and which was disclosed during the *Como Conference* in 1927: the complementarity between space-time intuition and the principle of causality. Bohr claims that: "[Quantum postulate] implies a renunciation as regards the causal space-time co -ordination of atomic process. (Bohr, 1934, p.52*)*

Heisenberg, in his book *The physical principles of the quantum theory*, expresses the complementary character of space-time intuition and the concept of causality:

> The resolution of the paradoxes of atomic theory can be accomplished only by further renunciation of old and cherished ideas. Most important of these is the (…) principle of causality.
>
> (…) Second among requirements traditionally imposed on a physical theory is that it must explain all phenomena as relations between objects existing in space-time.
>
> (...) Bohr has pointed out that it is therefore impossible to demand that both **requirements** [space-time description and causality] be fulfilled by

> the quantum theory. They represent complementary and mutually exclusive aspects of atomic phenomena. (Heisenberg, 1949: 62-64)

And he summarized the essential complementarity between space-time intuition and the principle of causality in the following table (Heisenberg, 1949: 65):

CLASSICAL THEORY
Causal relationships of phenomena described in terms of space and time
QUANTUM THEORY

Either		*Or*
Phenomena described in terms of space and time	Alternatives related statistically	Causal relationships expressed by mathematical laws
But		*But*
Uncertainty principle		Physical description of phenomena in space-time impossible

Thus, Bohr and Heisenberg recognize that the principle of complementarity introduces a limited validity to Kant's *a priori* notions. On the one hand, they realize that it is impossible to intuitively describe the microphysical phenomena, given that the formalism of quantum theory does not take place in the ordinary three-dimensional space but, rather, in a multidimensional vectorial space. On the other hand, they claim that it is not possible to totally discard classical intuitive representations. The principle of complementarity precisely defines the role played by intuitive pictures of atomic phenomena.

It may, however, be argued if these Kantian elements, used by Bohr and Heisenberg to interpret quantum formalism, is coherent with Kant's epistemology.

I do not think so. In my opinion, from a Kantian point of view, it does not make sense to consider the space-time intuition isolated from the principles of understanding, among which the principle of causality is but one. It should not be overlooked that, for Kant, intuition is connected to the two mathematical principles of pure understanding: the axioms of intuition and the anticipations of perception. These are the two principles that justify, *a priori*, the mathematical constitution of nature. It does not seem to me that the state vector evolution equation can, purely and simply, be considered as an expression of the causal law. For Kant, the principle that governs continuous temporal evolution, such as is the case of the mechanical laws expressed by partial differential equations, is not the second analogy of experience, but, rather, the principle of anticipations of perception. Curiously, there are almost no references to this principle in the epistemological discussions about the relationships between Kantism and quantum theory[3].

Moreover, it should be remembered that, when it comes to Kant, it is senseless to talk about causality without correlating it with intuition. According to his definition of the second analogy, the principle of chronological succession in accordance with the law of causality is a rule that intervenes in order to connect the empirical manifold. Kant puts it as follows: "in the perception of an event there is always a rule that makes the order in which the perceptions (in the apprehension of this appearance) follow upon one another a necessary order." (A193 - B238). Thus, considering Schrödinger's equation as an example of a causal law one does not find any bearing in the Kantian principle of causality, which is applicable only to a succession within the order of perceptions.

[3] See, for instance, Kauark-Leite (2009).

Outside the experimental context, Kant's second analogy no longer plays its role of justification of knowledge.

Therefore, a more detailed analysis to determine any similarity between Bohr's and Kant's respective approaches has brought about some unsurmountable problems leading us to suspect that such similarity does not, in fact, exist. However, should we take the term 'transcendental' in a wider sense, as suggested by John Honner in his 1982 article "The transcendental philosophy of Niels Bohr", an intimate relationship may be established between transcendental philosophy and Bohr's doctrine. Contrary to Henry Folse**,** for whom the similarity between Kant's and Bohr's thoughts is only apparent, John Honner declares: *If Bohr's philosophy is to be given a label, then that label should most appropriately bear the word 'transcendental'.* It should be noticed, therefore, that, according to Honner's statement, Bohr can no longer be considered a Kantian philosopher, but, rather, a transcendental philosopher. As Cassirer had already suggested, it is necessary to distinguish trancendental philosophy from strict Kantianism. In this sense, the strictly Kantian forms have an extremely limited range of validity and that transcendental arguments contain an epistemic legitimacy that goes far beyond the realms of classical mechanics.

Which are those new transcendental forms, which do not coincide with the pure sensible intuitions of space and time? Nor with the categories and principles of pure understanding? Should it be possible to identify them, a second issue should then be addressed: To which extent does the presumed universality - intrinsic to the transcendental principles – remain valid whilst science itself is an ongoing, ever changing process? This problem places under suspicion the unchanging character of the *a priori* forms and leaves us with the following alternative: we either replace the limited Kantian forms by transcendental, more general ones or we totally abdicate our aspiration for universality in favour of historical *a prioris* conditioned to specific theoretical systems.

In the context of quantum mechanics, C.F. von Weizsäcker, J. Petitot and M. Bitbol are undeniably the most significant representatives of the relative *a priori*.

However, why keep using the word 'transcendental' to label an approach totally alien to that of Kant? Why not talk about conventions in Poincaré's sense, as was once proposed by M. Schlick (1921/1979), without having to use a term traditionally linked to a strong foundationist program? The quantum theory is a privileged field where these issues deserve to be addressed in more depth. An analysis of the philosophical implications of Bohr's thought apparently reveals, in my opinion, that purely conventionalist or instrumentalist approaches cannot satisfactorily answer the question about how quantum objectivity is constituted. If we take the opposite realistic view, that quantum theory concernes unobservable entities with well defined properties, then the difficulties remain considerable.

As Bohr narrows the focus of his interpretation on the limits of the applicability of our concepts, he, in fact, does nothing but extend the Kantian analysis to a totally different epistemic situation. He states that the essence of the quantum postulate should be searched for on the inevitable limit of our possibilities of definitions[4]. It is worth remembering that the issue concerning the limits of knowledge – which plays a central role in the Bohrian approach – is an essentially Kantian issue. If we consider that the meaning of 'transcendental' must extend and comprise all the investigation about the conditions that limit our experience, then Bohr's philosophy must undoubtedly be viewed from a transcendental angle rather than from the angle of a strict Kantianism.

A typically Bohrian transcendental argument concerns the so-called 'conditions of an unambiguous communication', which are conditions that limit the very experience of human beings. The result of his analysis of the role of the ordinary language in quantum contexts

[4] See Bohr's letter to Schrödinger, dated 23/05/28 (BSC:16).

extends into two directions. On the one hand, it is impossible to use the concepts of ordinary language to produce any type of a univocal description of the microphysical nature without inevitably producing imprecisions and ambiguities. We can even point to the lack of competence of ordinary language to describe an unobservable reality where all named entities with lacks reference. On the other hand, Bohr points to the inexorable fact that, in their concomitantly experimental and communicative practice, physicists cannot refrain from using ordinary language, the terms of which denote both observable properties of objects and the equally observable relations between them. Classic concepts are necessarily used to describe experimental devices and results. For Bohr, these concepts are merely refined versions of our ordinary concepts about our daily experience and always appear interconnected in terms of space and time. The idea is that our experiences, which consist of actions and observations, should always be described within ordinary language terms.

This problem concerning the limitation of ordinary language does not appear in the context of classical physics. Here, natural phenomena are understood by means of a mathematical formalism introduced through a strict system of definitions and axioms. Laws of classical mechanics are expressed by means of mathematical equations whose symbols must be related to experimental facts or, more specifically, to measuring results. Associated with quantities and physical constants, the value of some of these symbols can be determined by means of measuring processes. While such a connection between symbols and measuring results remains, all phenomena will be represented by mathematical formalism. In this context, a biunivocal correspondence may be established between a pair of conjugated variables - such as position and momentum, the temporal evolution of which is given by a partial differential equation – and the simultaneously measured values of the said variables. One of the results of this association translates into the concept of trajectory. This concept expresses the isomorphism between the temporal evolution of symbolic formalism and the temporal evolution that can be observed when a material body is in movement. This isomorphism allows us to anticipate, in a perfectly deterministic way, the position and the momentum of a material body at any given time. The mathematical formalism of classic mechanics is then associated to the ordinary language of our perception, so as to ensure the concrete expression of the abstract symbolism of theoretical laws.

The extraordinary success of this close connection between symbols and measuring values inspired Carnap (1931 and 1932/33) and Neurath (1931, 1931/2 and 1932/33) to conceive the physicalist project, which turned the language of physics into the universal language of all sciences. According to this project, a proposition would only be meaningful if it could be translated into the language of physics, a language of objects and things and which expresses, with the aid of metric concepts, observational propositions that may be empirically verified. The possibility of translating any proposition in the physicalist language turns this language into a universal code which may be used to interpret every meaningful proposition. The experience structured in this linguistic way ensure the intersubjectivity of the verification required by science. The scientific language, no matter how abstract and removed from the ordinary linguistic use it may be, can be explained to any individual through his/her current language. According to this kind of pedagogical argument, if we can talk about an abstract situation and make sense out of it, we can also talk about this very same situation using a familiar and concrete language.

However, the epistemic situation becomes very complex in quantum mechanics with regard to the absence of an adequate criterion that is capable of correlating the mathematical symbols of the formal language to the concepts of the ordinary language. Should it be possible to avoid using ordinary language in the field of atomic physics, the problem would not exist. However, using only the language of mathematical formalism is not enough. We could think, and justifiably so, that the problem would, in principle, be solved if we could replace the ordinary language by another language, that is to say, a new and precise type of language governed by particular logical schemes and in total conformity with the formalism of mathematics. This new language would not be purely formal, in a logical sense, but, rather, a physical language using new words to describe without ambiguity the reality of the atomic events. Bohr, however, claims that it is a mistake to think that this is the solution to the problem. We do not have the means to replace the language used in our daily lives by another language which is supposedly based on a predicative semantics of referential objects.

Thus, according to the complementarity interpretation, we cannot avoid the paradox of the use of the ordinary language in the quantum theory. Nevertheless, should we insist on describing the atomic events by means of the terminology of classical physics, we would end up in the strange position where a word such as ‘electron’ is considered compatible with conflicting and mutually-excluding intuitive images. Should the term – ‘electron’ – be realistically interpreted as an object that can be putatively referred to a microphysical reality, then the contradictions are inevitable.

The ‘methodological wager’ of logical empiricists is based on the assumption that epistemological problems can be simplified and even solved if we take into account not the physical worlds, which are full of ontological assumptions, but, rather, the pure realm of physical languages. It is necessary, according to them, to correctly formulate meaningful questions to ensure that they be concerned, not with the existence of real entities but, rather, with the meanings of the terms contained in a proposition. In an attempt to find an ideal language exempt from metaphysical terms and comprising words with only empirical meaning, Carnap is faced with the problem of theoretical terms - such as ‘atom’, ‘electron’, ‘positron’ or ‘neutrin’ - which define the scientific unobservables. This problem is part of the debate recently held in the field of the philosophy of language and which was triggered mainly by Carnap's 1956 article - "The methodological character of theoretical concepts".

Carnap is aware of the fact that even a science such as physics cannot develop based only on purely empirical concepts. Physics has to propose theories containing certain concepts which cannot be explicitly defined in terms of observational concepts. His article "Testability and Meaning" (1936/1937) contains his change of heart in relation to the strong verificationist program of his Viennese phase. In this article, Carnap embraces the hypothesis that unobservable events of the physical world can never be completely verified by the evidence of observation. He proposes that complete verification should be disregarded and replaced by the more flexible criterion of confirmation. To replace the criterion of explicit definition of scientific terms [Cf. Russell (1918), Carnap (1928)], he proposes the adoption of the criterion of reducibility, thus emphasizing the open character of scientific terms and the fact that their meanings can never be fully defined.

In order to take into account the 'excess content' of theoretical terms, Carnap proposed the double-language doctrine, according to which a scientific theory is a systematic logical construction expressed in its own specific language, which, in turn, can be divided into two branches: an observational language (L_O) and a theoretical language (L_T). The vocabulary (V_O) of the observational language contains only terms directly connected to our capacity of observation whilst the vocabulary (V_T) of the theoretical language comprises non-observable terms.

This division of vocabulary terms led to an equivalent division of the level of the propositions, which were then separated into observational propositions and theoretical propositions.

The observational language, therefore, speaks of observables. What is considered an observable may be taken both in a strict sense and in a broad sense. The former sense, reserved to terms such as 'heat', 'cold', 'blue', 'red', 'big', 'small', etc, corresponds to a pre-scientific level of our daily language. This level of language also includes dispositional words, such as ‘elastic’, ‘soluble’, ‘flexible’, ‘fragile’, etc. The wider sense of observational language is used in scientific contexts and presupposes the use of an instrumental technique of observation. Thus, words such as ‘temperature’, ‘elasticity coefficient’ and ‘electric current’ are accessible only through a method of determination provided by an experimental arrangement. Even if we consider a range of experimental methods for determining the meaning of scientific observational terms - such as is the case with an electric current, which may be observed -by either the heat it produces in a conductor, -by the deviation of a magnetic needle, -by the amount of material separated by electrolysis process -or even by any other experimental arrangement - that which provides meaning to these terms, is the fact that they can be reduced to another set of terms which are determined by direct observation. The observational language may thus be subdivided into a language-object, whose vocabulary is directly accessible, and a physical language, with a vocabulary reduced to that of the first type. At the scientific level, quantitative terms (‘elasticity coefficient’ or ‘temperature’, for example), are used, whereas the language-object uses qualitative terms (such as ‘elastic’, ‘hot’, ‘cold’[5]).

Given the direct accessibility of observational terms, the language of observation is supposed to be completely interpreted. The observational propositions are considered exempt from any semantical problem, that is to say, they can be completely interpreted despite their hypothetical and consensual character. Even so, to be understood, terms or sentences of observational language require an intersubjective agreement between all the members of a particular language community. Carnap gives a full interpretation of such terms: ”Let us imagine that L_O is used by a certain language community as a means of communication, and that all sentence of L_O are understood by all members of the group in the same sense. Thus a complete interpretation of L_O is given”. (Carnap, 1956: 40).

[5] Cf. Carnap (1938: 51-54)

However, a complete interpretation of any particular language is possible only if we keep to the level of the observational language. The interpretation of a theoretical language is always partial. It is achieved by means of Correspondence rules (C), which allow the sentences of an observational language to be derived from those of theoretical language. The Correspondence rules are, therefore, sentences containing both V_T and V_O vocabulary terms. If, on the one hand, they establish the meaning of theoretical vocabulary terms, they, on the other hand, never define them completely. This reductive process through Correspondence rules can only determine the meaning of theoretical terms on a partial and conditional basis.

In the specific example of the term ‘electron’, Carnap (1973: 228-232) considers it an example of a concept whose description contains only theoretical terms. It is, therefore, absolutely impossible to define it in observational terms (Carnap, 1973: 229). Therefore, in order to interpret a term such as ‘electron’, it is necessary to relate ‘electron’ to phenomena observable by means of Correspondence rules. This interpretation, however, is never complete, and the system of postulates to which it belongs remains open. That means that new Correspondence rules may continuously be added in an endless succession.

It is Reichenbach who applies the double-language model in the specific case of the quantum theory. Similar to Carnap, Reichenbach considers that, in the case of quantum mechanics, the vocabulary (Vo) of observational terms is defined in relation to measurement processes. Thus, he states that:

> We have an observational language and a quantum mechanical language. The observational language contains terms such as “Geiger counter”, “Wilson cloud chamber”, “black line on a photographic film”, “indication of a dial”, etc; the phrases “measurement of u”, and “the result of the measurement of u” are defined in terms of these elementary expressions. Similarly, a physical situation ‘s’ can be defined in observational terms (…) The quantum mechanical language contains terms like “position q of an electron” and “momentum p of an electron”. Between the two languages there exists the following relation: The truth

> and falsehood of statements of the quantum mechanical language is defined in terms of the truth and falsehood of statements of the observational language. We say, for instance, "the electron has the position q", when we know that the statement, "a measurement of position has been made and its result was q", is true". (Reichenbach, 1944: 136)

For Reichenbach, the meanings of the quantum mechanical statements are based on the meanings of the observational terms, and, without this definition of meanings, it will never be possible to establish the language of quantum mechanics.

We know that Carnap/Reichenbach's semantic model about the theoretical/observational dichotomy of scientific concepts was harshly criticized by, among others, Hanson (1958, 1963), Feyerabend (1999), H. Putnam (1962) and G. Maxwell (1962, 1970). Each of them, in his own way, argues against the possibility of drawing a line between observational and theoretical terms.

However, the language problem stirred up by quantum mechanics has not been especially addressed either in Carnap's anti-realistic approach or in other realistic approaches such as those supported by G. Maxwell and H. Putnam. No account at all has been taken concerning the paradox of the linguistic limitation in the microphysical realm. Both approaches fail to make a distinction between the theoretical terms used in the language framework of classical physics and those used in quantum mechanics. Thus, the same semantic model which is valid for terms that define natural kinds, such as those defining biological species, is also valid for terms applicable to the unobservables. Terms such 'arthropods' and 'chromosome' are treated in the very same way as 'electron', 'positron' and 'spin'. Even Putnam did not pay particular attention to the specificity of terms attributed to the unobservables[6], even though he concerned

[6] See Putnam (1975), Putnam (1983) and Friedman & Putnam (1978).

himself with the logic of quantum mechanics[7] and with criticism of the Carnapian distinction between observational and theoretical terms.

Let us take as examples two theoretical terms: 'chromosome' and 'electron', and let us look up their respective meanings in a dictionary. We will find, for instance, the following definitions:

> **chromosome**: *the microscopic, threadlike part of the cell that carries hereditary information in the form of genes.*
> **electron**: *one of the constituent elementary particles of an atom.(…)Under normal circumstances, electrons move about the nucleus of an atom in orbitals that form an electron cloud bound in varying strengths to the positively charged nucleus.*

Those for whom quantum mechanics does not constitute a problem, may think that, both terms have very similar linguistic and epistemological features. Both derive from and have their meanings established within contemporary scientific theories - biology and physics, respectively. Both are parts that constitute matter - the cells for living creatures, and the atom for all beings. However, if biologists, on the one hand, could readily accept the correctness of first definition, the quantum physicists, could hardly accept the second definition. Let us suppose that, the editors of a particular dictionary, for the purpose of issuing a new edition, requested the community of quantum physicists to define the word 'electron' in the most exact way possible and to reflect all applicable state-of-the-art knowledge. The physicists would find themselves in the awkward position of having to concede that, unfortunately, any definitions of the word 'electron' that they could provide in ordinary language would be full of ambiguities. Some of these physicists would go even further and risk saying that such a word could in no way be defined on a final basis. Physicists are normally tolerant of the ambiguity of

[7] Cf. Putnam (1977).

dictionary definitions of terms used in atomic theory, and they concede that this ambiguity is itself part of the very nature of their knowledge.

Philosophers of language in general carry on as if both definitions had the same semantic status. With Carnap, the meanings of these two theoretical words - 'chromosome' and 'electron' - may be established through some kind of correspondence between them and observational terms. If, on the one hand, we accept that the criticism of Hanson, Feyerabend, Putnam and Maxwell really solved the problem concerning the distinction between the theoretical and the observational terms related to any scientific theory, on the other hand, we have to consider that still remains a problem the distinction between quantum physics vocabulary and classical vocabulary.

In my opinion, the solution to this problem cannot be found in terms of a semantic analysis of language, but, rather, in terms of a pragmatic approach. In order to analyze the conditions of possibility to say something significant, in ordinary language about the unobservables, we must now turn to the pragmatic-transcendental perspective. We thus realize how far removed Carnap's double-meaning language theory is from Bohr's complementary interpretation. This latter presupposes, that for the term 'electron', there exists a pragmatic interpretation of complementary descriptions, rather than a partial semantic interpretation, as we have in Carnap's approach.

The solution found by Bohr was to limit, in a complementary way, the use of concepts, renouncing the realistic ideal of producing space-time descriptions of the microphysical reality, within a framework of a predicative semantics. If physicists still use space-time descriptions containing classical terms they do so for purely pragmatic reasons. They must communicate their experimental results and, to do so, they must use ordinary language. None of the complementary descriptions in terms of wave and particle is compatible with a theory of reference that presupposes a microscopic reality of unobservable objects. The contradiction is avoided by considering that formalism is consistent in itself and with each contradictory empirical description. We are facing a case of reversed underdetermination of theories by the empirical data. It is not a matter of conflicting theoretical systems compatible with the same empirical situation, but, rather, of conflicting experimental situations with the same theoretical formalism. The contradiction appears when we try to include in one single interpretation both formalism and more than one case of experimental application as if they refer to the same unobservable reality. The only way to avoid ambiguity is to impose upon it a limitation in terms of the pragmatic use of concepts from the ordinary language.

I am of the opinion that the deep sense of Bohr's interpretation presents an approach that is at the same time pragmatic and transcendental. A further step should be taken towards the "pragmatization" of the *a priori*, in order to take into account the performative dimension of language must be taken into account, in order to eliminate some of the paradoxes of quantum mechanics. With Bohr, we had to admit the fact that the conditions required for understanding a physical phenomenon are, at the same time, the conditions of the very possibility of communication.

This performative dimension, sometimes overlooked in the epistemological analyses, proves helpful in an attempt to interpret the complementary role of theoretical concepts in experimental context quantum mechanics. I argue that the meaning of a proposition cannot be grasped independently from the contextual value of the proposition itself. The pragmatic-transcendental turn taken by contemporary philosophy started by Wittgenstein points to fact that, in order to understand certain enunciations/statements, the context in which they are made is a determinant of their meanings. Should we take the ordinary language as a part of a linguistic game also played by quantum physicists as they communicate experimental results, we would be in a better position to understand the role it plays in the very definition of quantum objectivity. This objectivity is no longer subjectively determined by a universal conscience – as claimed by Kant – but, rather, inter-subjectively limited by experimental contexts, which should always be communicated. I believe that such a perspective has important implications in terms of ensuring both a good interpretation of the quantum mechanics and the development of a sound theory of science.

But, what exactly is the novelty introduced by this pragmatic-transcendental approach? In a constitutive level, the physical knowledge of the world, contextually dependent upon the conditions of observation, aims at reconstructing phenomena within their logical- mathematical structure. However, this logical-mathematical rationality does not suffice. It always presumes the existence of the discursive level, that is to say, the level of ordinary language, in the light of which the experimental performances are described. These two kinds of rationality – mathematical and discursive - must be considered as parts of an interpretation process where merely formal symbols are related to ordinary concepts which are simultaneously subordinated to the experimental act of measuring and to that of communication. Thus, new transcendental principles must be found not only in the constitutive level of experience but also in the performative level, where the constitutive statements will ensure an intersubjective agreement.

From a pragmatic-transcendental perspective, it no longer suffices to think that only phenomenal objectivity is caused by an unobservable reality, even if such reality be unknown or hidden. It is time to seriously take into account the necessary inter-subjective character of objectivity for which a pragmatic perspective is required. The highest principle of all synthetic *a priori* judgments[8] may be reworded from a Bohrian point of view to read as follows: "the conditions of the possibility of experience in general are likewise conditions of possibility of an unambiguous communication of the results of experience, and that for this reason they

[8] "The conditions of the possibility of experience in general are likewise conditions of the possibility of the objects of experience, and that for this reason they have objective validity in a synthetic a priori judgment" (B197).

have objective validity in *a priori* propositions". The objectivity of experience, therefore, can be understood in the sense that it may be shared in an intersubjective way. Quantum mechanics is the best example of the performative act according to which the statements used to communicate experiences are themselves actions. Michel Bitbol's interpretation of quantum theory has led us to consider that the mathematical rationality of formalism cannot be detached from our condition of beings acting in the world.

We now have a wider picture of the different *a priori* dimensions. The pragmatic -transcendental perspective leads us to consider at least three such dimensions: that of the *a priori* as constitutive principles of quantum objectivity (mathematical and dynamical dimension); that of the *a priori* as regulative principles of quantum theory (ontological dimension); and that of the *a priori* as performative principles of communicative and experimental activity (pragmatical dimension). However, these three dimensions are not quite so independent from one another as they integrate in order that they may constitute the field of validation of our scientific practice. The constitutive and regulative *a priori* dimension of experience is, in quantum mechanics, inexorably attached to the *a priori* dimension of communication, which assumes that ordinary language plays a special role.

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