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Transcendental Approaches to Quantum Mechanics. Lessons from Bohr

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Abstract: The objective of this paper is to offer an analysis of several key elements within Niels Bohr's transcendental interpretation of quantum mechanics. After some stage setting, I will demonstrate that a transcendental perspective on Bohr offers several advantages over alternative interpretations. Specifically, I will argue that some of his most contentious claims become more plausible when viewed through a transcendental lens. However, despite these strengths, Bohr's approach faces challenges. Following an evaluation of what I consider to be the primary weakness in his framework, the final section of the paper will explore potential avenues for enhancing the viability of the Bohrian project, with a specific focus on the role of phenomenology as a potential solution.

Keywords: Niels Bohr; quantum mechanics; transcendental philosophy, measurement problem; phenomenology of physics

1. *Introduction*

For a long time, three main tenets about the Copenhagen Interpretation have been widely accepted. First, that it is the unrivalled orthodoxy among working physicists. Second, that it is a unified framework built on the two main interpretational pillars of indeterminacy and complementarity. And third, that its founding father and main proponent was Niels Bohr. As we know today, neither of these statements is true. Regarding the first, recent surveys indicate "a rather striking shift in opinion compared to the old days when the Copenhagen interpretation reigned supreme" (Tegmark 1998: 855). While the Copenhagen Interpretation is still favored by many working scientists, Everettian as well as information-theoretical approaches have positioned themselves as serious contenders (Schlosshauer et al. 2013).

Matters are even clearer regarding the second statement. As recent scholarship has shown, the idea of a unified Copenhagen Interpretation that sailed under the same banner ever since Bohr first introduced the concept of complementarity in 1927 is a mythological construction (Howard 2004). Rather, what became known as the Copenhagen Interpretation was not only an assemblage of ideas from Heisenberg, Dirac, von Neumann and others (Howard 2022). It is also the case that "the term 'Copenhagen interpretation' was not used in the 1930s but first entered the physicist's vocabulary in 1955" (Kragh 1999: 210).[1]

Finally, when considering Bohr's purported role as the progenitor of the Copenhagen Interpretation, more thorough examinations of his philosophical perspectives reveal a stark contrast to those typically associated with the Copenhagen Interpretation. For instance, building on Bohr's documented interest in William James, interpreters have speculated about pragmatist moments in Bohr's writings (Murdoch 1987). Considering Bohr's lifelong friendship with the Danish philosopher Harald Høffding, others haven identified traces of Kant's philosophy in Bohr's understanding of quantum mechanics (Honner 1982, Kaiser 1992, Chevalley 1994, Hooker 1994, Cuffaro 2010, Bitbol & Osnaghi 2013, Bitbol 2017). It is these transcendental interpretations on which I will focus in this article.

My paper is structured as follows: I will begin with some stage setting in section 2 by clarifying how the word "transcendental" is typically used in philosophy of physics. I will then, in section 3, focus on the specific sense in which Bohr's interpretation of quantum physics qualifies as transcendental. After presenting Bohr's core idea of treating experimental setups and common language as *necessary conditions of the possibility* for quantum experience, I will show that a transcendental reading of Bohr has several advantages over rival interpretations: Most importantly, I will argue that some of Bohr's most contentious claims can be made perfectly credible from a transcendental viewpoint. Building on these results, I will take a more critical look at Bohr's position in section 4. The focus on my discussion will be Bohr's attempt to understand quantum mechanics transcendentally without, however, making any positive reference to subjectivity or consciousness. One of my central claims in this paper is that this feature of Bohr's overall argument renders his position unconvincing. The aim of the final section 5 is to summarize the results, and to think about possible ways in which the Bohrian project could be rescued. It is here that I will look at phenomenology as the possible missing link.

2. *Transcendental Approaches to Quantum Mechanics*

Although, as we shall see, the concept underwent severe modifications in the early 20th century, and although this is not the place to engage in serious Kant scholarship, it is natural to start an exposition of the term "transcendental" with the philosopher who gave the concept its modern meaning. In the *Critique of Pure Reason*, Immanuel Kant famously wrote: "I call transcendental all knowledge which is occupied not so much with objects as with the mode of our knowledge of objects, in so far as this mode is to be possible *a priori*." (Kant 1965: A11/B25) And in the *Prolegomena to Any Future Metaphysics* we read: "The word 'transcendental' […] does not signify something passing beyond all experience but something that indeed precedes it a priori, but that is intended simply to make knowledge of experience possible." (Kant 1985: 373) In the early 20th century, Nicolai Hartmann commented on the nature of the

[1] Curiously, the term can be partly attributed to several Leninist-Marxist critics who had coined the label in their vigorous critiques of what they perceived as idealistic tendencies of Western physicists (Camilleri 2009: 34–40).

transcendental method as follows: "[T]he transcendental method is the procedure according to which, assuming the reality of an object, one infers the conditions of its possibility." (Hartmann 1912: 125; my translation)

For the purposes of this paper, the most noteworthy aspects are the following ones: Starting from actual experience or a given body of knowledge, the purpose of the transcendental method is to work its way back to the *necessary conditions of the possibility* of that very experience or body of knowledge. To get a first feel for what this means, consider the following simple example: Under normal conditions, we are competent in distinguishing cases of veridical perception from cases of, say, daydreaming. However, to successfully distinguish the two, there must be an underlying concept of objectivity according to which coffee cups qualify as existing whereas fairies and pink elephants do not. While this underlying concept usually remains implicit in the normal course of events, it is the purpose of the transcendental method is to explicate it by unearthing the conditions that must necessarily obtain in order for an object to be experienced as a specific kind.

As already Kant himself saw, the scope of such a regressive analysis does not have to be restricted to the everyday discourse about coffee cups or other meso- and macroscopic objects. Nothing speaks against the application of the transcendental method to the realm of scientific theories and the knowledge that seems to be engrained in them. In line with what we have said so far, then,

> elaborating a transcendental epistemology of physics does not mean looking for hidden entities beyond empirical knowledge, but rather undertaking a reflective research about the indispensible [sic!] preconditions of our knowledge and their relevance to the structure of physical theories. (Bitbol, Kerszberg & Petitot 2009: 2)

Or, to put it in the words of Sunny Auyang:

> Until now almost all philosophical investigations of quantum theories have either taken the concept of objectivity for granted or prescribed it as some external criterion, according to which the theories are judged. […] I adopt the opposite approach. I start with the premise that quantum field theory conveys knowledge of the microscopic world and regard the general meaning of objects as a question whose answer lies within the theory. This work asks quantum field theory to demonstrate its own objectivity by extracting and articulating the general concept of objects it embodies. […] What general conditions hold for us and the world we are in so that objects, classical and quantum, which are knowable through observations and experiments, constitute reality? How is knowledge of the quantum world possible? These are part of what Kant asked: How is empirical knowledge in general possible? (Auyang 1995: 7)

Let's take stock: Transcendental analysis is, first, a *regressive* undertaking in which we start from actual experience or a given body of knowledge to then, second, unveil the *necessary conditions of the possibility* of this very experience or body of knowledge. Although this will be the basic notion of transcendentality with which I will operate in the following, three additional qualifications are in order.

The first qualification is epistemological in nature and concerns the fact that, on the transcendental view, there is much more to experience than the mere passive registering of raw external data. If by "experience" we mean minimally meaningful, epistemically relevant information about a target system, any such experience presupposes that the transcendental conditions (whatever they ultimately may turn out to be) must already be in place in order for this experience to occur.

The second qualification concerns the relationship between the level of concrete experience and the transcendental structures preceding it. Quine's seminal criticism of the "Cartesian paradigm" in epistemology notwithstanding (Quine 1969), defenders of transcendental philosophy typically hold what Cassam calls the *a prioriy* thesis (Cassam 2003: 183), i.e. the thesis according to which the transcendentally necessary conditions are not open to straightforward empirical investigation. This is typically seen as a strictly *logical* point: If *x* is a transcendentally necessary condition for experience *y*, then, on pain of self-defeat, we cannot rely on *y* to account for *x*. I will come back to this point in more detail in the next section.

The third qualification concerns the notion of necessity that is at play in "necessary conditions of the possibility". Starting from the conviction that Newtonian Mechanics represents the prime example of universal knowledge about the empirical world, Immanuel Kant sought to establish that Euclidean geometry, understood as the mathematical representation of the a priori structure of human intuition of space, can be seen as a strongly necessary—and thus unchanging—condition of the possibility of all human experience. When Euclidean geometry was finally replaced by non-Euclidean, Riemannian geometry as the mathematical backbone of general relativity theory in 1915, several philosophers saw this as a definitive blow against any form of transcendental philosophy. Moritz Schlick was among the most vocal proponents of this line of critique:

> Now along comes the general theory of relativity, and finds itself obliged to use non-Euclidean geometry in order to describe this same world. Through Einstein, therefore, what Riemann and Helmholtz claimed as a possibility has now become a reality, the Kantian position is untenable, and empiricist philosophy has gained one of its most brilliant triumphs. (Schlick 1979: 351)

This is not the place to comment on this questionable weaponization of relativity theory against transcendental philosophy (for a critical discussion cf., e.g., Ryckman 2005, 2017). What is important in the context of this paper is that, although modern developments in physics make it impossible to uphold Kant's original position in all its details, the overall program and methodology of transcendental philosophy can be easily adapted to the challenges of modern science. One such adaption, which is especially relevant in the context of this paper, concerns the replacement of Kant's exceedingly strong notion of necessity with the more liberal notion of *conditional necessity*. Consider, for instance, Bitbol's, Kerzberg's and Petitot's definition according to which

> certain constitutive principles are necessary under the *condition* that a certain practice of research is implemented. But practices may evolve and a new network of presuppositions maybe then become conditionally necessary. Then, surprising as it may seem, a set of constitutive principles can be *necessary* and *provisional* at the same time! (Bitbol, Kerszberg & Petitot 2009: 17)

Let us now, with these remarks as a backdrop, take a closer look at Niels Bohr's interpretation of quantum theory.

3. *Niels Bohr on the Necessary Conditions of the Possibility of Quantum Experience*

Among the many idealizations underlying classical physics, *non-disturbance* matters most in the context of this paper (Bohr 1961b; Berghofer, Goyal & Wiltsche 2021: 427-429). The basic idea is this: Although we know that actual measurements always involve some degree of interaction with the measured system, and thus unavoidably disturb it, in classical physics these actual measurements are treated as approximations to an *ideal* measurement that involves no interaction whatsoever, and thus does not disturb the measured system at all. Hence, whenever a physical system is disturbed during measurement—think of the hissing sound that occurs if you place the pressure gauge on the valve stem of your car tire—this disturbance is seen as a matter of mere technological realizability.

It is due to the non-disturbance assumption that, at least on a theoretical level, interactions between apparatus and target system can be neglected in classical physics. However, as Bohr emphasizes, "in quantum physics this interaction […] forms an inseparable part of the phenomenon" (Bohr 1958a: 4). The reason is the *quantum postulate*, i.e. Planck's discovery of the universal quantum of action $\hbar$ which, according to Bohr, forms the very essence of quantum theory (Bohr 1961c). $\hbar$ connects properties of particles (energy E and momentum p) to properties of waves (frequency f and wavelength λ) through the two equations

$$E = \hbar \cdot f$$

and

$$\lambda = \hbar / p.$$

From these equations it follows that, first, the value of physical properties like radiation or energy cannot come in infinitely small amounts but is always quantized. Second and *contra* non-disturbance, measurement interactions can never be neglected in quantum mechanics: Since the quantum of action is finite in size, any measurement interaction is at best of the same order of magnitude as the interactions it is supposed to measure. This, according to Bohr, has far-reaching epistemological consequences because "objective description can be achieved only by including in the account of the phenomena explicit reference to the experimental conditions, [which] emphasizes in a novel manner *the inseparability of knowledge and our possibilities of inquiry*" (Bohr 1958b: 12; my emphasis). Or, to put it in the words of Werner Heisenberg: "[W]hat we observe is not nature in itself, but nature exposed to our method of questioning." (Heisenberg 1958: 58)

It is important to emphasize the profound epistemological consequences that follow from these basic considerations. Consider, for instance, the following passage:

> [O]ne sometimes speaks of "disturbance of phenomena by observation" or "creation of physical attributes to atomic objects by measurements." Such phrases, however, are apt to cause confusion, since words like phenomena and observation, just as attributes

> and measurements, are here used in a way incompatible with common language and practical definition. (Bohr 1961a: 73)

I understand this passage as follows: Natural-language words like "observation," "attribute," "disturbance" or "creation" carry a multitude of ontological commitments originating from our experience in the everyday lifeworld. For example, if we say that we *disturb* a system through an act of measurement, the implicit assumption is that the system must have existed prior to the measurement. Likewise, if we say that we *create* a physical attribute through an act of measurement, we implicitly assume that the attribute did not exist prior to the measurement. Bohr's point is that the acknowledgment of the quantum postulate renders it impossible to continue describing quantum systems in this manner. Since, as we have seen, measurement interactions cannot be disentangled from the measured interactions, the information we get from our measurements are never about the quantum system *itself* but about the *interaction* between the quantum system and the measurement apparatus. Hence, instead of allowing everyday language to project a naïve ontology on quantum systems, we must accept that statements about these quantum systems *pre-observation* are, literally speaking, meaningless.

What we have discussed so far might be a lot to take in, especially for philosophers and physicists with realist leanings. However, even more perplexing to commentators was Bohr's repeated insistence "that the description of the experimental arrangement and the recording of observations must be given in plain language, suitably refined by the usual physical terminology" (Bohr 1958a: 3). What this means is that no matter how radically quantum theory deviates from classical physics, the language of the latter remains indispensable for communicating measurement outcomes and describing the experimental configuration. Or, as Bohr puts it in his famous *Rutherford Memorial Lecture*:

> [T]he mathematical formalism of quantum mechanics and electrodynamics merely offers rules of calculation for the deduction of expectations about observations obtained under well-defined experimental conditions *specified by classical physical concepts*. (Bohr 1958c: 60; my emphasis)

It is important to note that this is true in even in cases where we make the experimental configuration part of our quantum description. Even then,

> some ultimate measuring instruments, like the scales and clocks which determine the frame of space-time coordination – on which, in the last resort, even the definitions of momentum and energy rest – must always be described entirely on classical lines, *and consequently kept outside the system subject to quantum mechanical treatment*. (Bohr 1996a: 316; my emphasis)

There are two things to say about this passage. First, readers familiar with phenomenology will not help but be reminded of Husserl's remarks in the *Crisis of European Sciences* that, no matter how great the distance between science and lifeworld may seem to be, "that which ultimately grounds the theoretical-logical ontic validity for all objective verification, i.e. as the source of self-evidence, [are lifeworld objects like] visible measuring scales, scale markings etc., [and that these lifeworld objects] are used as actually existing things not as illusions" (Husserl 1970: 126).

Second, attention should be placed on the italicized portion of the quotation: For what Bohr is saying here is not only that the ultimate measuring device must be described classically. In effect, he makes the much stronger claim that *any* quantum mechanical description of reality must remain *incomplete* because it fails to incorporate the measurement configuration that is last in the observational chain. We shall return to this important point below.

As I have mentioned, Bohr's emphasis on the necessity to describe instruments classically has puzzled many commentators because it seems to confront us with two equally unattractive options (for further details, *cf*., Howard 1994, Zinkernagel 2016): One options is to commit to a two-world ontology in which reality is neatly divided into a microworld, ruled by quantum mechanics, and a macroworld world, behaving in accordance to classical physics. The alternative is to read Bohr along instrumentalist lines, thus advocating a strict form of epistemic agnosticism about the quantum world. There is no point in reexamining the myriad of scientific and philosophical reasons for the untenability of both these views. For the purposes of this discussion, it is sufficient to point out that Bohr did not endorse any of them. Regarding the idea of a two-world ontology, Bohr admits that,

> discriminating in each experimental arrangement between those parts of the physical system considered which are to be treated as measuring instruments and those which constitute the objects under investigation may indeed be said to form *a principal distinction between classical and quantum-mechanical description of physical phenomena*. (Bohr 1996b: 701)

However, Bohr is quick to add that this discrimination is "purely a matter of *practical* convenience" (Bohr 1996a: 316; my emphasis; Bohr 1996b: 701). This rules out the idea of a sharp *ontological* rift between quantum and macro world: How can the distinction between classical and quantum be practical in nature if physical reality is also said to be divided into two fundamentally different regions?

The situation is similar concerning the attempt to read Bohr along instrumentalist lines. If Bohr was an instrumentalist, then, depending on whether his instrumentalism had a more operationalist or a more constructive-empiricist flavor, he would either deny that propositions about the quantum realm have truth values at all, or he would claim that we can never have reasons to believe or disbelieve any such propositions. However, although, as we shall see, Bohr rejected the idea that theories and models are representational vehicles whose purpose it is to mirror a theory-independent reality, he was not agnostic about quantum reality either. For example, as Bohr's assistant Aage Petersen reports, Bohr was convinced that quantum mechanics contains an entire epistemology that ultimately "concerns what we can *say* about nature" (Bohr, quoted in Petersen 1963: 12). As we will explore in greater detail below, this extends well beyond the confines of classical instrumentalism.

Confronted with the deadlock posed by two equally unappealing options, a transcendental interpretation of Bohr finally emerges as a viable third alternative. The basic thrust of such an interpretation is described by Michel Bitbol as follows:

> [J]ust as Kant did, Bohr undertook a reflective analysis of the generic structure of our capabilities to know. However, unlike Kant, Bohr distanced himself from a study of mental faculties such as sensibility and understanding. He rather focused on a technological counterpart of sensibility, namely, the measuring apparatus, and on an

> intersubjective counterpart of understanding, which is common language. (Bitbol 2017: 52)

According to this transcendental reading, then, the basic idea behind Bohr's position is that the measurement setup and common language are to be understood as *transcendentally necessary conditions of the possibility of quantum experience*. This has several far-reaching consequences, as we shall see now.

First, and this relates to an issue I have already addressed in this section and the section before, it follows very naturally from such a transcendental reading that there cannot, in principle, be any meaningful *pre-measurement* discourse about quantum systems. The reason is this: If the measurement instrument together with the whole experimental setup enjoys the status of a transcendentally necessary condition of the possibility of quantum experience, then it is logically fallacious to talk about quantum nature *independently from any measurement device*. The fallacy is similar to the circularity involved in trying to prove the axioms of Euclidean geometry within the system of Euclidean geometry. Any attempt to do so only shows that one has not understood basic concepts such as "axiom," "logical relation" or "proof". Note that this way to look at things also aligns neatly with other parts of Bohr's position, such as his conception of the term "phenomenon": Bohr insists that "the word *phenomenon* [is limited] to refer exclusively to observations obtained under specified circumstances, including an account of the whole experiment." (Bohr 1948: 317) Insofar as physics is concerned with a systematic description of phenomena, any attempt to refer to quantum systems pre-measurement and thus independently of the experimental arrangements exceeds the boundaries of meaningful physical discourse.

Second, if the measurement apparatus, together with the whole experimental setup, has the status of a transcendentally necessary condition of the possibility of quantum experience, then the fact that apparatus and setup must be described classically does not have any *ontological* implications, thus ruling out the misguided idea of a two-world ontology. Bitbol and Osnaghi express this point very succinctly:

> By stipulating that we should use the classical mode of description to account for the measuring instruments, the measurement outcomes, and the experimental procedures, Bohr seems to grant them a sort of "extraterritorial status". It is important to realize, however, that Bohr's prescription in no way presupposes or implies an ontological distinction between macroscopic and microscopic systems. There is nothing in the *physical* nature of macroscopic objects that distinguishes them from the microscopic ones, and which rules out the possibility of describing them as quantum systems. Bohr's concern is rather to emphasize the specific *function* that the measuring apparatuses accomplish in the system of knowledge; that of ensuring the intersubjective agreement about experimental results and procedures, thereby fulfilling a condition of the possibility of objective experience. (Bitbol & Osnaghi 2013: 152–153)

Returning to the classical Kantian understanding of the transcendental as "knowledge which is occupied not so much with objects as with the *mode* of our knowledge of objects" (Kant 1965: A11/B25; my emphasis), it becomes immediately clear why this transcendental reading is indeed a viable solution of the problems associated with Bohr's classical/quantum divide. As Bitbol and Osnaghi suggest, the measurement apparatus has an "extraterritorial status" only in the sense of it being a transcendentally necessary condition for the possibility of experiencing quantum phenomena. This means that we must chose a different theoretical framework for the description of the measurement apparatus *not* for *ontological*, but for *purely logical* reasons. Having said this, the resulting view does not qualify as instrumentalism either because getting clear about the relation between measurement apparatus and quantum experience is itself a necessary condition for understanding "what we can *say* about nature" (Bohr, quoted in Petersen 1963: 12). As these considerations show, Bohr's position indeed turns out to be too sophisticated for the somewhat simplistic dichotomy between epistemic agnosticism and ontological dualism.

Third, and closely related to the previous point, a transcendental interpretation can account for the fact that the introduction of a classically describable measuring apparatus is necessary for quantum experience while it is at the same time "a matter of practical convenience" (Bohr 1996b: 701) where exactly the cut between quantum and classical description is made. Generally speaking, the scope of quantum mechanics is unrestricted in the sense that *everything* can be made the object of quantum-mechanical description. At the same time, however, a measurement instrument must be introduced *at some point* in order to make quantum experience possible in the first place. But since, as the previous logical considerations have shown, this ultimate measurement instrument cannot be described quantum-mechanically, quantum mechanics, although unrestricted in its scope, must always and necessarily remain incomplete. The same point has also been made by Asher Peres and Wojciech Zurek:

> [A]lthough quantum theory is universal, it is not *closed*. Anything can be described in it, but something must remain unanalyzed. […] [A]lthough it can describe *anything*, a quantum description cannot include *everything*. (Peres & Zurek 1982: 810)

4. *Problems with the Transcendental Reading of Bohr*

What should we think of the transcendental reading of Bohr? Quite generally, I agree with those commentators who find it impossible to overlook the distinctly Kantian tone in many of Bohr's writings (Honner 1982, Kaiser 1992, Chevalley 1994, Hooker 1994, Cuffaro 2010, Bitbol & Osnaghi 2013, Bitbol 2017). Bohr's restriction of the term "phenomenon" to that which appears under classically describable experimental conditions (Bohr 1948: 317), his limitation of quantum physics to "what we can *say* about nature" (Bohr, quoted in Petersen 1963: 12), his self-understanding of helping "to clarify the conditions, in each field of knowledge, for the analysis and synthesis of experience" (Bohr 1949: 236), his rejection of any "sharp separation between object and subject" (Bohr 1961c: 96) or his frequent references to "measuring instruments [as the] conditions under which the phenomena appear" (Bohr 1949: 246) all have a clear Kantian ring to them. Furthermore, as I have tried to argue in the previous section, a transcendental reading is the most natural solution for some of the problems that were traditionally associated with Bohr's position. For instance, while an ontological as well as an instrumentalist reading of the classical/quantum-distinction are fraught with difficulties, a transcendental interpretation brings Bohr's own statements on the topic into a coherent whole.

One could also make the case that interpreting Bohr in a transcendental light offers the unique benefit of incorporating a Kantian epistemology, without committing to the focus on mental faculties that is usually associated with Kant's philosophy. What I mean is this: On the one hand, Bohrian transcendentalism tells a story about the nature of quantum experience that is both in line with the relevant physics and significantly more sophisticated than the construal of observation as just the passive registering of raw external data. Yet, at the same time, Bohr seems to omit every reference to consciousness or subjectivity. This is because, as we have seen, the original Kantian emphasis on mental faculties is replaced by Bohr with a focus on impersonal measurement devices and common language. This exclusion of subjectivity could be perceived as progress, particularly in the eyes of those who believe that for a theory to be well-behaved, it must be devoid of any subjective elements. We will revisit this point in more detail below.

Despite the aforementioned points, however, it is important to note that Bohr's interpretation of transcendentalism is not without its challenges. To understand the issue, let us begin by revisiting, once again, why the ultimate measurement apparatus must be considered a transcendentally necessary condition of the possibility for quantum experience. Building on the insight that "transcendental argumentation is essentially counterfactual" (Kannisto 2020: 150), the answer is that the ultimate measurement apparatus enjoys this privileged status because without it, *there simply wouldn't be any quantum experience in the first place*. This is, as we have said, also the reason why the ultimate measurement apparatus evades the quantum mechanical description and must thus be accounted for in classical terms.[2] However, the problem with this line of argument is that, if the criterion for identifying a transcendentally necessary condition for the possibility of quantum experience is an essentially counterfactual one, *then many more things than just measuring apparatuses and common language should count as transcendentally necessary*. Let me give a concrete example to illustrate what I mean.

Assume that Audrey goes to the laboratory to perform a double-slit experiment. To do so, she must prepare the experimental arrangement in a particular way, namely by directing a laser at two closely spaced slits and by preparing a photomultiplier tube behind the barrier. When Audrey finally observers the characteristic quantum phenomenon, then, according to Bohrian transcendentalism, the measuring apparatus enjoys the special status of a transcendentally necessary condition of this quantum experience. The reason is, as we have heard, that without the measuring apparatus, there would not be the characteristic interference pattern of light and dark stripes for Audrey to experience. The problem is, however, that what seems true of the laser, the barrier and the photomultiplier tube is arguably also true of a myriad of other background conditions. Consider, for instance, the background condition that the lab in which the experiment is performed must be filled with enough air. The counterfactual criterion seems to apply to this case as well: If there wasn't enough air in the lab, it would not be possible for Audrey to experience the characteristic interference pattern of light and dark stripes. Yet, if this much is admitted, an obvious

[2] On closer inspection, this is not quite true. While it is a consequence of the status of the apparatus as a transcendentally necessary condition of the possibility of quantum experience that the apparatus cannot be described in the language of quantum mechanics, it does not follow that the apparatus must be described *classically*. According to Hooker, it is another transcendental argument through which the language of classical physics is designated as being privileged in this respect (Hooker 1994: 176).

question arises: If we grant measurement apparatuses a special status because of the counterfactual argument that there wouldn't be any quantum experience without these apparatuses, aren't we, in light of this criterion, also forced to grant air molecules the status of transcendentally necessary conditions of the possibility of quantum experience? And, building on what has been said before, wouldn't this also imply that, according to Bohrian transcendentalism, oxygen cannot be described quantum-mechanically but only classically? I take it that even the most devoted proponents of Bohrian transcendentalism will agree that these consequences are inacceptable.

Certainly, there are potential rebuttals to this challenge. One could argue that my reasoning subtly introduces a human observer into a narrative that is explicitly designed to avoid any direct references to subjectivity. Once we distinguish more sharply between quantum *phenomena* and quantum *experience*, my argument could be defused by emphasizing that, although there wouldn't be any quantum *experience* for *human observers* in the absence of oxygen, the quantum *phenomenon* of a characteristic interference pattern would still occur.[3] However, it is crucial to understand that while this rebuttal may address the specific case of air molecules, the broader challenge still persists. This is because there are myriads of other background conditions which are not connected to human observers in any obvious way but which, in light of the counterfactual criterion from before, should be granted the status of transcendentally necessary conditions. For instance, regardless of the existence of oxygen, there wouldn't be any characteristic interference pattern if the laboratory for the two-slit experiment was not located on a rocky planet but on a gas planet instead. Just like before, granting the location on a rocky planet the status of a transcendentally necessary condition of the possibility for quantum experience seems inacceptable yet still inevitable.

The challenge that I am presenting can be summarized as follows: Solely relying on counterfactual reasoning makes it impossible to differentiate between the transcendentally necessary conditions for quantum experience and epistemically irrelevant background conditions. Or, to put it differently: While it seems obvious that the experimental setup through which quantum phenomena are revealed and enough oxygen in the lab are, epistemically speaking, not on par, the Bohrian framework appears to fall short in distinguishing the epistemic difference between the two. When confronted with this issue, an advocate of Bohrian transcendentalism might propose two additional strategies: The first strategy is to assert that a distinction between epistemically significant and purely incidental background conditions can be made by simply depending on the relevant physics itself. An argument to this effect could run as follows: It is indeed accurate to say that any given event is, in some way, causally linked to everything else in the event's past light cone. However, whether a particular condition just happens to be in an event's past light cone or is necessary for the possibility of the event's occurrence is a *scientific* matter that can only be decided by looking at the relevant theory, in our case quantum mechanics itself.

Although this argument may sound convincing at first glance, its untenability becomes apparent once we remind ourselves of the reasons for Bohr's insistence that the ultimate measuring apparatus must be "kept outside the system subject to quantum mechanical treatment" (Bohr 1996a: 316). As I have explained, the only reasonable

[3] One could add that, as a matter of fact, the experiment would even lead to cleaner interference patterns if performed in a vacuum because there would be fewer sources of disruption.

construal is to view this as a version of the "a priority thesis" according to which the transcendentally necessary conditions cannot be analyzed within the very framework for which they are constitutive. Or, to put it differently: If *x* is a transcendentally necessary condition for *y*, then, on pain of self-defeat, we cannot rely on *y* to account for *x*. However, if we were to depend on quantum mechanics to identify the conditions that are transcendentally necessary for the possibility of quantum experience, then we would be self-defeating in exactly this way: We would commit the fallacy of analyzing the transcendentally necessary conditions within the very framework for which they are constitutive. Given that this would compromise the transcendental nature of Bohr's overall stance, I do not view this as a viable solution to the current problem.

An advocate of the Bohrian position might employ another strategy, which involves highlighting the interpretation of "necessity" in contemporary versions of transcendentalism. As previously noted, modern transcendentalists typically use a concept of *conditional necessity* according to which "certain constitutive principles are necessary, *provided that a specific research practice is implemented*" (Bitbol, Kerszberg & Petitot 2009: 17; my emphasis). Building on this construal of necessity as being dependent on specific research practices, one could argue as follows: Whether *x* is a transcendentally necessary condition of the possibility for *y* depends on whether *x* is part of a distinctive research practice that must be carried out to achieve a particular epistemic end which is relevant for *y*. Reflecting on the previous example, we would thus arrive at the following conclusion: While the arrangement of lasers, barriers, and photomultiplier tubes forms part of a research practice aimed at a specific epistemic end, factors such as having sufficient air in the lab or being situated on a rocky planet do not.

Yet, I am doubtful of the viability of this strategy. My worry, in a nutshell, is that, by tethering the concept of necessity to research practices aimed at specific epistemic goals, one effectively reincorporates an epistemic agent into the interpretation of quantum mechanics. Although I will suggest in the ensuing section that this is indeed the most promising strategy, I remain unconvinced that it is a viable choice for those wishing to adhere faithfully to the original Bohrian program. The reason is that, *pace* Bitbol (2017; Bitbol & Osnaghi 2013), I agree with the majority of commentators that "anyone who reads Bohr carefully can see that his references to 'the observer' refer to the observer qua physical system, not qua consciousness," (Faye & Folse 2017: 5), or that, as Howard puts it, "Bohr was always careful to physicalize the 'observer'" (Howard 2004: 671). This seems to align with Bohr's understanding of objectivity as that which remains after "eliminating subjective elements" (Bohr 1961a: 70), his claim that "[t]he description of atomic phenomena has […] a perfectly objective character, in the sense that no explicit reference is made to any individual observer" (Bohr 1958a: 3), or his emphasis that "the notion of an ultimate subject […] find[s] no place in an objective description as we defined it" (Bohr 1961a: 79). Hence, my challenge for the transcendental interpretation of Bohr stands: While it seems obvious that the experimental setup through which quantum phenomena are revealed and enough oxygen in the lab are, epistemically speaking, not on par, the Bohrian framework appears to fall short in distinguishing the epistemic difference between the two.

5. *Concluding Remarks: Phenomenology to the Rescue!*

In the preceding sections, my objective was dual-pronged: On the one hand, I have put forth arguments suggesting that a transcendental interpretation of Bohr holds considerable merit. Not only do numerous remarks of his have a distinct Kantian undertone. A transcendental reading of his work also emerges as the most natural resolution to some of the challenges traditionally linked with Bohr's stance. Yet, as I have also argued, Bohrian transcendentalism ultimately falls short due to its inability to differentiate between transcendentally necessary conditions of the possibility of quantum experience and merely contingent background conditions. The reason is, as I have showed, Bohr's understanding of how transcendentally necessary conditions are to be identified: His counterfactual criterion is overly permissive, failing to isolate the conditions that are not just contingently the case but also epistemically relevant for quantum experience. Although this problem could potentially be addressed by considering the epistemic goals associated with specific research practices, such a strategy is at odds with Bohr's insistence on omitting any reference to conscious subjects in our interpretation of quantum physics.

Before proposing a solution to this dilemma, I would like to briefly discuss the reasons for the still widespread belief that the systematic exclusion of subjectivity and consciousness is an essential requirement for any reasonable interpretation of quantum mechanics. While a detailed discussion would be too extensive for the focus of this paper (*cf.*, for details, French 2023: chapters 2 and 3), it is safe to say that the common reluctance to refer to consciousness in debates about quantum mechanics is largely due to the controversial history of the so-called "consciousness causes collapse"-interpretation. This viewpoint is commonly summarized as follows: In addressing the measurement problem, which is to explain how the wave function collapses from superposition to a single measured value upon measurement,[4] *consciousness* is posited as the cause for this collapse. The origin of this view is often attributed to John von Neumann who, in his monumental *The Mathematical Foundations of Quantum Mechanics*, introduced a distinction between three regions, "I […] the system actually observed, II the measuring instrument, and III the actual observer." The fact that von Neumann referred to III in terms of an "abstract 'ego' [which] remains *outside* of the calculation" (von Neumann 2018: 273; my emphasis) led many to believe that, on his view, it is non-material consciousness that causes the wave function to collapse.

While it has been shown that the views of not only von Neumann but also Eugene Wigner were significantly more nuanced than this caricature (see French 2023: chapters 2 and 3), the proposition that non-physical consciousness somehow induces

[4] To better understand the measurement problem, it is helpful to revisit the two seemingly contradictory principles at the core of quantum mechanics. Firstly, we have the Schrödinger equation, which describes the temporal evolution of the quantum state. The Schrödinger equation is is unitary, deterministic, and linear, and its linearity implies that two solutions can be combined to form another solution. This, then, is the principle of *quantum superposition* that highlights the wave character of quantum objects. The quantum state of a system is described by its wave function. The superposition principle entails that wave functions can be added together, thus forming a new wave function. Essentially, this principle suggests that prior to measurement, quantum systems appear capable of existing in multiple states simultaneously. However, secondly, we have the *collapse principle* which posits that upon measurement, the wave function collapses from a superposition state to a single definite value. The apparent necessity of this principle arises not so much from theoretical deliberations but from our empirical observation that we never detect superposition states but only definite values. For example, when measuring an electron's spin, we always observe either spin-up or spin-down, never both. The challenge at the heart of the measurement problem is understanding this apparent collapse of the wave function.

the collapse of the wave function has been the target of severe criticism. Specifically, it was Hilary Putnam (1961; 1981) and Abner Shimony (1963) who highlighted the utter mysteriousness of the notion that something non-physical could cause dramatic changes in the states of physical systems. Due to these criticisms, which received much attention in "mainstream" discourse, any position affirmatively mentioning conscious observers became a non-starter in philosophy of quantum mechanics. My contention is that it is this mindset in the light of which a transcendental interpretation of Bohr could indeed be seen as the best of two worlds: It offers the epistemological sophistication typically associated with different forms of (neo-)Kantianism. At the same time, however, Bohr's transcendentalism avoids any direct reference to subjectivity or consciousness, and thus steers clear of strong metaphysical assumptions such as mind/body dualism.

What we have seen in recent years, however, are several attempts to present *phenomenology* as an alternative framework for discussing the relationship between consciousness and quantum mechanics. One of the advantages of such phenomenological frameworks is that, while placing consciousness at the center of attention, they circumvent the well-known counterarguments against the "consciousness causes collapse" view. Consequently, as I will argue, they could also potentially serve as a solution to the previously mentioned challenges associated with the Bohrian stance. In what follows, I want to briefly mention one such proposal, namely the London and Bauer approach to the measurement problem.

Fritz London's and Edmond Bauer's short 1939 monograph *La Theorie de l'Observation en Mecanique Quantique* was driven by two main objectives. First, it aimed to offer a "concise and simple" (London & Bauer 1983: 219) elucidation of the measurement problem in the spirit of von Neumann's approach. Second, it sought to illuminate the relationship between the observer and the observed system in quantum mechanics. Although London and Bauer's work was well-known in physics circles, its phenomenological dimension largely went unnoticed until it was brought to light in a series of recent publications by Steven French (French 2002, 2020, 2023).[5] The essence of their account can be summarized as follows (cf., also, Berghofer & Wiltsche 2024): London and Bauer begin by asserting that "[a] measurement is achieved only when the [measurement outcome] has been *observed*" (London & Bauer 1983: 251). This is to say that, on their view, a measurement is only completed if a conscious observer has registered the outcome of a measurement, for instance by observing the position of a pointer. Furthermore, it is characteristic of London's and Bauer's account to "consider the ensemble of three systems, (*object x*) + (*apparatus y*) + (*observer z*), as a combined and unique system [which will be described] by a global wave function" (London & Bauer 1983: 251). All technicalities aside, what this clearly shows is that nothing in

[5] Fritz London, while largely unrecognized in philosophical circles, is an extraordinary figure who, like many physicists of his era, blurred the lines between philosophy and physics. His nomination for the Nobel Prize in chemistry four times and once for the Nobel Prize in physics attests to the wide-ranging impact and significance of his work. Interestingly, however, London began his academic career in philosophy, completing his first doctoral dissertation titled "Über die Bedingungen der Möglichkeit einer deduktiven Theorie" under the guidance of Munich phenomenologist Alexander Pfänder. Published in Husserl's *Jahrbuch für Philosophie und Phänomenologische Forschung* in 1923, London's dissertation was characterized as "a set theoretic concretization of Husserl's largely programmatic account of a macrological philosophy of science" (Mormann 1991: 70). For a comprehensive understanding of London's connection to phenomenology, refer to French's authoritative exploration on the subject (French 2023).

London and Bauer's account suggests the existence of a non-physical consciousness that externally influences physical systems, mysteriously triggering the collapse of the wave function. The very point of their interpretation is rather "that the formalism of quantum mechanics already implies a well-defined theory of the relationship between the object and the observer, a relation quite different from that implicit in naïve realism, which had seemed, until [recently], one of the indispensable foundation stones of every science" (London & Bauer 1983: 220).

Instead of placing consciousness outside the realm of quantum description, London and Bauer construe of the wave function as the mathematical description *of an interrelated system of object, apparatus, and observer*. However, what makes their account truly phenomenological is London's and Bauer's emphasis of the status of the observer who "has *with himself* relations of a special character" (London & Bauer 1983, 252). These relations are described as

> a characteristic and quite familiar faculty which we can call the "faculty of introspection." [The observer] can keep track from moment to moment of his own state. By virtue of this "immanent knowledge" he attributes to himself the right to create his own objectivity—that is, to cut the chain of statistical correlations summarized in $\sum_k \psi_k u_k(x) v_k(y) w_k(z)$ by declaring "I am in the state w_k" or more simply, "I see $G = g_k$," or even directly, "$F = f_k$". (London & Bauer 1983: 252)

What sets the observer apart from the other components of the system is her ability to direct her attention to her own states. While the term "introspection" may be contentious in this context, those acquainted with phenomenology will recognize that London and Bauer are introducing here the familiar phenomenological distinction between the straightforwardly object-directed attitude of lived experience and the attitude of reflection. It is through reflection on her own state that "the observer establishes his own framework of objectivity and acquires a new piece of information about the object in question" (London & Bauer 1983, 252). Thus, consciousness is not privileged in quantum mechanics because it somehow magically causes the wave function to collapse. Instead, what distinguishes conscious observers is their ability to separate themselves from the wave function through acts of reflection. Here is how London and Bauer express this point:

> [I]t is not a mysterious interaction between the apparatus and the object that produces a new ψ for the system during the measurement. It is only the consciousness of an "I" who can separate himself from the former function $\psi(x, y, z)$ and, by virtue of his observation, *set up a new objectivity* in attributing to the object henceforward a new function $\psi(x) = u_k(x)$. (London & Bauer 1983: 252)

The extent of London and Bauer's indebtedness to phenomenology not only becomes evident through their direct reference to Husserl who is praised to have "systematically studied such questions [questions regarding the necessary and sufficient conditions for an object of thought to possess objectivity; H.W.] and has thus created a new method of investigation called 'Phenomenology'" (London & Bauer 1983: 259). As French observes (French 2002: 484), the close connection to phenomenology is even more obvious in the original text where what is translated here as "set up a new objectivity" reads "*constituer une nouvelle objectivité*". Hence, what London and Bauer are effectively saying is that the conscious I *constitutes* a new objectivity by stepping out of the stream of lived experience and directing an act of reflection on this stream. This shift of attitude, then, is what we perceive as the so-called "collapse" of superposition into a single outcome.

An exhaustive analysis of London and Bauer's interpretation of the measurement problem would exceed the scope of this paper. However, it is worth mentioning it in this context because it shows that there are ways to discuss the relationship between consciousness and quantum mechanics that avoid the pitfalls typically associated with "consciousness causes collapse" interpretations. Should my assertion hold true that the issues with Bohrian transcendentalism originate from his neglect of consciousness and subjectivity, then phenomenology might just be the missing element needed to fulfil Bohr's original vision. Undoubtedly, further work is required to concretely illustrate what this would entail. However, while the endeavor to incorporate Bohr's insights into a broader phenomenological framework seems enticing, it warrants a separate paper for a comprehensive discussion.

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