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Niels Bohr as philosopher of experiment: Does decoherence theory challenge Bohr's doctrine of classical concepts?

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ABSTRACT

Niels Bohr's doctrine of the primacy of "classical concepts" is arguably his most criticized and misunderstood view. We present a new, careful historical analysis that makes clear that Bohr's doctrine was primarily an epistemological thesis, derived from his understanding of the functional role of experiment. A hitherto largely overlooked disagreement between Bohr and Heisenberg about the movability of the "cut" between measuring apparatus and observed quantum system supports the view that, for Bohr, such a cut did not originate in dynamical (ontological) considerations, but rather in functional (epistemological) considerations. As such, both the motivation and the target of Bohr's doctrine of classical concepts are of a fundamentally different nature than what is understood as the dynamical problem of the quantum-to-classical transition. Our analysis suggests that, contrary to claims often found in the literature, Bohr's doctrine is not, and cannot be, at odds with proposed solutions to the dynamical problem of the quantum–classical transition that were pursued by several of Bohr's followers and culminated in the development of decoherence theory.

1. Introduction

In spite of the attention Bohr's writings have received over the last three decades, scholarly opinion on how we should understand his philosophy remains divided (Brock, 2003; Favrholdt, 1992; Faye, 1991; Faye & Folse, 1994; Folse, 1985; Honner, 1987; Katsumori, 2011; Murdoch, 1987; Plotnitsky, 1994, 2006). Much confusion still reigns over how we should understand Bohr's repeated insistence that we *must* use classical concepts. This situation is all the more lamentable, given that, as Don Howard has rightly noted, "the doctrine of classical concepts turns out to be more fundamental to Bohr's philosophy of physics than are better-known doctrines, like complementarity" (Howard, 1994, p. 202). Scholars have long pondered over precisely why Bohr felt that classical concepts should play such a primary role in quantum physics. In perhaps his most frequently quoted account of the doctrine, in his contribution to the 1949 Einstein *Festschrift*, Bohr declared:

> It is decisive to recognize that, *however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms.* The argument is simply that by the word "experiment" we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangement and of the results of the observations must be expressed in unambiguous language with suitable application of the terminology of classical physics (Bohr, 1949, p. 209).

One can find this view, or at least anticipations of it, in Bohr's writings during the 1920s, but by the 1930s it came to occupy a central place in Bohr's epistemological reflections on quantum mechanics. Indeed Bohr was remarkably categorical about this point. As he was to put it in a lecture in the early 1930s: "The unambiguous interpretation of any measurement *must* be essentially framed in terms of classical physical theories, and we may say that in the sense the language of Newton and Maxwell will remain the language of physics for all time" (Bohr, 1931, p. 692, emphasis added).

Over time a number of criticisms have been raised against these views of Bohr's. Most recently, spurred by the insights brought about the decoherence program (Bacciagaluppi, 2012;

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Joos et al., 2003; Schlosshauer, 2004, 2007; Zeh, 1970; Zurek, 1981, 1982, 2003), a number of physicists have suggested that Bohr's musings about the primacy of classical concepts, and by extension his doctrine of an (ostensibly) fundamental quantum–classical divide, amount to little more than superfluous semantic or philosophical baggage, much of which has been discredited by recent developments. Dieter Zeh, for example, has contrasted the dynamical approach of decoherence with the "irrationalism" of the Copenhagen school (Joos et al., 2003, p. 27). Erich Joos, who attributes the origins of decoherence to a dissatisfaction with the "orthodoxy of the Copenhagen school" and "the desire to achieve a better understanding of the quantum–classical relation" (Joos, 2006, p. 54), has argued that "the message of decoherence" is that "we do not need to take classical notions as the starting point for physics," given that "these emerge through the dynamical process of decoherence from the quantum substrate" (Joos, 2006, p. 77).

In this paper, we will take such claims and characterizations as our motivation for pursuing a careful historical and philosophical investigation of Bohr's views regarding his doctrine of classical concepts and the problem of the quantum–classical relationship. We will also analyze how these views relate to what we will call the "dynamical" approaches to the problem of the quantum-to-classical transition, approaches that include the theory of decoherence. As we shall see, decoherence is only the last step in a long line of attempts to undergird (or supplant) Bohr's doctrines by an explicit dynamical and physical account. Such approaches were already pursued by a number of Bohr's followers—notably Weizsäcker and Rosenfeld—in the 1960s, who, far from seeing it as an invalidation of Bohr's basic insight, regarded it as providing a justification of his views.

In this paper, we raise and address two central questions. The first question is why, and in what sense, Bohr believed that classical concepts were indispensable in the description of experiments. Given the large degree of scholarly dispute and confusion about the exact meaning of Bohr's writings and his views, this requires that we pay careful attention to Bohr's texts. Here we echo Don Howard's call "to return to Bohr's own words, filtered through no preconceived dogmas" (Howard, 1994, p. 201). In particular, we need to disentangle Bohr's views from those of his contemporaries who professed to speak on his behalf. Much of the confusion over Bohr's philosophy has resulted from a mistaken tendency to assume that Bohr's views formed the central plank in a unified and widely shared viewpoint commonly known as the "Copenhagen interpretation." Yet extensive historical scholarship over the past 30 years has challenged, if not seriously undermined, the notion that any such consensus among the founders of quantum mechanics ever existed.[1]

Further complicating matters is the notoriously vague and imprecise use of the term "classical" in much of the literature. This term is frequently employed to refer variously to concepts, dynamical properties, phenomena, laws, or theories, without regard for the subtle but important distinctions. While Bohr often left it to his readers to decipher the precise meaning of ambiguous phrases such as "classical description," in his more deliberate moments he did take care to distinguish between the use of *classical concepts* (such as position and momentum) and *classical dynamical theories*. In his reply to the EPR paper, for example, Bohr emphasized the necessity of using "classical *concepts* in the interpretation of all proper measurements, even though the classical *theories* do not suffice in accounting for the new types of regularities with which we are concerned in atomic physics" (Bohr, 1935, p. 701, emphasis added). Bohr was also careful to distinguish between our use of classical terminology and the dynamical properties of quantum objects. As he recognized, objects like electrons simply do not possess "such inherent attributes as the idealizations of classical physics would ascribe to the object" (Bohr, 1937, p. 293). Yet, Bohr repeatedly emphasized that we are simply forced to use the conceptual vocabulary of classical physics, albeit within certain limits of applicability, in describing experiments on quantum objects. Put simply, whenever we speak of an indeterminacy of an electron's *position* or *momentum*, we invariably fall back on the use of classical concepts. It was in this sense that Bohr used expressions such as "the terminology of classical physics" or the "framework of classical physical ideas."

The interpretation of Bohr's doctrine we present in this paper differs in many crucial respects from those that can be found in the extensive literature on Bohr. There is now consensus among Bohr scholars that his doctrine of classical concepts should be understood epistemologically. However, there is still widespread disagreement on what epistemological position Bohr held. Much of the recent literature has attempted to make sense of Bohr's views either by situating them in the context of a particular philosophical tradition, such as positivism or Kantianism, or alternatively by trying to reconstruct from Bohr's writings, a position vis-à-vis the contemporary realism debates.[2] As Henry Folse rightly points out, while it is true that Bohr's "description of phenomenal objects has a certain Kant-like appearance," such an appearance is deceptive, given that complementarity has nothing to do with "how experiences phenomena arise in the subject's consciousness" (Folse, 1985, p. 219). If we are to understand what was distinctive about Bohr's view, we cannot simply say it was grounded in an epistemological view of the primacy of classical language—rather we must ask what Bohr saw as the fundamental "task of epistemology." While the attempts to characterize Bohr's view with relation to different strands of realism and antirealism have led to many important insights, and have happily led to a far more nuanced view of his philosophy than the positivist image that prevailed in the 1960s, such attempts have often inadvertently obscured Bohr's "epistemological lesson." In responding to the challenge of the EPR paper, Bohr was, of course, forced to confront issues concerning the "completeness of quantum mechanics," but his doctrine of classical concepts, as we stress below, was not motivated by the problem of how to interpret the quantum-mechanical formalism. Bohr's primary concern was to articulate an epistemology of experiment, not an epistemology of quantum

[1] As Catherine Chevalley points out, "what makes Bohr so difficult to read is the fact that his views were identified with the so-called *'Copenhagen Interpretation of Quantum Mechanics,'* when such a thing emerged as a frame for philosophical discussion only in the mid-1950s" (Chevalley, 1999, p. 59). We must be clear that the term "Copenhagen interpretation," as it is commonly used, refers to a range of different physical and philosophical perspectives that emerged in the decades following the establishment of quantum mechanics in the late 1920s. As Jammer points out in his *Philosophy of Quantum Mechanics*: "The Copenhagen interpretation is not a single, clear-cut, unambiguously defined set of ideas but rather a common denominator for a variety of related viewpoints. Nor is it necessarily linked with a specific philosophical or ideological position" (Jammer, 1974, p. 87). Indeed the very idea of a unitary interpretation only seems to have emerged in the 1950s in the context of the challenge of Soviet Marxist critique of quantum mechanics, and in the defense of Bohr's views, albeit from different epistemological standpoints, by Heisenberg and Rosenfeld (Camilleri, 2009a; Chevalley, 1999; Howard, 2004).

[2] The contributions by Favrholdt, Fay, Folse, Krips, McKinnon in the 1994 volume on Bohr all focus on the extent to which Bohr's views depart from a realist interpretation of the theory of quantum mechanics (Faye & Folse, 1994; see also Faye, 1991; Folse, 1985). Murdoch, for example, has construed Bohr's disagreement with Einstein fundamentally as a debate about the realist interpretation of quantum mechanics (Murdoch, 1987, p. 236). There have been a number of efforts to draw comparisons between Bohr's views and Kantian epistemology (Bitbol, 2013; Cuffaro, 2010; Folse, 1985, pp. 217–221; Honner, 1982; Kaiser, 1992; Murdoch, 1987, pp. 229–231). More recently there have been renewed efforts to make sense of Bohr's writings by situating them in the Helmholtzian tradition of theoretical physics, or to read them through the lens of philosophical traditions such as hermeneutics and deconstruction (Brock, 2003; Katsumori, 2011; Plotnitsky, 1994).