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BOOK REVIEW

J. Faye & H.J. Folse (eds.), *Niels Bohr and the Philosophy of Physics. Twenty-First Century Perspectives*, London: Bloomsbury Academic, 2017, 384 pp., US$114.00 (hardback). ISBN 9781350035126.

This book comes twenty years after Faye and Folse's (1994) seminal book on the same topic. Many scholars who contributed to the original volume have also written in this one; however, this collection also includes many new authors. The original argument is still intriguing. As neither of us are Bohr scholars, in this review we will address theoretical, rather than historical, questions regarding Bohr's philosophy.

It is well known that Bohr's life-long reflection on the foundation of quantum mechanics is not easy to interpret, because the Danish physicist sometimes changes perspectives and also because he uses obscure language. This obscurity was not voluntarily chosen by Bohr, but is due, rather, to the complexity of the subject matter; nevertheless, Bohr's ambiguity favoured even heavily biased misinterpretations.[1]

For friends of scientific realism Bohr's thinking leads in the wrong direction. Indeed, Bohr's philosophy has been interpreted as a form of neo-positivism, as a type of neo-Kantianism, and as a kind of pragmatism. Probably all of these points of view are in part historically unsuitable, but they share a common feature: anti-realism. According to neo-positivism, science concerns only data; according to neo-Kantianism, the structure of a scientific object depends above all on our categories; according to pragmatism, scientific truths do not say anything directly about reality, but only about how to achieve certain results in actions. We do not deny that data are more certain than hypotheses about what is not observed, nor that our categories are important in determining objectivity, nor the importance of science for action; however, we pursue a philosophical project based on the idea that the most important aim of the empirical sciences is to establish what reality is in itself. In clear opposition to this perspective, in this volume Plotinsky

[1] Here we refer to the large esoteric literature inspired by Capra (1975); the latter is based partly on Bohr's thought. A quick look at the name register of Capra's book shows that after Einstein, Bohr is the most quoted physicist. On this kind of literature, cf. Stenger (2009); for a partly favorable interpretation of this movement, cf. Kaiser (2011).

enthusiastically endorses Bohrian anti-realism, and he proposes it as the best philosophical perspective for twenty-first century physics.

Bohr's position was developed at the time of neo-positivism; in those days some, such as Frank (1936), interpreted uncertainty relations in such a way as to ascribe to Bohr a quasi-verificationist attitude, i.e. in their opinion the Danish physicist maintained that it is *not* possible *to speak* simultaneously and with complete precision of the position and the momentum of a particle. Note the emphasis on linguistic meaninglessness. Beyond the soundness of this interpretation of Bohr's thought, it is now clear that the operationist flavour of the uncertainty principle proposed initially by Heisenberg (1930, pp. 13ff.) is controversial. In fact, all scholars accept the so-called "preparation uncertainty principle": in quantum mechanics it is not possible to prepare a state so that its position and its momentum are precisely predictable. But it is not clear how to interpret this uncontroversial principle: does the principle mirror an ontological indeterminacy, or does it derive only from an experimental impossibility (Hilgevoord, Uffink 2016)? Be it as it may, the main point is that today no one maintains the neo-positivist interpretation of Bohr's philosophy. Indeed, as Faye (1991) has shown, Bohr quite often argues with the neo-positivist Danish philosopher Jørgensen about the interpretation of complementarity. One of the first to develop a neo-Kantian interpretation of quantum mechanics, and especially of Bohr's point of view, was Heisenberg's pupil C. F. von Weizsäcker. That orthodox quantum mechanics is friendly to a neo-Kantian interpretation is evident, since many think that the wave function does not represent reality but only our knowledge of predictable data.[2] But another question is whether Bohr can be associated with neo-criticism. Weizsäcker (1955) clearly traces back to Kant the centrality of both spatio-temporal description and causality, necessary to the classical description of the measurement apparatus. In this volume the Kantian interpretation of Bohr's position is developed by Bitbol and Kauark-Leite.

Jan Faye's 1991 book was a turning point in the scholarship on Bohr's philosophy, both for its philological rigour – direct access to Danish-language material – and for the high quality of its philosophical analysis. Faye ascribes to Bohr a sort of "objective anti-realism", according to which nothing could be said about non-observable reality, but common experience is objective inasmuch it is inter-subjectively communicable. Nevertheless, this position slips quite naturally into a form of pragmatism, according to which the aim of science is that of building a reasonable, communicable image of inter-subjective experience. Indeed, Faye's

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[2] On the Kant-friendliness of orthodox quantum mechanics, cf. Fano (1995). On a very popular epistemological interpretation of the wave function, cf. Fuchs (2010). There are also many very controversial realistic interpretations; cf. Ney, Albert (2013).

contribution to the present volume is even more pragmatically oriented, and Folse's paper moves along the same lines.[3]

Building on Bohr's discovery of atomic structure in 1913, Tanoma emphasizes that the Danish physicist, as a very good researcher, is a realist. He maintains, furthermore, that Bohr would never have abandoned his realist attitude, even after the full development of quantum mechanics. Dieks, too, proposes a realist reading of Bohr's philosophy. First, he emphasizes the importance of the mathematical formalism of the theory behind the Danish physicist's qualitative language. Secondly, he notes that Bohr's approach is compatible with all recent formulations of quantum mechanics without postulation of the collapse of the wave function. Thirdly, he shows that, even if, according to Bohr, formalism is only a symbolic form, this formalism is the basis for his elaboration of the notion of complementarity. In this sense, Dieks argues, we can speak of Bohr's realism.

Kristian Camilleri's paper is based on Kroes's (2003) distinction between a *functional* and a *structural* description of an experimental apparatus. The latter is essentially physical, whereas the former involves the determination of which property the apparatus is designed to measure. In other words, the former implies a normative notion as well. The distinction is important for a better understanding of Bohr's philosophy of quantum mechanics. In fact, many scholars look at Bohr's reflections on quantum mechanics as an answer either to the question "What is quantum reality?", or to the question "How can we interpret quantum formalism?" Camilleri argues that, to the contrary, Bohr's challenge can be framed as "How can we acquire knowledge through experimentation?" This is very similar to Fock's (1957) "Soviet" interpretation of Bohr's approach. Clearly the answer to this question involves a normative notion since we are speaking of knowledge. In order to measure something, it is necessary that the measurement apparatus be in space and time. Furthermore, the causal nexus between the apparatus and the measured object must be clearly identifiable. This means that measurement is based both on a causal explanation and on a spatio-temporal description of the interaction between the measurement apparatus and the measured object, that is, on *classical* concepts, for, as is well known, in quantum mechanics causality and spatio-temporal description are complementary and incompatible. This argument must not be confused with the dynamical problem of the quantum-classical transition. Bohr's point is not physical, but conceptual and normative. In order to conduct experiments we need both a causal and a spatio-temporal explanation, and such co-presence occurs only in classical physics.

Camilleri's reading is highly original and stimulating. However, every normative notion we endorse is based on one or more facts. For instance, if one decides

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[3] Note that Folse (1985, 1994), too, attempted to defend a realist interpretation of Bohr's philosophy, but since then he has gradually moved toward a pragmatist reading.

to measure the length of a table with a plastic rod, it is because one knows that at room temperature plastic is rigid. Now, we agree that in order to measure it, it is necessary to be acquainted with the causal flux from the object to the apparatus,[4] but it can be questioned whether the determination of the spatio-temporal location of the apparatus is really necessary in measurement. On this question Camilleri is silent.

Probably the weakest point of Bohr's interpretation of quantum mechanics is the absence of any dynamical explanation of the quantum-classical transition. Dorato in this volume develops Howard's (1994) and Zinkernagel's (2016) interpretation of this absence. The idea is that in every measurement process there must be non-separability between the apparatus and the system, non-separability involving only a subset of possible observables. And this subset could change according to which micro-property one is measuring. Both Howard and Zinkernagel, though sympathetic with this Bohrian perspective, are not completely satisfied: the former because he prefers his ontological analysis of non-separability, the latter because he is aware of the mystery of such non-separability. Dorato also outlines an analogy between quantum-classical transition and the Sorites paradox: there are bald men and men with hair, but at how many hairs does the threshold between the two groups lie? Just so, Dorato claims, there are classical and quantum systems, but it is not clear at which magnitude there is a passage from the one to the other. The analogy, however, is unconvincing, because it merely means that "bald" and "having hair" are sometimes excessively gross predicates. It would be preferable to describe the situation counting all the hairs one by one. The task of science is that of solving the Sorites paradox case by case with the discovery of suitable, more finely tuned predicates.

Camilleri also addresses the topic of the 'quantum to classical' transition, aided in his efforts by Schlosshauer, one of the finest scholars in decoherence theory. They emphasize that decoherence could fill, at least in part, the dynamical gap left by Bohr in his epistemology. Bächtold's discussion moves along the same lines.

Bacciagaluppi tells the sad story of the relationship between Everett and Bohr, which was perhaps one of the reasons for the former's abandoning physics. He emphasizes the increasing importance that the 'many-worlds' interpretation of quantum mechanics has acquired today, after its integration with decoherence, and he concludes that Bohr's philosophy is quite friendly to this new trend in the foundations of physics.

Landsman's very technical paper shows that in a certain sense the algebraic approach to quantum mechanics is in line with Bohr's thesis of the necessity of the classical description of the measurement apparatus. In this framework, Bohr's

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[4] In this context the other way around is not relevant, even if we know that quantum mechanics presupposes an uncontrollable influence of the measurement apparatus on the measured system.

issue becomes the necessity to gain access to non-commutative C*-algebras through commutative ones. As usual, the mathematical formulation in the algebraic approach is very elegant, but we are not able to understand the physical reasons that support this "principle of accessibility". Landsmann concludes his paper by sketching a new way to have decoherence, that is to explain the collapse of the wave function, in this Bohrian perspective.

We pass now to Mermin's paper. Regarding Quantum Bayesianism (QBism) we suspect there is some confusion between (a) the method through which we attempt to discover how reality is constituted and (b) the results of these attempts. Namely, it could be reasonable[5] that a single scientist builds on a certain probability given to a hypothesis about the external world, and then he updates this probability through Bayesian conditionalization on the basis of his new experiences, but it is not clear that this framework could be used in giving account of an already formulated scientific theory, as quantum mechanics is. Be that as it may, in his contribution to the present volume, Mermin, one of the promoters of QBism, on the one hand shows that Bohr's point of view is similar in part to this new perspective, and on the other hand he emphasizes the difference between the Copenhagen interpretation and QBism. Indeed, both interpretations agree that the wave function represents knowledge and not reality, but only QBism maintains that this knowledge belongs to a single scientist and that it concerns his external world.

By the end of the book[6] one has the strange feeling that Bohr's philosophy is too flexible. As Popper (1982, 103) once said: "Bohr's complementarity cannot be so [in rational terms] criticized, I fear; it can only be accepted or denounced – perhaps as being *ad hoc*, or as being irrational, or as being hopelessly vague." And there is something true in Gell-Mann's (1976, 29) famous words: "Niels Bohr brainwashed a whole generation of theorists into thinking that the job (that is, an adequate philosophical presentation of quantum mechanics) was done 50 years ago." Clearly the "brainwashing" was unintentional.

Physics, however, is not philosophy and we know very well that physicists must be methodologically opportunistic. If Bohr's philosophy is used to justify *status quo* physics, it is a regressive framework (Fano, 82/83). But such is not always the case. Zinkernagel (2016) shows how the necessity for a classical description plays an important role in very recent hypotheses such as loop quantum gravity and cosmology. The same line is pursued in Perovič's beautiful contribution to this volume. He considers complementarity as an instrument to interpret the weird experimental results of the time – the twentieth century – and not as a

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[5] Actually, it is not clear that it is always possible to ascribe *quantitative* probabilities to our scientific beliefs.

[6] Let us mention that the volume also contains an attempt, made by Osnaghi, to show the relevance of Bohr's reflections for the philosophy of language.

general metaphysical conception; that is to say, complementarity is not a top-down framework, but a bottom-up conceptual instrument that gives sense to quantum experiments *provisionally*. We emphasize the term "provisional", often used by Perovič. What he holds, in other words, is that complementarity is a method for doing physics. In particular, complementarity is based on two principles:

- P1 "Synthesizing theoretical accounts that seem opposed in light of particular metaphysical presuppositions can be beneficial in explaining the known and empirically examined phenomena and predicting new ones." Namely, the metaphysics suggested by a physical model could be in contrast with that proposed by another useful one.
- P2 "Experimental limits were placed on the scope of theoretical frameworks, that is, on the understanding of physical properties," meaning that no physical model holds for all situations.

Perovič proceeds to demonstrate that P1 and P2 played an important role in the discovery of the tunnel effect in the twentieth century, and they could be methodologically useful even today in the discussion of the velocity of the same effect.It is not clear whether Perovič's P1 and P2 faithfully present Bohr's complementarity, but it is certain that this kind of argumentation shows how to couch a progressive research program in terms of the reflections of the Danish physicist.

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