Reading Bohr: Physics and Philosophy

by

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Preface

This book is an exploration of the relationships between physics and philosophy in Niels Bohr's work, in quantum mechanics, and, finally, in physics itself, as, in Galileo's phrase, a "mathematical science of nature." It reassesses the place of Bohr's thought and writing both in the history of modern physics, from Galileo and Newton on, and equally in the history of modern philosophy. At the same time, the extension of the project undertaken by the book to quantum physics itself (rather than only Bohr's interpretation of quantum mechanics) and physics in general is crucial to the project. My title may also be read, by replacing the colon with a comma, as "reading Bohr, physics, and philosophy."

The main reasons for this expansion of the project's scope are as follows. While the relationships between physics and philosophy in Bohr's work have been considered in commentaries on Bohr, the implications of Bohr's work for the history of the relationships between physics and philosophy have not. I shall argue, however, that these implications are significant not only for our understanding of the history of quantum theory or physics in general but also for our assessment of the future of both, even if we finally want *to move beyond* Bohr and perhaps especially if we do. It is difficult *to leave Bohr behind* in considering quantum theory and its history. But in this case we can "move beyond" without "leaving behind," just as we moved beyond classical physics to relativity and quantum mechanics and then to quantum field theory without leaving anything behind. This is what the project of the book ultimately aims to accomplish, as it ends with quantum field theory in Chapter 5, and the relationships between physics and philosophy in Chapter 6, the final chapter of this study.

I shall pursue this project by means of close readings of some of Bohr's key works on his interpretation of quantum mechanics as complementarity. This approach is somewhat unorthodox in the fields of history and philosophy of quantum theory, even in studies specifically dedicated to Bohr. It has, however, several advantages not only, self-evidently, for understanding Bohr's work but also for understanding quantum theory and physics, and the relationships between them and philosophy beyond Bohr's work. First of all, it allows one to address with greater rigor and effectiveness the key questions at stake in the Bohr-Einstein confrontation and ongoing debates concerning quantum mechanics still shaped by this confrontation. One can mention such perpetual subjects as the double-slit and other "archetypal" quantum-mechanical experiments, the nature of quantum probability, and the experiment of A. Einstein, B. Podolsky, and N. Rosen, and J. S. Bell's and related theorems, some of which will be discussed in detail in the book. The approach also enables one to perceive and articulate more sharply than previously the key developments and transformations of Bohr's interpretation of quantum

mechanics as complementarity. Most significant among them were those that occurred, first, under the impact of Bohr's debate with Einstein and, second, under the impact of the developments of quantum theory, both quantum mechanics itself and quantum electrodynamics and quantum field theory. The subject, especially the importance of the second factor just mentioned (some among more recent studies have discussed the first factor), has not been adequately addressed in the literature, to the considerable detriment of our understanding of the history of quantum physics. The book aims to fill this lacuna. As I said, one chapter of the book, Chapter 5, will be devoted to the relationships between quantum mechanics and quantum field theory, and the epistemological questions these relationships pose. The relationships among classical physics, relativity, and quantum mechanics will be addressed throughout the book, as they were throughout Bohr's work. A closer reading of Bohr shows that they are considered there in more depth and with greater significance than previously realized, and, thus, helps us to gain a greater insight into these relationships, crucial for physics and for our understanding of what physics is and of how it works.

Indeed, while this may be especially true in Bohr's case, in part given the proportion of physics contained in verbal formulations rather than mathematical formulas, or formal logical deductions that have dominated the foundational work on quantum mechanics, I would argue more generally that the role of reading in physics is more significant than is commonly acknowledged. Physics is also reading. It is the interpretation of texts, as well as of (and often jointly with) physical theories themselves, which may be especially true when dealing with quantum mechanics and its interpretation, but is also true throughout the history of classical physics or relativity. The history of quantum mechanics, from the work of founding figures to the most recent developments, certainly offers remarkable examples of both, both in general and specifically as concerns our encounters with Bohr's ideas. This history appears to be indissociable from interpreting Bohr's ideas, from reading Bohr.

The peculiarity of Bohr's writings is in part due to the peculiar nature of quantum physics, and of Bohr's interpretation and epistemology of it. In commenting on the difficulties involved in "Discussion with Einstein on Epistemological Problems in Atomic Physics," arguably his most definitive work on quantum epistemology, Bohr said: "Rereading these passages, I am deeply aware of the inefficiency of expression which must have made it very difficult to appreciate the trend of the argumentation aiming to bring out the essential ambiguity involved in reference to physical attributes of objects when dealing with phenomena where no sharp separation can be made between the objects themselves and their interaction with the measuring instruments." Such separation and, hence, the description of (the properties of) quantum objects and processes themselves (as opposed to certain effects of their interaction with measuring instruments upon the latter) are impossible in Bohr's interpretation. This impossibility expresses the essence of Bohr's epistemology. As Bohr also argues, however, this

impossibility "provides room for new physical laws," and opens a space of new possibilities for physics and knowledge in general. An argument of this type is indeed not easy to make, especially to make efficiently.

On the other hand, some of the peculiarities in question are peculiarly Bohr's, especially insofar as Bohr's key terms, such as phenomena, individuality, atomicity, or complementarity, have unconventional and sometimes idiosyncratic meanings, which is often the case in dealing with philosophical terms and concepts. Bohr's writings appear to pose more substantial demands than customary in scientific texts as concerns paying special attention to particular formulations; carefully adhering to the particular meaning of his terms; understanding the philosophical (rather than only physical and mathematical) structure of his concepts; writing in different languages involved (Bohr wrote and thought on the subject in several languages) and translations between them; and so forth. These demands are not always met by Bohr's readers, which leads to significant misunderstandings of his arguments. Naturally, my point is not that one cannot disagree with Bohr's views or criticize his arguments, but the special conditions, often missed by Bohr's critics, that a meaningful reading or, if necessary, criticism would entail in his case.

The present book, nearly unavoidably, follows Bohr in its presentation of its subject. The approach does carry a potential benefit of opening the discussion to a broader readership, beyond those comprised by physicists and philosophers. On the other hand, the situation is complicated by the task, which I thought imperative, of retaining the rigor invariably found in Bohr's writings when dealing with quantum phenomena and quantum mechanics. (Bohr's excursions beyond quantum physics, even when using his concepts, such as complementarity, are, as he admits, speculative and less thorough.) Even though Bohr famously insisted that one should make one's presentation of what is fundamentally at stake in quantum physics available to a willing and open-minded layperson, his writings, even, and in some respects, especially, his philosophical writings, are not easy. While they do not always require technical knowledge of physics and mathematics (sometimes they do, even if implicitly, and at key points), they are not an easy reading and certainly do not conform to the genre of popular exposition. His writings are not inaccessible, but they are not always immediately accessible, and demand considerable effort on the part of any reader, not unlike philosophical works, such as those of Kant or Hegel, whose thought, as I shall discuss in the last chapter of this book, defines modern philosophy, the philosophical aspects of Bohr's (or Einstein's) work included. This study is also an attempt to negotiate this difficult balance between rigor and accessibility in presenting Bohr's writings, in reading Bohr.

The study addresses primarily Bohr's *interpretation* of quantum mechanics, and most especially the version developed in the wake of EPR's argument and finalized in "Discussion with Einstein," which refines Bohr's earlier versions of complementarity. Accordingly, most of my epistemological claims pertain to this interpretation rather than

to the experimental data or mathematical formalism of quantum mechanics (if they can be seen as independent of an interpretation), or other interpretations of quantum mechanics, including those associated with "the Copenhagen interpretation." The latter rubric must be applied with great caution, given the differences between such interpretations and the thought of the different figures involved, even those who are considered, and consider themselves, close to Bohr (Heisenberg and Pauli, among them). These differences are much greater than it is usually argued and often outweigh the shared features, important as the latter may be. I would argue that, once considered in all of its aspects, Bohr's interpretation (in the present reading or "interpretation") is unique and, I would also argue, uniquely radical epistemologically. On several occasions, which I shall specify as I proceed, I shall advance arguments, both those arising from within Bohr's interpretation and relatively independent ones, that exceed the limits of Bohr's interpretation and lead to more general claims. They concern in particular the status of Bohr's interpretation as *an* interpretation, one among many possible interpretations, of quantum mechanics.

The project of the book could have been pursued on an even broader scale and via a more extensive textual engagement with Bohr's writings, in particular by extending this engagement to Bohr's works preceding his work on quantum mechanics, beginning at least with those on his 1913 theory of the hydrogen atom. Tempting as it may be (and was to the present author), such an extension would amount to an immensely long, nearly interminable investigation, even if one were to restrict oneself to Bohr's work. I ended up by making a virtue out of necessity and, while retaining the emphasis on reading, conceived of the project as a collection of *essays*, a genre defined by the lack of completion or the claim of completion. The approach inevitably entails certain losses, especially in Bohr's case, since nearly every paragraph (and often a single sentence) of his work on complementarity offers a rich source of possible commentary and a platform for further thinking about Bohr, physics, and philosophy. The Introduction and, to some degree, Chapter 1 are designed to offer an introduction to Bohr's key ideas, discussed in detail later in this study. In general, however, in accordance with the genre of the essay, each chapter may, in principle, be read independently, which also leads to some repetitions, although I tried to keep such repetitions minimal.

Bohr's writings may themselves be seen as conforming to the genre of the essay. Bohr has never written a book that would offer a sustained exposition of his interpretation (he, again, offered several) or of quantum mechanics and the phenomena in question in it as complementarity. At most, he published collections of his articles, essays, on the subject, even though he saw quantum mechanics as a complete theory (within its scope) and this completeness was a major theme of his incomplete, essay-like writings. On the other hand, quantum mechanics may well be, and in the ultimate version of Bohr's interpretation is, irreducibly incomplete, even within its own scope, insofar as it offers no description or even conception of the ultimate objects and processes it is concerned with and even appears to imply that such a description or conception is in

principle impossible. It may lead us, yet again (one does not need quantum mechanics to do so), to ask whether the philosophy written in the "book" of nature, or in "the book of nature" that we write, in part in the language of mathematics, is indeed a book or a collection of essays. The latter appears to be rather more likely, at least to the present author. This is not necessarily a bad thing, although it would make the "dream of a final theory" in physics all but impossible, which may, however, not be so bad either.

It is worth stressing, however, that Bohr's essays offer us rigorous physics, as rigorous as any, and are sometimes compelled to pursue their arguments in an essay form in order to maintain this rigor. Planck's article introducing his black-body radiation law and with it quantum physics and Heisenberg's first paper of quantum mechanics have something of this quality as well, as does Bohr's so-called Como lecture, "The Quantum Postulate and the Recent Development of Atomic Theory," which introduced complementarity. All of these works may be seen as essays. Most of Bohr's endlessly revised writings were always essay-like, never finished. This was even how Bohr defined a "manuscript": as something to be further worked on. In all of these cases, however, his science was as rigorous as it could be, as was the quality of thought, coupled to a strength of conviction, which is, however, not the same as believing in delivering the final word on the subject. Only these qualities, always found in Bohr's works, define an essay, while this type of belief, never found in Bohr, is antithetical and inimical to it.

One can at most hope for, and certainly cannot count on, coming close to such works in undertaking the project of an essay. Going astray on such an adventure is more likely. All one can do is to try one's best to stay the course.