

Niels Bohr's Philosophy of Quantum Physics

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Introductory remarks at the defence for the Philosophical doctoral degree.
Regarding the dissertation:

Niels Bohr's Philosophy of Quantum Physics. In the Light of the Helmholtzian Tradition of theoretical Physics

1. Suppose, I want to introduce a new theory. My theory is that when someone - who is still a fan of his childhood football club, also when their best team plays poorly; when such a person defends his doctoral thesis, there will be more people present wearing a white shirt than people wearing a black shirt. Now, let me see....

Happily, when formulating my theory and using it to make observations about all you fine people, I knew - long before any of you arrived here - what to look for. I know how to distinguish a shirt from a sweater or t-shirt; and I can clearly distinguish black and white. And not to forget: I know in advance that any of the people that wears a shirt will most likely wear *one* shirt only.

I am here using a well-earned lesson of Galileo, which physicists first expressed in their language, and which philosophers later expressed in *their* language. The lesson is that if we want to study and model a section of Reality by means of a special set of concepts - in short, if we want to introduce a theory - we must be clear how we distinguish and identify the kinds of objects we want to study. In classical physics, Galileo taught this lesson by restricting the proper field of inquiry to the *relative motion* between things. So **if** classical physics is a study of how things, like stellar objects and planets, can move relative to one another in a regular fashion, **there must be** a way in which such objects are present in our observations. We must be able to trace the motions we investigate in space and time. If we could not locate individual motions in space and time, we could not even *try* to find out, what lawfully characterizes such motions; for instance (and that's Kepler's law)

that the angular momentum of planetary motions is a constant, and that the numerical value of this constant differs for each planet, relative to the distance to the Sun.

So in the language of classical physics, in order that we can have a theory about a certain subject matter we must presuppose that we already have two things in place. First, we must have a *kinematical* framework in which we can define how the things to be studied might be *distributed* in space and time; and secondly, like we know that the colour of the shirt that occupies a certain seat in this room may have changed after our break, later this afternoon, either because a new person is sitting there or because someone has changed his shirt for some reason; we must have a *dynamical* understanding of the powers and properties that might successively occupy specific places in space.

The paradigm case of our lesson became this: Classical mechanics (Newton's three Laws of Mechanics) presupposes both a classical kind of kinematics (Galileo's) and a classical kind of dynamics (such as Newton's theory of Universal Gravitation). But the lesson of Galileo covers any other physical discipline. One could not introduce the electrodynamics theory of Maxwell if one did not know in advance what it means for a *field* of electric and magnetic vectors to be prolonged in space, and for currents and magnetic inductions to be displaced within the field. Or, one could not introduce the idea of a statistical mechanics, if one did not know in advance what it means for a large number of molecules to constitute a certain gas, and how a shift in the pressure or temperature was an indication of how the individual tiny molecules move, in average, across well defined boundaries within the space occupied by a given gas.

Now, Kant formulated our lesson in the language of philosophy. He considered space and time as two necessary forms of intuition without which our ability to entertain concepts in our language would not make empirical sense. Famously, he argued that using concepts without, and not within, the intuition of space and time, would be an empty formal exercise of words. He showed how the physical sciences in fact *do* integrate their subject matter in the intuition. He pointed out how the objects of the physical studies were defined by the language of geometry; the very science of how to construct

ideal objects in space. So by linking the application of physical concepts, like force and mass, to a certain kind of geometrical constructs, lines and curves; the foundation was laid for our having a distinct experience of physical Reality.

So our lesson, when put in the language of philosophy says: The possibility that human beings can have a certain, theoretical, *experience* presupposes that we can already posit the objects of this experience within our imagination or intuition, in space and time; and the method for this anticipation of a kind of experience yet to come, was the ability to schematise, to freeze in geometric fashion, how these objects can be identified in space and time.

So interestingly but not surprisingly, when Heisenberg explained what it takes to establish a new kind of mechanics - a quantum mechanics - he had learnt the lesson of both Galileo and Kant: For he showed, first how we could have a new kind of *kinematics* concerning the presence of quantum physical phenomena, and secondly that we could also have a new *dynamics* concerning these features. It is simple; add a new kinematics to a new dynamics and you have got a new mechanics; you have got a new kind of theoretical understanding of physical regularities.

This was actually the way Heisenberg expressed himself in the first textbook on quantum mechanics from 1929. But two years before, in the famous paper where he formulated the Indeterminacy Relations, he had used the language of Kant, even in the title of the paper: "On the new intuition in Quantum Physics". Heisenberg knew well that the lesson of Galileo and the lesson of Kant was the same.

For Heisenberg and for Niels Bohr, quantum mechanics was supposed to be a theory about atomic structures. So we might ask: "How are such structures present?". Well - not like shirts and planets, visible to the naked eye. However, atoms are present within certain experimental arrangements and uses of apparatus. What we can call "atomic processes" are open to direct observation within certain experiments; for instance, we can observe the spectral lines that corresponds to a certain shift in the energy condition of an electron bound within a given atom.

Atoms are not more strange objects than gasses; and the possibility of coming to know about atoms is actually a lot better than the possibility of our coming to know about a lot of others things. The only special thing about quantum mechanics is that the classical forms of intuition are replaced by a new schematisation of things: We do no longer picture how what we study, as such, and in itself, is placed in space and time. We picture instead how *features and parts* of our field of study can be embedded within the concrete kinds of experiments we can perform.

2. This is how I account for the development of quantum mechanics in my dissertation. However, my book is primarily about how this new quantum mechanics gave rise to a series of philosophical worries for Niels Bohr. Certainly, Heisenberg, Einstein, Schrödinger and others all had their special worries; but I concentrate on Bohr's, and try to show that even if the worries never led him to formulate a clear philosophical view, we can say that he successfully showed how not only philosophers of quantum physics but philosophers of science, in general, as well as philosophers of culture and language, could learn something by reflecting on the special conditions of quantum mechanics.

I think my book is the first, ever, to clearly separate the philosophical concerns of Bohr from the story about how the development of quantum mechanics involved an assessment of the lessons of Galileo and Kant. I am not the first to claim that Bohr wanted to teach a new lesson. But I am the first to argue that the establishing of quantum mechanics, as such - by Heisenberg, Schrödinger, Born, and Dirac - did not dismiss the classical lesson of both Gallileo and Kant, in spite of the truly radical character of quantum physics

I argue that Bohr reflected on the possibility of quantum physics in a broader perspective than the lesson of Gallileo and Kant calls for. Bohr reflected on the entire history and possibility of modern experimental physics; Galileo, Newton, Maxwell, Einstein, and quantum mechanics included.

I explain how all of physics involves what Bohr called an *idealization* of the reality of things; and I discuss how what he called "complementarity" is a methodology for transforming idealizations into objective and real insight into the nature of things.

In contrast to Heisenberg's original view, Bohr modified the lesson of Galileo and Kant. In relation to both kinematics and dynamics, he distinguished between the kinematics (or dynamics) of the object of study and the kinematics (or dynamics) of the *experimental design*. He then argued that the kinematics of the possible objects of study was dependent on the *dynamics* of the experimental design, just as the dynamics of the possible objects of study was dependent on the *kinematics* of the design. So what Bohr called "space-time representation" is no longer associated with only *one* kind of dynamics. The tracking of particles and the detection of waves correspond to different kinds of experiments, dynamically speaking. Consequently, the unity between the kinematics and the dynamics of the objects of study points in different directions. There is no *one* form of classical *causality* corresponding to the production of quantum physical phenomena. But still, these classical forms of causality, as well as their corresponding experimental conditions, can be seen as *complementary* to one another. And so, "Complementarity" becomes a generalization of "ordinary causality".

As I said, the framework of complementarity is more than a means for surveying a range of atomic physical phenomena; it is a methodological effort to construct a proper map of an entirely new and surprising part of the world, which no quantum physicist before Bohr had ever envisaged. Bohr not only taught us how to observe very special "shirts"; he showed how "shirts", deep down, are a kind of objects we never dreamed could exist. I mean; he showed that the world of *bound energy* including the ways in which such energy can be transformed into different kinds of *free energy*, is a kind of world we never knew existed. Similarly, he showed how the world of biology is a world of life creating and life maintaining powers, including the transformation into different kinds of organic self-development and organic functional stability we find it hard to imagine. And he showed how the cultural world is a manifold of expressions of conscious life including the transformation into different kinds of traditions, institutions, behavioural and emotional patterns, historically bounded roles, values, and aesthetic forms, the emergence of which excite us.

As I read Bohr, the history of theoretical physics is a metaphysical eye-opener. We see the world in a radically different way; in more abstract terms

- yes, but also in a way in which we are fully aware of how - as Bohr put it - what we do as actors and what we learn as spectators, are two sides of the same coin. The study of Nature is therefore also a study of us. The deep truth about Nature is that someone *like us* can acquire knowledge about it; that someone like us can *construct and utilize instruments* in our learning about Nature.

This implies that the development of the sciences is not a goal in itself but is also a way in which our Human Kind develops *itself*. We do not stand in opposition to Nature as we study it; instead we learn to become the voice of Nature. For there is no pre given book of Nature to read; there is only Nature - which happens to have a voice; namely us. No wonder that Bohr saw himself in close affinity with the poet, and scientist, Goethe.

3. Allow me to address the honourable committee: In your evaluation, I think you do not distinguish clearly between my account of quantum physics as neo-Kantian (where I am not original but historically to the point) and my account of Bohr's Goethean philosophical reaction to the advent of quantum physics (which, in contrast to other such account like that of C. Chevalley, is consistent; for Goethe's was a consistent response to Kant).

In my book, I declare that a lot of recent philosophical discussions about the "interpretation" of quantum mechanics are inadequate in relation to what I see as a historical fact; the fact that neo-Kantian considerations actually defined the agenda of the early quantum mechanics from 1925-27. I do not argue that these recent discussions make no philosophical sense what so ever. Also, I do not claim that Bohr's was the only reasonable philosophical response to the agenda of 1927; and here, Einstein's and Schödinger's philosophical concern with quantum physics may be a case in point. I merely argue that if one sees these reactions (to the neo-Kantian type of a new mechanics) as directed specifically against Bohr's Goethean-like response to the advent of quantum physics; one goes wrong.

Finally, I want to stress how my invocation of the philosophy of language - of both Michael Dummett and Wittgenstein - is a crucial part of this critique of mine: I argue that Bohr provided what you can call a *linguistic turn* of Goethean-like views. Here, the association of various scientific practices with

certain linguistic practices goes deep. The issue I address is what it takes, at all, to see a certain practice, scientific or not, as a *linguistic* practice. Thus, I criticize recent attempts to ascribe a semantic/linguistic view to Bohr for failing to address this issue; as if we all knew in advance what characterizes, say, a realistic linguistic practice as opposed to an anti-realistic such. Our issue could never be whether or how Bohr adopts a certain given "position" in a philosophical landscape portrayed in advance. At least, analytic philosophers should know that the very idea of a linguistic practice changed with the advent of the development of the intuitionist mathematics of Brouwer. I have tried to argue that, according to Bohr, the very idea of a linguistic practice has changed also in the light of the development of quantum physics.

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Niels Bohr and his Atomic Model Source: FamousScientists.org. Few scientists have made as much impact on the modern world as Niels Bohr. The result of Bohr's work on the structure of the atom gave rise to everything from the atomic age to laser beams and quantum computing and his name is overshadowed by his critics and those who built off his work to make names for themselves. A Complementarity: A New Philosophy of Physics. One of Bohr's more controversial and lasting contributions to the debate was his introduction of the concept of Complementarity. Bohr found that if you were to take a measurement of an electron with one apparatus, it would predictably behave like a particle. Make the same measurement with another apparatus and suddenly it behaved like a wave.