

# Indeterminism and the Bohm Interpretation of Quantum Mechanics

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## 1. Introduction

The interpretation of quantum mechanics developed by David Bohm and Basil Hiley (1993) is sometimes called the ontological interpretation because it tries to give a coherent ontological explanation of quantum phenomena while still producing the same results as do the other interpretations. The Bohm interpretation is not entirely free of what may be characterized as weird features (e.g., non-locality and active and passive information), but the ones that are present in said interpretation do not seem quite as weird as some of the features of other interpretations. One example of such features is that the all possible outcomes of a quantum measurement are realized in different universes, another that Schrödinger's cat remains in a state of both alive and dead at the same time until a conscious observer opens the box and thereby effectively causes one of the states to become manifest. These are two examples of features that are not present in the Bohm interpretation.

One reason why many people prefer an interpretation of quantum mechanics other than the Bohm interpretation is, I believe, because of the indeterminism that is implied in one way or another in those interpretations. I want to argue that it is possible to accept the Bohm interpretation of quantum mechanics without giving up indeterminism in nature. This may seem strange considering the deterministic character of this interpretation, but as I hope to show, it makes sense when Bohm's general and more philosophical ideas are taken into account, something which is natural to do if one accepts the Bohm interpretation of quantum mechanics. To me it seems that many only consider Bohm's interpretation of quantum mechanics and fail to notice or understand his broader ideas about nature and reality.

I will start with a discussion of Heisenberg's uncertainty principle—one of the cornerstones of quantum mechanics—and the different ways of interpreting it. Once it has been shown that it is possible to see the uncertainty to be of the epistemological rather than the ontological kind, I will go on to discuss determinism and indeterminism in the context of Bohm's ideas. This text will not give a detailed account of Bohm's ideas in general or the Bohm interpretation of quantum mechanics; the interested reader is referred to Bohm (1957, 1980) and Bohm and Hiley (1993).

## 2. The Uncertainty Principle

The uncertainty principle, or the indeterminacy principle as it is also called, is commonly written as  $\Delta p \Delta x \geq h$ , where  $\Delta p$  is the uncertainty in the momentum of the particle,  $\Delta x$  the uncertainty in the particle's position, and  $h$  is Planck's constant. There are other ways of writing this principle: one is  $\Delta E \Delta t \geq h$ , where  $\Delta E$  is the uncertainty in the energy and  $\Delta t$  is the uncertainty in the time.

Heisenberg's uncertainty principle says that there is a limit on the accuracy with which you can simultaneously measure conjugate attributes. In the case of the position and the momentum, the uncertainty principle says that the more accurately the position of a particle is measured, the less accurately can its momentum be measured, and vice versa. To get high accuracy in the measurement of, say, the momentum, an accurate measurement of the position must be sacrificed. If the momentum is measured with perfect accuracy, then there is complete uncertainty in the particle's position.

The uncertainty principle has led many to conclude that it sets not only an epistemological limit on what we can know but also an ontological one. This means that we really cannot know more than the uncertainty principle allows us to know because there simply exists nothing more that can be known beyond its limit. Meaning cannot be given to the dynamic attributes of a particle beyond the uncertainty principle. Herbert (1985) writes that the uncertainty principle does not arise from any kind of disturbance introduced by the measurement; it is a fact of nature. If disturbances were the cause of the uncertainty principle, then it would be

these that caused the uncertainty, and thus the particle would have both position and momentum simultaneously even though measurement disturbances would make it impossible to measure both of them at the same time.

The Bohm interpretation, being an ontological interpretation, does not agree that the uncertainty principle sets an ontological limit on knowledge. It says that particles do have all attributes simultaneously. On this view the uncertainty principle is purely epistemological. Furthermore, contrary to what is believed when the uncertainty principle is taken to set an ontological limit, the uncertainty is due to disturbances introduced by measurements: “what Heisenberg’s principle refers to is not the actual momentum of the particle itself, but the value of the momentum that can be attributed to the particle after what is commonly called a measurement of the momentum” (Bohm & Hiley, 1993, p. 114). Due to the participatory nature of measurements, the actual and the measured values can differ (Bohm & Hiley, 1993). In other words, the particle has all attributes simultaneously, but measuring them introduces disturbances that cause the measured values to be different from the actual ones. The participatory nature is negligible on the macroscopic scale and that is why we do not see such disturbances on that scale (Bohm & Hiley, 1993).

What the Bohm interpretation shows is that it is not necessary to interpret the uncertainty principle as setting an ontological limit on what can be known. The Bohm interpretation has given an alternative interpretation in the form of an epistemological explanation of the uncertainty principle within an ontological interpretation of quantum mechanics, and accounted for its effects in terms of measurement disturbances due to the participatory nature of measurement while retaining the notion that the particle does have all properties simultaneously clearly defined.

It is my belief that many prefer the view that the uncertainty principle sets an ontological limit on what we can know because such a limit is seen as a clear sign of an inherent indeterminism in nature, and indeterminism is something that I think is important to most of us, whether or not we consciously acknowledge it. A completely deterministic world seems to be a very gloomy world indeed, where everything is predetermined and there is no room for creativity or free will. Here it is worth mentioning that quantum mechanics *per se* is not capable of shedding much light on

the question of free will since quantum indeterminism does not represent what is meant by free will. So, in light of this the question of whether or not it is possible to subscribe to the Bohm interpretation and still have the notion of indeterminism emerges. The answer may at first blush seem to be negative, but a closer examination of Bohm's more general ideas of the nature of reality shows that this is not the case.

### **3. Determinism and Indeterminism in Bohm's Worldview**

The account of the uncertainty principle given by the Bohm interpretation of quantum mechanics seems to remove the support for inherent indeterminism in nature that people find in interpretations that give said principle an ontological status. Even if people believe that the Bohm interpretation has plenty of potential, and perhaps even think it is the best of the available interpretations, they may be reluctant to support it due to its seemingly deterministic character. This would in my opinion be a mistake. There is no doubt in my mind that one can subscribe to the Bohm interpretation and still have indeterminism in some sense.

To begin with, it will be useful to look at what Bohm writes on the subject of mechanism. He thinks that even though one may use an entirely quantitative theory, one is not adopting a mechanistic viewpoint if one does not at the same time assume that the theory is complete, and therefore "mechanism cannot be a characteristic of any theory, but rather [...] a philosophical attitude towards that theory" (Bohm, 1957, pp. 37–38). A theory is not mechanistic or non-mechanistic, but one's attitude toward it is. The most essential feature of mechanism in Bohm's view is that it is about reduction to quantitative changes only; there are no qualitative changes (Bohm, 1957).

By looking at Bohm's more general ideas of the nature of reality, it becomes evident that Bohm's ideas are not mechanistic; rather, they are organic. In fact, Bohm (1957) has criticized mechanism for the assumption that absolute and final features of any theory are at least in principle attainable. He writes that "the possibility is always open that such a feature has only a relative and limited validity, and that the limits of its

validity may be discovered in the future” (Bohm, 1957, pp. 131–32). In other words, Bohm thinks it wrong to expect that any theory will be universal and have unlimited validity; there is always the possibility of a domain in which such a theory would not be applicable. Furthermore, such an assumption “contradicts the basic spirit of the scientific method itself, which requires that *every* feature be subjected to continual probing and testing” (Bohm, 1957, p. 132). Already here it can be seen that mechanism is insufficient since it assumes unlimited validity and finiteness of nature, that there exists a most fundamental level.

Mechanistic thinking deals with quantity, but Bohm (1957) suggests that quality is at least as important as quantity, and he talks about the *qualitative infinity of nature*. With this he means the unlimited totality that is everything. There are infinitely many interconnected levels, each being a relatively autonomous and stable abstraction of the totality. Bohm thinks that things are not actually separate and independent of each other even if this seems to be the case. One must take into consideration the background and cannot focus exclusively on the object of interest as isolated from its environment. Even though the object can be seen as independent, it is still subjected to influence from the general background. Lower levels affect higher levels and higher levels affect lower levels in *reciprocal relationships*, and the background provides overall influence and is influenced reciprocally (Bohm, 1957).

Reciprocal relationships are interesting as they show that while every entity is dependent on and influenced by the infinite background, the entity influences the background. The connection goes both ways: the background both influences and is influenced, every entity both influences and is influenced. Thus, there can never be any real separation. As Bohm emphasizes a number of times, everything is an infinite and unlimited totality. All things are seen as abstractions of certain aspects of this totality, and these abstractions are only valid in certain domains under certain conditions and are only relatively autonomous.

If the idea of nature’s qualitative infinity is correct, then mechanistic determinism is not applicable (Bohm, 1957). If it were, it would be possible for a superior being with knowledge of all the positions and velocities of all particles in the entire universe to

calculate everything that has happened and everything that will ever happen in the universe. This, however, Bohm believes is impossible (Bohm, 1957). He writes:

First of all, let us recall that no matter how far one goes in the expression of the laws of nature, the results will always depend in an unavoidable way on essentially independent contingencies which exist outside the context under investigation, and which are therefore undergoing chance fluctuations relative to the motions inside the context in question. For this reason, the causal laws applying inside any specified context will evidently not be adequate for the perfect prediction even of what goes on inside this context alone.

Secondly, however, the essential independence of different contexts implies that the processes taking place within a given context cannot provide a complete and perfect reflection of what goes on in the infinite totality of possible contexts. (Bohm, 1957, pp. 158–59.)

Because of the qualitative infinity of nature, perfect determinism is not possible since it would require one's knowledge and experiments to be infinite as well. Furthermore,

over an infinite period of time, the determination of even the essential features of an effect is evidently not purely mechanical, because it involves not only an infinite number of contingent factors but also an infinity of kinds of qualities, properties, laws of connection, all of which themselves undergo fundamental changes with the passage of time. (Bohm, 1957, p. 160.)

Bohm writes that necessary causation and chance contingencies represent two sides of any process and that consideration of “only one of these sides [...] always constitutes an approximation that cannot apply without limit, but that must eventually be corrected and supplemented by taking into account the other side” (Bohm, 1957, pp. 29–30). This also applies to determinism and indeterminism. The two are aspects of the same underlying process and can be seen as opposites that complement each other; each is required for the other to exist. Bohm writes:

It should be noted [...] that all the new developments that occurred in the conceptual structure of physics during the nineteenth century were in such a sense as to suggest that none of the various possible mechanistic schemes, *deterministic and indeterministic*, that have been suggested at different times are really fundamental, but rather, what should be our fundamental starting-point is the full

richness of the patterns of natural law. [...] This pattern implies that all the laws of the various levels and all the different general categories of law, such as qualitative and quantitative, determinate and statistical, etc., represent different but necessarily interrelated sides of the same process. Each side gives an approximate and partial view of reality that helps correct errors coming from the sole use of the others, and each treats adequately an aspect of the process that is not so well treated or perhaps even missed altogether by others. (Bohm, 1957, pp. 66–67, emphasis added.)

Determinism and indeterminism are limited and only valid and meaningful in certain abstractions from the qualitatively and quantitatively unlimited totality. Bohm and Hiley (1993, p. 324) write that the totality of a certain context “cannot be entirely self-determined, because it always depends in various ways on what has been left out.” What is seen as indeterministic in one theory may seem deterministic in another theory, just as those deterministic features may seem indeterministic on the next, deeper level. In other words, determinism may dominate in one domain while indeterminism dominates in another (Bohm, 1957).

In Bohm’s worldview it cannot be said that either determinism or indeterminism is the ultimate principle; both are abstractions of the totality and both have limited domains of applicability, neither being primary. The appropriate view “will depend both on the unknown totality and on our particular mode of contact with it (e.g. the kinds of experiments we are able to do)” (Bohm & Hiley, 1993, p. 324). Since determinism and indeterminism are abstractions of the totality, it is clear that the totality is beyond both of them, for how could the totality ultimately be deterministic or indeterministic when these two modes are but abstractions of it?

On a related note, Pylkkänen (1995) has argued that an internal realist (one who thinks that the observer has a special role in any description of reality) can accept the Bohm interpretation without turning into a metaphysical realist and that the Bohm interpretation is not a step backwards for epistemology. This suggests that what may at first seem to be incompatible with the Bohm interpretation can be seen as perfectly compatible when Bohm’s ideas are closely scrutinized. The key lies in Bohm’s broader, philosophical ideas about the nature of reality. One should not be too quick to rule out the Bohm interpretation of quantum mechanics because it does not seem to

fit with one's more general worldview without a close look at the notions that underlie the interpretation.

## 4. Conclusion

It is indeed possible to support the Bohm interpretation of quantum mechanics without giving up indeterminism. Even though the Bohm interpretation may at first seem to imply a return to classical physics with its determinism and mechanism, such a return can be rebutted when the more general ideas in Bohm's worldview are taken into consideration. Only by doing so is it possible to get an idea of what Bohm's ideas imply in a broader perspective. Though determinism may dominate on the quantum level, indeterminism may be at work on a deeper level; and even so, ultimately neither determinism nor indeterminism has meaning or validity in the qualitatively and quantitatively infinite totality, the undivided wholeness.

## References

Bohm, D. (1957). *Causality and Chance in Modern Physics*. London: Routledge.

—— (1980). *Wholeness and the Implicate Order*. London: Routledge.

Bohm, D. & B.J. Hiley (1993). *The Undivided Universe*. London: Routledge.

Herbert, N. (1985). *Quantum Reality: Beyond the New Physics*. New York: Anchor Books.

Pylkkänen, P. (1995). "Does Taking the Bohm Interpretation Seriously Make You Into a Metaphysical Realist?" In *New Directions in Cognitive Science*, P. Pylkkänen & P. Pylkkö (eds.), pp. 70–76, Helsinki: Finnish Artificial Intelligence Society.