Bohmian mechanics as Cartesian science

Michael Esfeld
University of Lausanne, Department of Philosophy
Michael.Esfeld@unil.ch, www.michaelesfeld.com

(published in Angelo Bassi, Sheldon Goldstein, Roderich Tumulka and Nino Zanghì (eds.): *Physics and the nature of reality. Essays in memory of Detlef Dürr*. Cham: Springer 2024, pp. 383-392)

Abstract

The paper shows how Bohmian mechanics fits into modern science as conceived by Descartes. The primitive ontology of particle positions only vindicates the Cartesian conception of matter as *res extensa* also in the domain of quantum physics. Finally, I briefly sketch out how Bohmian mechanics can also be construed as respecting the limits that Descartes set for modern science: there is no conflict between the ontology and dynamics of matter as set out in Bohmian mechanics and a Cartesian stance that takes the mind to be irreducible to matter.

1. From de Broglie and Bohm to Bohmian mechanics

For many years, I've misconceived the de Broglie-Bohm quantum theory. Louis de Broglie's (1928) original proposal is one of a wave-particle dualism. Thus, in the double slit experiment, the particle goes through one slit and the wave travels through both slits. But this doesn't make sense: As soon as one considers a system that consists of more than one particle, the wave function cannot be construed as a wave that spreads in physical space. Whatever it may be, the wave *function* isn't a wave.

David Bohm's (1952) revival of de Broglie's (1928) proposal is of another sort: Bohm associates the wave function with a specifically quantum force that is known as the quantum potential. Accordingly, he writes the guiding equation down as a second order equation. But this isn't convincing either. Whatever it may be, the wave function cannot be a Newtonian force. It doesn't satisfy Newton's third law. That is precisely the reason why position is an additional, so called hidden variable in Bohm's theory: the wave function acts on the particles, but the particles don't act back on the wave function. Hence, knowing the wave function does in general not provide information about the actual particle positions. Consequently, it isn't possible to conceive the *dynamics* of quantum objects along the lines of classical dynamics by adding a specifically quantum force. Trying to do so draws the attention away from the crucial point, namely that it is possible – and reasonable – to conceive the *ontology* of quantum objects on a par with the ontology of classical objects, namely as particles that always have a determinate position and hence move on trajectories. The confusion about a quasi-classical dynamics in Bohm's (1952) proposal often provokes the misconception that throws the baby away with the bathwater, namely to abandon the classical ontology of particles together with the classical dynamics.

Although the wave function can neither be a wave nor a force spreading in physical space, the view is widespread that in Bohm's quantum theory, both the particles and the wave function make up the basic ontology of physical things. Thus, David Albert writes in his seminal book of 1992 that was the first book that cleared up all the fuzz about measurement in quantum mechanics:

> What the physical world consists of besides particles and besides force fields, on this theory, is (oddly) *wave functions*. … The *quantum-mechanical wave functions* are conceived of in this theory as genuinely physical *things* … (Albert 1992, p. 135)

This is odd indeed. For me, I couldn't make sense of that and therefore didn't take Bohm's theory seriously for many years. For if indeed that were the truth of the matter, the Everettian had a good argument to convince the Bohmian: If we need the wave function anyway in our ontology of physical things, there's no point to admit particles in addition to the wave function as so called hidden variables. Harvey Brown (who used to be a Bohmian) and David Wallace (who is an outspoken Everrettian) drove that point home in a famous paper in 2005 (see Brown and Wallace 2005). However, Everettian quantum mechanics hardly is a convincing alternative through its denial of empirical reality, that is, the existence of a distribution of matter in space and time that manifests itself in measurement outcomes. By way of consequence, for lack of a better alternative, the legacy of Copenhagen still is influential and framed also my thoughts about quantum mechanics for many years, albeit purged of positivism and the fuzz about measurement.

However, everything is clear since Detlef Dürr, Shelly Goldstein and Nino Zanghì have developed Bohmian mechanics since the end of the 1980s. In their seminal paper published in 1992 (Dürr, Goldstein and Zanghì 1992), they write:

> What we regard as the obvious choice of primitive ontology—the basic kinds of entities that are to be the building blocks of everything else (except, of course, the wave function)—should by now be clear: Particles, described by their positions in space, changing with time—some of which, owing to the dynamical laws governing their evolution, perhaps combine to form the familiar macroscopic objects of daily experience. (Quoted from the reprint in Dürr, Goldstein and Zanghì 2013, p. 29)

Hence, the conclusion from the fact that an ontology of both the particles and the wave function being physical things is unconvincing is not that there only is the wave function. On the contrary, the ontology – that is, the primitive ontology of matter in space and time – is particles only. John Bell has laid the ground for clearing up the confusion in this way since he has coined the term "local beables" in 1975 (see Bell 1975).

What, then, is the wave function? According to Dürr, Goldstein and Zanghì, the wave function is nomological. That is not to say that it is a law on a par with the guiding equation or Newton's three laws. It is to say that it plays a nomological role: It consists in the role that it exercises for the motion of the particles – instead of being a physical entity over and above the particles. Again, John Bell makes this point without using the term "nomological" in the paper in which he introduces the notion of local beables in 1975:

> One of the apparent non-localities of quantum mechanics is the instantaneous, over all space, 'collapse of the wave function' on 'measurement'. But this does not bother us if we do not grant beable status to the wave function. We can regard it simply as a convenient but inessential mathematical device for formulating correlations between experimental procedures and experimental results, i.e., between one set of beables and another. Then its odd behaviour is acceptable as the funny behaviour of the scalar potential of Maxwell's theory in Coulomb gauge. (Quoted from the reprint in Bell 1987, p. 53)

Bell's wording here is unnecessarily instrumentalist. The crucial point is this one: If the particles are recognized as local beables, then we have all the beables that are required in physics. There is no need to admit the wave function as a further beable. Refusing to do so has moreover the advantage that it helps to dissipate concerns about quantum non-locality being some kind of "spooky action at a distance" (Born and Einstein 1971, p. 158) in Bohmian mechanics.

Bohmian mechanics satisfies Einstein's principle of separability (see Einstein 1948; English translation of the decisive passage in Howard 1985, pp. 187-188): Each particle always has a definite position of its own, and position is the only property of the particles. There are no superpositions of anything in physical space. Furthermore, in Bohmian mechanics, the violation of Einstein's principle of local action is not tied to – and hence not limited to – wave function collapse; the wave function never collapses. The rejection of superpositions and the respect of the principle of separability have the consequence that quantum non-locality is generic in Bohmian mechanics. For instance, in the double slit experiment, the trajectory of the particle after it has passed through one slit depends on whether or not the other slit is open. That dependence is immediate and independent of the distance between the two slits. The non-locality hence arises well before the particle hits the screen and a measurement occurs. But there's no action between the two slits.

In treating the wave function as nomological instead of as a physical entity on a par with the particles, Bohmian mechanics brings out that the nomological structure of the world is non-local. This means that the dynamics of the universe is holistic: The time evolution of any one particle in the universe is correlated with strictly speaking the time evolution of any other particle in the universe via the universal wave function figuring in the guiding equation. These non-local correlations are a nomological primitive. There is no further explanation or account of why the dynamics of the universe is non-local rather than local. In particular, there is no action in the sense of something spreading or being transmitted instantaneously across physical space. And there's no holism that blurs the distinction between the particles: They always have a determinate position, and position is their only property.

If the wave function is nomological in this sense, all the major stances in the metaphysics of laws of nature can be applied to it. In particular, it admits a treatment in the framework of what is known as Humeanism. On Humeanism, the primitive ontology is the *entire* ontology. Laws are the axioms or theorems of the best system, that is, the system that strikes the best balance between being simple and being informative in representing the evolution of the particular matters of fact, the particles in the case of Bohmian mechanics. In philosophical shoptalk, the laws supervene on the particle trajectories throughout space and time. The trajectories determine the laws, instead of the laws predetermining, governing or even producing the trajectories.

Applying this stance to the wave function leads to quantum Humeanism, which was elaborated on by several researchers independently of one another in the 2010s (Callender 2015, Miller 2014, Esfeld 2014, Bhogal & Perry 2017). The wave function is a parameter that figures in the best system. Hence, first come the particle trajectories as a matter of fact, then comes the universal wave function as dynamical parameter that belongs to the system that yields the best representation of the particle trajectories in terms of being simple and informative. This stance makes evident again that there is no conclusive reason to admit any sort of a necessary connection between distinct particles. As a matter of fact, when one seeks for a simple and informative representation of their motion, this will be one that represents their motion as being correlated via an entangled wave function figuring in the law of motion. That is all that there is to quantum non-locality.

Furthermore, quantum Humeanism implies that not only the wave function is nomological in being a parameter in the best system, but so are all the other physical magnitudes apart from the primitive variable of position. In Bohmian mechanics, all the magnitudes apart from position are situated on the level of the wave function, including the classical magnitudes of mass and charge (see Brown et al. 1995 and 1996). They're not intrinsic properties of the particles (see Esfeld et al. 2017). Hence, the primitive ontology, the mosaic of matter in space and time, consists of naked particles so to speak that are characterized only by their positions. This stance has subsequently become known as Super-Humeanism (see Esfeld and Deckert 2017, chapter 2.3).

Detlef Dürr wasn't a Humean about the nomological structure for sure. But this isn't a big deal to my mind: Humeanism is helpful to illustrate a number of issues such as the significance of non-locality as sketched out in this section. The big deal is to be clear about the distinction between on the one hand ontology in the sense of a primitive ontology of matter in space and time and on the other hand dynamical or nomological structure in the sense of what enters our physical theories in virtue of the function that it exercises for the motion of matter as captured by the primitive ontology.

2. Matter as res extensa

In the first discussion that I had with Detlef Dürr in September 2011, Detlef emphasized that all there is to matter is particles standing in spatial relations and the change of the relations – in short, matter moves. Everything else is dynamical or nomological structure consisting in the role that it plays for the motion of matter. This means that Bohmian mechanics is Cartesian science. Bohmian mechanics illustrates that Cartesianism remains valid in quantum mechanics. By "Cartesian science", I mean natural science as construed by Descartes.

The main feature of the Cartesian conception of matter is objectivity: The sensory qualities such as colours, sounds, tastes, smells and the like do not belong to the things in nature, but to our way of gaining knowledge of them by using our senses. If one abstracts from all these features, what remains of the natural world is extension and change in extension – that is, motion (see notably *Principia Philosophiae*, part 2, § 4). As physics then shows, extension, in turn, is in the last resort point particles standing in distance relations to each other.

There is a good reason for admitting that objectivity boils down to such a meagre treatment of matter: When examining a knowledge claim in science, all the empirical evidence that can be obtained to confirm or invalidate the claim in question consists in observations of the positions and changes of position of discrete objects. Accordingly, all measurement outcomes are recorded as relative positions within configurations of discrete objects – such as, for instance, pointer positions or digital numbers on a screen. John Bell emphasizes this point:

> … in physics the only observations we must consider are position observations, if only the positions of instrument pointers. It is a great merit of the de Broglie–Bohm picture to force us to consider this fact. If you make axioms, rather than definitions and theorems, about the 'measurement' of anything else, then you commit redundancy and risk inconsistency. (Quoted from the reprint in Bell 1987, p. 166)

The qualification "in physics" is appropriate: Common sense observations typically involve colours, sounds or scents of spatially arranged objects. In common sense, the positions of objects are discerned by means of these sensory qualities. Science abstracts from the sensory qualities. What then remains are the relative positions of discrete objects and their change. These are correlated with the sensory qualities, in the sense that science can account for changes in sensory qualities on the basis of changes in position.

According to physics, macroscopic objects are composed of microscopic objects that ultimately are point particles standing in distance relations. Consequently, if a theory describes the spatial arrangement of the particles and its change in time correctly – that is, the arrangement and evolution of fermionic matter (see Bell 1987, p. 175) –, it has got everything right that can ever be checked in scientific experiments (see also Maudlin 2019, pp. 49-50). Two theories that agree on the spatio-temporal arrangement of the elementary particles defined in terms of the positions of these particles only cannot be distinguished by any empirical means, whatever else they may otherwise say and disagree on. By the same token, two possible worlds with the same spatio-temporal arrangement of the elementary particles are indiscernible by any scientific means.

This is the strongest argument for treating position as the only basic or primitive physical magnitude, and thus for the natural world, insofar as it is accessible to science, being *res extensa* only: Admitting anything else over and above positions as basic or primitive would imply treating empirically indiscernible situations or worlds as being nonetheless different in some matters of fact. Obviously, this is a generalization of Leibniz' famous argument against Newton's ontological commitment to absolute space and time (see notably Leibniz' third letter to Clarke, § 5, in Leibniz 1890, pp. 363-364): The argument applies, in fact, to anything that is admitted as ontologically primitive in the scientific description of the world beyond relative positions and their change.

That notwithstanding, if all that there is to matter is distance relations between sparse point particles and the changes in these distances, it may seem that their material nature fades away upon inquiry. However, this concern is unfounded. There is nothing incoherent in the notion of point particles as elaborated on in Bohmian mechanics.

If there is a plurality of objects, there has to be something that individuates them – that is, something that answers the question why *this* is one object, *that* another, etc., so that there is a plurality of objects instead of just one. Furthermore, there also has to be something that unites these objects so that they make up a world. In other words, there has to be a world-making relation; that is, a relation that binds all and only those objects together that belong to a world. It is evident that the distance relation fulfils the latter task: All and only those objects that are spatially related constitute a world. If there were objects not at a distance from each other, they would inhabit different worlds. If they are related by distance, they are in one and the same world (see Lewis 1986, pp. 69-81).

Moreover, the distance relations – and only they – individuate the objects: What distinguishes each object in a configuration of objects is the position that it has relative to all the other objects. Even if a configuration is partially symmetrical, there always is at least one object in the real world outside that symmetry relative to which all the other objects can be distinguished. Magnitudes that are attributed to physical objects over and above their relative positions – such as mass or charge – cannot distinguish the latter: they differentiate between various kinds of particles, such as the particle species admitted in today's standard model of elementary particles. But they cannot distinguish between the individual particles within a species or kind, because all the particles of a given species – such as, for instance, all electrons – have the same values of mass, charge, etc. The demand for something that individuates the physical objects is fulfilled by the distance relations, and by them only. Therefore, there is no need for anything more than distance relations to both individuate the objects and have a relation that binds them together so that they constitute a world.

Indeed, one can regard these considerations as confirming the Cartesian metaphysics of nature, and vindicating it also in the context of contemporary science including quantum mechanics: Nature, insofar as it is accessible to scientific enquiry, is *res extensa.* That is to say, there is nothing more to matter than extension in the guise of distance relations individuating point particles and the change in these relations. Against this background, Dirk-André Deckert and myself have set out to show in our book published in 2017 how modern physics can be construed on the basis of a primitive ontology of matter that is defined by the following two axioms or principles:

(1) There are distance relations that individuate simple objects – namely, matter points.

(2) The matter points are permanent, with the distances between them changing. (Esfeld and Deckert 2017, p. 21).

At this general level, the geometry into which the configuration of matter has to be conceived as being embedded in order to achieve a representation of its dynamics remains completely open. Accordingly, the viability of this primitive ontology has to be vindicated for each physical theory separately, as outlined in the book Esfeld and Deckert (2017).

3. Mind as res cogitans

When I asked Detlef Dürr about the nature of the mind, he tended to reply that we shall tackle this subject when we will have a better understanding of physics. It seems to me that this attitude is based on a misunderstanding: Everything becomes clear when one realizes that Bohmian mechanics is Cartesian science. Unfortunately, our discussions about these issues came to an abrupt end through Detlef's untimely death.

Cartesian science abstracts from all subjective judgements and seeks objectivity. That is how one gets to Bohmian mechanics: matter being featureless point particles in motion. However, this very method of seeking objectivity implies that it can in principle not be applied to subjective features. If the scientific viewpoint consists in abstracting from the latter in order to reach objectivity, then it simply follows that those same subjective features are not accessible to the scientific viewpoint.

This limitation concerns in the first place sense experience. A being that has sense experience is not merely an object that moves according to certain laws of motion; rather, it has a subjective perception and feeling of what it is like to be in the world, having certain qualitative experiences. Science can discover sufficient physiological conditions for having sense experience, and the content of the experience may supervene on certain brain states, given certain conditions in the environment. Nevertheless, any scientific theory misses the qualitative character of the experience, the subjective perspective on the world. It cannot account for what it is like to see colours, taste cheese, smell smoke, jump for joy, etc. Accordingly, the issue of how to account for subjective experience has come to be known as the hard problem of consciousness following Chalmers (1996).

Subjective experience pertains to many higher-level animals. Thought and action – which, as far as we know, characterize only humans – presuppose a subjective perspective on the world, and thus experience, but are still categorically different from it. The obvious argument against human thought and action not being accessible to the method of Cartesian science is that in the case of these, the issue is not what the objective facts are, but how human subjects assess them in forming beliefs and intentions for action. This brings in free will. A being forms beliefs if and only if she has the capacity to position herself with respect to her sensory impressions, desires and needs and to make up her mind by deliberating about reasons for her beliefs and actions.

This freedom is also a presupposition for science. The very formulation, endorsement and testing in experience of a scientific theory presupposes the freedom of scientists to position themselves with respect to the evidence. The referents of the theory – whatever the theory poses as existing in the world – cannot impose acceptance of the theory on persons or justify the theory. In that sense – as beings that formulate and justify theories – persons are as ontologically primitive as are the point particles.

As one can spell out Cartesian *res extensa* in terms of point particles being individuated by distance relations, so one can spell out Cartesian *res cogitans* in terms of relations that are characteristic of the mind, namely thinking relations. That is to say: Standing in distance relations (extension) makes it that points are matter points (point particles), whereas standing in thinking relations makes it that points are minds. In neither case is there a substance in the sense of a thing with an intrinsic essence (see Esfeld 2020, chapter 3, for details).

Being clear about the distinction between primitive ontology and dynamical structure is a big deal also because it dissipates concerns that one may have about the theory of matter being incompatible with the central features of the mind such as notably free will. Bohmian mechanics is a deterministic theory. However, on Bohmian Humeanism, the trajectories that the particles take in fact fix what the wave function of the universe is, instead of the wave function governing or even producing the trajectories. Hence, on this stance, there is no conflict between a deterministic dynamics and humans having free will because the laws being deterministic doesn't imply that anything that happens in the world is predetermined in the sense of being necessitated by something else. Against this background, there is the prospect of making a precise proposal how there can be – even libertarian – free will in a Bohmian universe (see Esfeld 2020, chapter 2.3, and Esfeld 2022 for details, although the proposal still needs elaboration).

Furthermore, Bohmian mechanics leaves many options in the philosophy of time open, including even presentism. As Tim Maudlin notes,

> Bohm's theory is deeply congenial to an ontology which maintains that all which exists is that which exists *now*, i.e. at a point in time classically conceived. … Those puzzled about the status of velocities in an ontology in which only an instant of time *exists* can happily adopt a Bohmian ontology of particles (with position) and the wave-function. (Maudlin 2011, p. 113 note 22)

Bohmian mechanics is not even committed to absolute time. It can be conceived in a Leibnizean, relationalist framework. As Detlef Dürr (2020) showed in one of the last research projects to which he contributed, Bohmian mechanics can be done on shape space, that is, by working only with relational and thus scale invariant quantities, instead of conceiving the particle configuration as being inserted in an absolute space and time. Hence, in Bohmian mechanics, the ontology of space and time can be as parsimonious as the ontology of matter.

In particular, if one endorses Bohmian presentism (which can be construed as relationalist presentism) and Bohmian Humeanism, there is no problem to admit an open future, which one may consider as being required for free will.

This is the big deal: epistemic humility about science without compromising the scientific enterprise. Bohmian mechanics shows how one can be committed to a fully objective, fully scientific realist and fully deterministic theory of matter and its evolution and yet be clear about the limits of objective science. There's nothing in this theory that imposes anything on us that might be considered as coming into conflict with central features of the mind such as the openness of the future or human free will even on a libertarian conception of free will. To avoid the pitfalls of scientism – that is the view that science in the sense of modern natural science is unlimited –, there is no need to compromise physics in any way (as done when one takes quantum mechanics to undermine deterministic laws of nature or even realism). One just has to understand how Bohmian mechanics vindicates Cartesian science also in the domain of quantum physics.

References

Albert, David Z. (1992): *Quantum mechanics and experience*. Cambridge (Massachusetts): Harvard University Press.

Bell, John S. (1975): "The theory of local beables". *Th-2053-CERN*, 28 July 1975.

Bell, John S. (1987): *Speakable and unspeakable in quantum mechanics*. Cambridge: Cambridge University Press.

Bhogal, Harjit and Perry, Zee (2017): "What the Humean should say about entanglement". *Noûs* 51, pp. 74-94.

Bohm, David (1952): "A suggested interpretation of the quantum theory in terms of 'hidden' variables. I and II". *Physical Review* 85, pp. 166-179, 180-193.

Born, Hedwig and Max and Einstein, Albert (1971): *The Born-Einstein letters. Translated by Irene Born*. London: Macmillan.

Brown, Harvey R., Dewdney, Chris and Horton, G. (1995): "Bohm particles and their detection in the light of neutron interferometry". *Foundations of Physics* 25, pp. 329-347.

Brown, Harvey R., Elby, Andrew and Weingard, Robert (1996): "Cause and effect in the pilot-wave interpretation of quantum mechanics". In: J. T. Cushing, A. Fine and S. Goldstein (eds.): *Bohmian mechanics and quantum theory: an appraisal*. Dordrecht: Springer. Pp. 309-319.

Brown, Harvey R. and Wallace, David (2005): "Solving the measurement problem: de Broglie-Bohm loses out to Everett". *Foundations of Physics* 35, pp. 517-540.

Callender, Craig (2015): "One world, one beable". *Synthese* 192, pp. 3153-3177.

Chalmers, David J. (1996): *The conscious mind. In search of a fundamental theory*. Oxford: Oxford University Press.

de Broglie, Louis (1928): "La nouvelle dynamique des quanta". In: *Electrons et photons. Rapports et discussions du cinquième Conseil de physique tenu à Bruxelles du 24 au 29 octobre 1927 sous les auspices de l'Institut international de physique Solvay*. Paris: Gauthier-Villars. Pp. 105-132. English translation in G. Bacciagaluppi and A. Valentini (2009): *Quantum theory at the crossroads. Reconsidering the 1927 Solvay conference*. Cambridge: Cambridge University Press. Pp. 341-371.

Dürr, Detlef, Goldstein, Sheldon and Zanghì, Nino (1992): "Quantum equilibrium and the origin of absolute uncertainty". *Journal of Statistical Physics* 67, pp. 843-907.

Dürr, Detlef, Goldstein, Sheldon and Zanghì, Nino (2013): *Quantum physics without quantum philosophy*. Berlin: Springer.

Dürr, Detlef, Goldstein, Sheldon and Zanghì, Nino (2020): "Quantum motion on shape space and the gauge dependent emergence of dynamics and probability in absolute space and time". *Journal of Statistical Physics* 180, pp. 1-43.

Einstein, Albert (1948): "Quanten–Mechanik und Wirklichkeit". *Dialectica* 2, pp. 320-324.

Esfeld, Michael (2014): "Quantum Humeanism". *Philosophical Quarterly* 64, pp. 453-470.

Esfeld, Michael (2020): *Science and human freedom*. London: Palgrave-Macmillan.

Esfeld, Michael (2022): "Super-Humeanism and mental causation". In: C. J. Austin, A. Marmodoro and A. Roselli (eds.): *Powers, time and free will*. Cham: Springer. Pp. 257-272.

Esfeld, Michael and Deckert, Dirk-André (2017): *A minimalist ontology of the natural world*. New York: Routledge.

Esfeld, Michael, Lazarovici, Dustin, Lam, Vincent and Hubert, Mario (2017): "The physics and metaphysics of primitive stuff". *British Journal for the Philosophy of Science* 68, pp. 133-161.

Howard, Don (1985): "Einstein on locality and separability". *Studies in History and Philosophy of Science* 16, pp. 171-201.

Leibniz, Gottfried Wilhelm (1890): *Die philosophischen Schriften von G. W. Leibniz. Band 7. Edited by C. I. Gerhardt*. Berlin: Weidmannsche Verlagsbuchhandlung.

Lewis, David (1986): *On the plurality of worlds*. Oxford: Blackwell.

Maudlin, Tim (2011): *Quantum non-locality and relativity.* Chichester: Wiley-Blackwell. Third edition. First edition 1994.

Maudlin, Tim (2019): *Philosophy of physics. Quantum theory*. Princeton: Princeton University Press.

Miller, Elizabeth (2014): "Quantum entanglement, Bohmian mechanics, and Humean supervenience". *Australasian Journal of Philosophy* 92, pp. 567-583.