Why the ontology of Bohmian mechanics cannot include only particles or particles and the wave function

Shan Gao
Research Center for Philosophy of Science and Technology,
Shanxi University, Taiyuan 030006, P. R. China
E-mail: gaoshan2017@sxu.edu.cn.

July 3, 2023

Abstract

I propose a simple experiment and argue that the result of this experiment rejects the view that there are only particles or particles and the wave function in the ontology of Bohmian mechanics.

Bohmian mechanics or the pilot-wave theory of de Broglie and Bohm is an alternative to standard quantum mechanics initially proposed by de Broglie (1928) and later developed by Bohm (1952). In this theory, a complete description of a quantum system is provided by the configuration defined by the positions of its particles together with its wave function. The wave function follows the Schrödinger equation. The particles, called Bohmian particles, are guided by the wave function, and their motion follows the so-called guiding equation. Although Bohmian mechanics is mathematically equivalent to quantum mechanics, there is no clear consensus with regard to its physical interpretation. In particular, it has been debated what the ontology of Bohmian mechanics really is. According to some authors, the universal wave function is not ontic, representing a concrete physical entity, but nomological, like a law of nature (Dürr et al, 1992; Allori et al, 2008; Goldstein and Zanghì, 2013; Esfeld et al, 2014; Goldstein, 2021). On this view, there are only particles in space and time in the ontology of Bohmian mechanics.[1] While according to others (Bohm and Hiley, 1993; Holland, 1993; Gao, 2017; Hubert and Romano, 2018; Valentini, 2020), the

[1]Note that unlike Humeanism and dispositionalism, primitivism about laws as suggested by Maudlin (2007) attributes a fundamental ontic role to the universal wave function. Thus, on primitivism one may also say that the ontology of Bohmian mechanics includes both particles and the wave function even when assuming the nomological view of the wave function (see Dorato and Esfeld, 2015; Dorato, 2015 for a different view).

ontology of Bohmian mechanics includes both particles and the wave function. In this paper, I will present a new analysis of the ontology of Bohmian mechanics. Concretely speaking, I will propose a mass measurement experiment and argue that the result of this experiment rejects the view that there are only particles or particles and the wave function in the ontology of Bohmian mechanics.[2]

Suppose in a lab there are two settings, each of which contains a box, a measured particle and a test particle. The two boxes are identical. The two measured particles have different masses and they are in the same ground state in the two boxes, and their Bohmian particles are at rest in the same position in the two boxes. The two test particles, which are identical and whose initial states are the same Gaussian wavepacket narrow in both position and momentum, are shot along a straight line near the two boxes and perpendicular to the line of separation between the two boxes, and their Bohmian particles have the same initial velocities. The interactions are supposed to be adiabatic so that the ground state of each measured particle does not change during the process. According to the Schrödinger equation, the trajectories of the wavepackets of the two test particles will be deviated by different amounts due to the different gravitational interactions between the test particles and the measured particles. Moreover, according to the guiding equation, the trajectories of the Bohmian particles of the two test particles will be also deviated by different amounts. Different deviations indicate that the measured particles have different masses (see Figure 1).

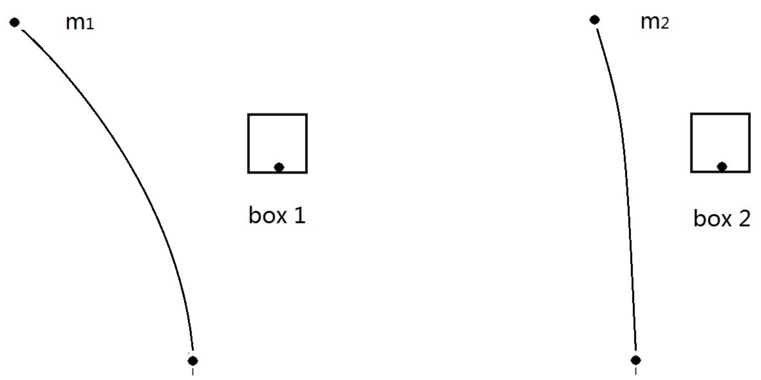

Figure 1: A simple experiment that measures the mass of a particle

Now let's use this experiment to examine several views about the ontology of Bohmian mechanics. The first view is that there are only Bohmian

[2]My analysis and its result also applies to charge and other dynamical state-independent parameters in the Schrödinger equation.

particles without mass property in the ontology of Bohmian mechanics. According to this view, the initial ontic states or states of motion of the Bohmian particles in the two settings are the same (when assuming space translation invariance). Since the laws of motion for the two settings are the same,[3] the later ontic states of the Bohmian particles in the two settings will be also the same, which means that the trajectories of the test Bohmian particles will be deviated by the same amount. This is inconsistent with the above predictions of Bohmian mechanics.

The second view is that there are only Bohmian particles with mass property in the ontology of Bohmian mechanics. According to this view, the initial ontic states of the Bohmian particles in the two settings are different, since the two measured Bohmian particles have different masses. However, the different masses of the two measured Bohmian particles do not lead to the different deviations of the trajectories of the two test Bohmian particles. This is what the laws of motion of Bohmian mechanics says. The deviation of the trajectory of the wavepacket of each test particle (and thus the deviation of the trajectory of each test Bohmian particle) is caused by the gravitational interaction between the test particle and the measured particle as described by the interaction Hamiltonian in the Schrödinger equation, which has nothing to do with the measured Bohmian particle and whether it has mass. A simpler way to see this is to consider the special cases in which the two Bohmian particles in the boxes are in one node of their wave functions initially. In this case, the two measured Bohmian particles do not exist during the experiment and thus they cannot influence the motion of the two test Bohmian particles. Thus, the second view is inconsistent with the predictions of Bohmian mechanics either.

The third view is that there are only Bohmian particles and the wave function in the ontology of Bohmian mechanics, and the wave function is regarded as a physical field in a fundamental high-dimensional space (Albert, 1996, 2013, Ney, 2021) or a multi-field in three-dimensional space (Forrest, 1988; Belot, 2012; Hubert and Romano, 2018; Romano, 2021), or a lawlike ontological element (e.g. on the nomological view of the wave function with primitivism about laws) (Maudlin, 2007). According to this view, if the Bohmian particles have no mass property, then the initial ontic states of the Bohmian particles and the wave functions in the two settings will be the same. Then, like the first view, this view is inconsistent with the predictions of Bohmian mechanics. If the Bohmian particles have masses, then like the second view, we can also argue that this view is inconsistent with the predictions of Bohmian mechanics, since the different masses of the measured Bohmian particles do not lead to the different deviations of the trajectories of the test Bohmian particles.

[3]Since the two settings (which are the same in ontology) cannot be distinguished, the laws of motion must be the same for them.

The above three views seem to include all current views on the ontology of Bohmian mechanics. The first two views include the nomological view of the wave function with Humeanism or dispositionalism about laws. The third view includes the nomological view of the wave function with primitivism about laws and the conventional view that there are particles (with mass property) and the wave function (as a physical field without mass property) in the ontology of Bohmian mechanics. The above analysis shows that these views are inconsistent with the predictions of Bohmian mechanics.

To sum up, I have argued that the current views on the ontology of Bohmian mechanics are not complete enough for explaining the results of certain mass measurement experiments. The reason is that these views do not take the mass parameter in the Schrödinger equation seriously. In my view, it will be a great challenge for the Bohmians to include mass properly in the ontology of Bohmian mechanics.[4]

References

[1] Albert, D. Z. (1996). Elementary Quantum Metaphysics. In J. Cushing, A. Fine and S. Goldstein (eds.), Bohmian Mechanics and Quantum Theory: An Appraisal. Dordrecht: Kluwer, 277-284.

[2] Albert, D. Z. (2013). Wave function realism. In Ney, A. and D. Z. Albert (eds.), The Wave Function: Essays on the Metaphysics of Quantum Mechanics. Oxford: Oxford University Press. pp. 52-57.

[3] Allori, V., S. Goldstein, R. Tumulka, and N. Zanghì (2008). On the common structure of Bohmian mechanics and the Ghirardi-Rimini-Weber theory, British Journal for the Philosophy of Science 59 (3), 353-389.

[4] Anandan, J. and Brown, H. R. (1995). On the reality of space-time geometry and the wavefunction. Found. Phys. 25, 349-360.

[5] Belot, G. (2012). Quantum states for primitive ontologists: A case study European Journal for Philosophy of Science, 2(1): 67-83.

[6] Bohm, D. (1952). A suggested interpretation of quantum theory in terms of “hidden” variables, I and II. Physical Review 85, 166-193.

[7] Bohm, D. and B. J. Hiley (1993). The Undivided Universe: An Ontological Interpretation of Quantum Theory. London: Routledge.

[4]For some early discussions on this issue see Holland (1993, Sec. 3.3.1), Brown, Dewdney and Horton (1995), Anandan and Brown (1995), Brown, Elby and Weingard (1996) and Gao (2012).

[8] Brown, H. R., Dewdney, C. and Horton, G. (1995). Bohm particles and their detection in the light of neutron interferometry. Found. Phys. 25, 329.

[9] Brown, H. R. , Elby, A. and Weingard, R. (1996). Cause and effect in the pilot-wave interpretation of quantum mechanics, in: Bohmian Mechanics and Quantum Theory: An Appraisal, eds. J. T. Cushing, A. Fine, S. Goldstein. Kluwer: Dordrecht.

[10] de Broglie, L. (1928). La nouvelle dynamique des Fields Quanta. In J. Bordet (eds.), Electrons et photons: Rapports et discussions du cinquime Conseil de Physique. Paris: Gauthier-Villars. pp.105-132. English translation: The new dynamics of quanta, in Bacciagaluppi and Valentini (2009), pp.341-371.

[11] Dorato, M. (2015) Laws of nature and the reality of the wave function. Synthese, 192, 3179-3201.

[12] Dorato, M. and M. Esfeld (2015). The metaphysics of laws: dispositionalism vs. primitivism. In: Tomasz Bigaj and Christian Wthrich (eds.), Metaphysics in Contemporary Physics Pozna Studies in the Philosophy of the Sciences and the Humanities, vol. 104), pp. 403-424. Amsterdam/New York, NY: Rodopi, Brill.

[13] Dürr, D., S. Goldstein, and N. Zanghì (1992). Quantum equilibrium and the origin of absolute uncertainty. Journal of Statistical Physics 67, 843-907.

[14] Esfeld, M., Lazarovici, D., Hubert, M. and Dürr, D. (2014). The ontology of Bohmian mechanics. British Journal for the Philosophy of Science. 65 (4), 773-796.

[15] Forrest, P. (1988). Quantum Metaphysics. Oxford: Basil Blackwell.

[16] Gao, S. (2012). Is the electron's charge 2e? A problem of the de Broglie-Bohm theory. http://philsci-archive.pitt.edu/9087.

[17] Gao, S. (2017). The Meaning of the Wave Function: In Search of the Ontology of Quantum Mechanics. Cambridge: Cambridge University Press.

[18] Goldstein, S. (2021). Bohmian Mechanics, The Stanford Encyclopedia of Philosophy (Fall 2021 Edition), Edward N. Zalta (ed.), https://plato.stanford.edu/archives/fall2021/entries/qm-bohm/.

[19] Goldstein, S. and N. Zanghì (2013). Reality and the Role of the Wave Function in Quantum Theory. In Quantum Physics Without Quantum Philosophy, pp. 263-278. Berlin, Springer.

[20] Holland, P. R. (1993). The Quantum Theory of Motion: An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics. Cambridge: Cambridge University Press.

[21] Hubert, M. and Romano, D. (2018). The wave-function as a multi-field. European Journal for Philosophy of Science 8, 521-537.

[22] Maudlin, T. (2007). The Metaphysics within Physics. Oxford: Oxford University Press.

[23] Ney, A. (2021). The World in the Wave Function: A Metaphysics for Quantum Physics. Oxford: Oxford University Press.

[24] Romano, D. (2021). Multi-field and Bohm's theory. Synthese 198, 10587-10609.

[25] Valentini, A. (2020). Foundations of statistical mechanics and the status of the Born rule in de Broglie-Bohm pilot-wave theory. In V. Allori (ed.), Statistical Mechanics and Scientific Explanation: Determinism, Indeterminism and Laws of Nature. World Scientific. pp. 423-477.