What if there are only particles in Bohmian mechanics?

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Abstract

It has been suggested that the wave function of the universe is not ontic but nomological, and there are only particles in ontology in Bohmian mechanics. In this paper, I show that empirical differences are not grounded in a difference in the ontology for some measurements according to this theory.

Suppose a scientist tries to find if there is something or nothing in a box. She finds that her detector, which does not react to an empty box, reacts to the box. Then she concludes that there is something in the box, which results in the reaction of her detector. This is the common practice of doing science. However, a skeptic may not believe this line of reasoning. He thinks that there is still nothing in the box, and why the detector reacts differently to the box and to an empty box is because the laws of Nature are different for the two situations. Does anyone agree with the skeptic? Some Bohmians, maybe. In this paper, I will point out that in Bohmian mechanics with particle ontology only, empirical differences from some measurements are not grounded in a difference in the ontology.

Bohmian mechanics or the pilot-wave theory of de Broglie and Bohm provides an ontology of quantum mechanics in terms of particles and their trajectories in space and time (de Broglie, 1928; Bohm, 1952). In Bohmian mechanics, a complete realistic description of a quantum system is provided by the configuration defined by the positions of its particles together with its wave function. The law of motion is expressed by two equations: a guiding equation for the configuration of particles and the Schrödinger equation, describing the time evolution of the wave function which enters the guiding equation. The law of motion can be formulated as follows:

$$\frac{dX(t)}{dt} = v^{\Psi(t)}(X(t)), \tag{1}$$

$$i\hbar \frac{\partial \Psi(t)}{\partial t} = H\Psi(t), \tag{2}$$

where $X(t)$ denotes the spatial configuration of particles, $\Psi(t)$ is the wave function at time t, and v equals to the velocity of probability density in standard quantum mechanics. Moreover, it is assumed that at some initial instant t_0, the epistemic probability of the configuration, $\rho(X(t_0), t_0)$, is given by the Born rule: $\rho(X(t_0), t_0) = |\Psi(X(t_0), t_0)|^2$. This is the quantum equilibrium hypothesis, which, together with the law of motion, ensures the empirical equivalence between Bohmian mechanics and standard quantum mechanics.

The status of the above equations is different, depending on whether one considers the physical description of the universe as a whole or of a subsystem thereof. Bohmian mechanics starts from the concept of a universal wave function (i.e. the wave function of the universe), figuring in the fundamental law of motion for all the particles in the universe. That is, $Q(t)$ describes the configuration of all the particles in the universe at time t, and $\Psi(t)$ is the wave function of the universe at time t, guiding the motion of all particles taken together. It has been suggested that the wave function of the universe is not ontic, representing a concrete physical entity, but nomological, like a law of nature (Dürr et al, 1992; Allori et al, 2008; Esfeld et al, 2014; Goldstein, 2021). On this view, there are only particles in ontology in Bohmian mechanics.

Take the double-slit experiment as an example. According to Bohmian mechanics with the nomological view, in the double-slit experiment with one particle at a time, the particle goes through exactly one of the two slits, and that is all there is in the physical world. There is no field or wave that guides the motion of the particle and propagates through both slits and undergoes interference. The development of the position of the particle (its velocity and thus its trajectory) is determined by the universal wave function and the positions of other particles in the universe, and the non-local law of Bohmian mechanics can account for the observed particle position on the screen (Esfeld et al, 2014).

In the following, I will present a new analysis of Bohmian mechanics with the nomological view. Consider a measurement of the energy of two electrons being in different energy eigenstates in two identical boxes. The measurement results will be different. According to Bohmian mechanics with the nomological view, the ontic states of the two systems may be the same; there are only one Bohmian particle in each box, and they may be at rest in the same position relative to the box during the measurement.

Moreover, even if the two Bohmian particles are at rest in different positions in the two boxes, they do not result in different measurement results; the result of the measurement of the energy of an electron being in the same energy eigenstate in a box is always the same, independently of where the Bohmian particle of the electron is in the box. Note that the environment is the same for the two measurements. Thus, in Bohmian mechanics with the nomological view, empirical differences from the above measurements are not grounded in a difference in the ontology.

A similar argument can be given for the projective measurements of the eigenstates of all observables other than position. In addition, we can also give an argument even for position by means of protective measurements (Aharonov and Vaidman, 1993; Aharonov, Anandan and Vaidman, 1993; Gao, 2015). Let the explicit forms of the above two energy eigenstates at a given instant be $\psi_i(x)$ and $\psi_j(x)$, and the measured observable A be (normalized) projection operators on small spatial regions V_n having volume v_n:

$$A = \begin{cases} \frac{1}{v_n}, & \text{if } x \in V_n, \\ 0, & \text{if } x \notin V_n. \end{cases} \tag{3}$$

A protective measurement of A in these two states then yields

$$\langle A \rangle_i = \frac{1}{v_n} \int_{V_n} |\psi_i(x)|^2 dv, \tag{4}$$

$$\langle A \rangle_j = \frac{1}{v_n} \int_{V_n} |\psi_j(x)|^2 dv, \tag{5}$$

which is the average of the densities $\rho_i(x) = |\psi_i(x)|^2$ and $\rho_j(x) = |\psi_j(x)|^2$ over the small region V_n, respectively. Since the two energy eigenstates are different, we can choose a measured position where these two results are different. Thus, empirical differences from protective measurements of position may be not grounded in a difference in the ontology either.

Finally, it is worth noting that in Bohmian mechanics with particle ontology only, empirical differences from projective measurements of position (or another observable in a superposition of different eigenstates of the observable) are indeed grounded in a difference in the ontology. By a projective measurement of position, we can measure where the Bohmian particle is within the precision of $|\psi(x)|^2$ (Dürr et al, 1992).

To sum up, I have argued that empirical differences from some measurements are not grounded in a difference in the ontology in Bohmian mechanics with particle ontology only. This result seems counter-intuitive. Whether it poses an issue for the theory deserves further study.

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