Studies in History and Philosophy of Modern Physics 44 (2013) 365–378

Contents lists available at ScienceDirect

Studies in History and Philosophy of Modern Physics

journal homepage: www.elsevier.com/locate/shpsb

Bohmian mechanics without wave function ontology

Albert Solé

Department of Philosophy, Facultat de Filosofia i Lletres, Edifici B, Universitat Autònoma de Barcelona, 08193 Bellaterra, Cerdanyola del Vallès, Barcelona, Spain

ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form
4 July 2013
Accepted 26 July 2013
Available online 13 September 2013

Keywords:
Bohmian mechanics
Quantum mechanics
Quantum potential
Wave function
Explanation
Causation

ABSTRACT

In this paper, I critically assess different interpretations of Bohmian mechanics that are not committed to an ontology based on the wave function being an actual physical object that inhabits configuration space. More specifically, my aim is to explore the connection between the denial of configuration space realism and another interpretive debate that is specific to Bohmian mechanics: the quantum potential versus guidance approaches. Whereas defenders of the quantum potential approach to the theory claim that Bohmian mechanics is better formulated as quasi-Newtonian, via the postulation of forces proportional to acceleration; advocates of the guidance approach defend the notion that the theory is essentially first-order and incorporates some concepts akin to those of Aristotelian physics. Here I analyze whether the desideratum of an interpretation of Bohmian mechanics that is both explanatorily adequate and not committed to configuration space realism favors one of these two approaches to the theory over the other. Contrary to some recent claims in the literature, I argue that the quasi-Newtonian approach based on the idea of a quantum potential does not come out the winner.

When citing this paper, please use the full journal title *Studies in History and Philosophy of Modern Physics*

1. Introduction

Wave function realism is the view that the wave function refers to and faithfully represents a physical substance that exists “out there” in the world—some sort of wave function stuff. Historically, such a view has not enjoyed much credence. Although Schrödinger first attempted to interpret the wave function as a real vibrating process, the difficulties of such a view very soon became apparent. First, the Gaussian wave packet of a free electron quickly spreads out, thus complicating any explanation of the notorious particle character of the electron. Second, and more importantly, the wave function of an N-particle system is not a function of the three ordinary spatial coordinates, but is defined in *configuration space*; that is, the 3N-dimensional space each point of which represents a possible configuration of the N particles in three-dimensional space. Therefore, to think of the wave function as a real vibrating process would be to make a commitment to the existence of configuration space and very few were at the time willing to accept such revisionary metaphysics. In addition to these difficulties, the fact that there is only a statistical link between the measured properties of a system and the wave function prompted a grossly instrumentalist interpretation of the latter.[1]

The anti-realist attitude towards the wave function seems, however, to be reversed in the context of Bohmian mechanics. As is well known, the ontology of that theory includes particles that describe precise trajectories. Those trajectories depend on the wave function very much as the trajectories of particles depend on gravitational and electromagnetic fields in classical mechanics. Because of this analogy, it has become customary in Bohmian mechanics to interpret the wave function as representing a physical field that guides the particles—despite its multidimensional character.[2] In this paper, I resist such an interpretation and I assess the prospects for

[1] As I note above, wave function realism amounts to the view that the wave function is a physical *object*. This is how wave function realism has been understood by many authors, among them Albert (1996). There are clearly more possibilities when it comes to understanding the nature of the wave function. For instance—and following Belot's (2012) apt classification—the wave function can alternatively be taken to represent either a *property* of a physical system or a *law*. According to these interpretive possibilities, the wave function does not exist as a separate physical substance, yet it obviously retains some degree of reality; hence, they should not be conflated with instrumentalism. In what follows, I will explore in depth some variants of these latter interpretive suggestions within the context of Bohmian mechanics.

[2] Examples of Bohmians who are committed to a field interpretation of the wave function are: Bell (1987), Valentini (1992), Holland (1993), and Bohm & Hiley (1993).

E-mail address: Albert.Sole@uab.cat

1355-2198/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.shpsb.2013.07.004

interpreting Bohmian mechanics without making a commitment to the physical existence of a field or any other entity that is defined in configuration space. In what follows, I will refer to interpretations that are not committed to the existence of physical entities inhabiting configuration space as *three-dimensionalist* interpretations of the theory.

The issue of how to interpret Bohmian mechanics is a topic that has many ramifications. I restrict my considerations to the putative implications that enforcing the three-dimensionalist desideratum may have upon another important interpretive debate within the Bohmian camp. That debate essentially concerns the form of the fundamental law of motion of Bohmian particles and the explanatory resources that are naturally available to the Bohmian. Defenders of what I will call the *quantum potential* approach to the theory claim that Bohmian mechanics is essentially a second-order theory with a law of motion for Bohmian particles that is identical to Newton's Second Law, except for the addition of a new quantum force arising from a potential energy term that depends on the wave function. Those who are sympathetic to such an approach consider that the dynamic and explanatory concepts characteristic of Newtonian mechanics also perform a fundamental explanatory role in Bohmian mechanics.[3] In contrast, according to defenders of the *guidance* approach, Bohmian mechanics is essentially a first-order theory and it is the velocity, rather than the acceleration, that plays a privileged role.[4,5] Some authors defend, in addition, the idea that the guidance approach to the theory incorporates dynamic and explanatory concepts that are somehow akin to those that are characteristic of Aristotelian physics.

Although the three-dimensionalist commitment seems, *prima facie*, totally irrelevant with regards to the disagreement between defenders of the two approaches to Bohmian mechanics, recent developments in the literature seem to indicate quite the opposite. Dürr et al. (1992, 1997) (hereafter, DGZ) were the first authors to develop a fully-fledged three-dimensionalist interpretation of the theory. In broad terms, those authors claim that the wave function must not be interpreted as a physical object, but should be seen as law-like in nature. In addition, DGZ are explicit in rejecting second-order dynamic concepts and openly support the guidance view. Their interpretation has not escaped criticism and it is dismissed as explanatorily wanting by Belousek (2003) and Suárez (2007). These latter two authors consider the quantum potential approach to be superior in terms of explanatory power and each of them draws on conceptual resources that are characteristic of that approach to build a three-dimensionalist interpretation of Bohmian mechanics that purportedly fares better than the DGZ interpretation in accounting for the phenomena.

In what follows, I argue—in contrast to what Belousek and Suárez maintain—that the desideratum of an interpretation of Bohmian mechanics that is both three-dimensionalist and adequate from the point of view of explanation does *not* provide grounds for favoring the quantum potential approach. I do so, first, by arguing that the DGZ interpretation may not turn out to be so explanatorily wanting, if accounts of explanation other than those vindicated by Belousek and Suárez are considered. Second, I introduce two new three-dimensionalist interpretations of the theory that rely only on resources that are characteristic of the guidance approach and, nevertheless, are at least as explanatory as Belousek's and Suarez's own interpretive proposals *according to those authors' favorite accounts of explanation*.

The paper is structured as follows. In Section 2, I briefly motivate the program of devising a three-dimensionalist interpretation of Bohmian mechanics by reviewing some of the problems of wave function realism. In Section 3, I properly introduce Bohmian mechanics and the interpretive divide between the guidance and the quantum potential approaches. I place particular emphasis on Valentini's (1992, 1997) attempt to interpret the guidance approach to the theory as underwriting the postulate of Aristotelian forces, since this postulate will be highly relevant to my own interpretive proposals. In Section 4, I introduce DGZ's interpretation within the guidance approach, carefully assessing the attempt by those authors to provide a nomological reading of the wave function. In Section 5, I evaluate both Belousek's (2003) criticism of the DGZ interpretation and the three-dimensionalist interpretive proposal within the quantum potential approach that he offers in reply. In Section 6, I discuss Suárez's (2007) three-dimensionalist interpretation of Bohmian mechanics, which is also committed to the quantum potential approach. In Section 7, I introduce two new three-dimensionalist interpretive proposals that operate within the guidance approach and compare them with Belousek's and Suárez's interpretations of the theory, and I show that the new proposals accrue some explanatory advantages. I end with some brief concluding remarks in Section 8.

The specific theme of this paper is the contrast between the guidance and the quantum potential views, and its bearing upon the project of devising a satisfactory three-dimensionalist interpretation of the theory. However, I also hope to offer valuable, up-to-date assessments of many of the extant interpretations on offer, thus providing a general survey of how well (or badly) we can interpret Bohmian mechanics without wave function ontology.[6]

2. Wave function ontology?

Despite its poor historical record, wave function realism has recently been on the up, due in part to the polemic defense of such a view by Albert (1996) and ever increasing interest in the (Everettian) many-worlds interpretation of quantum mechanics. Albert argues that realism about quantum mechanics in any of its interpretations commits one "to think of wave functions as physical objects in and of themselves" and the conclusion he draws from this is that "the space *we* live in […] is *configuration*-space" (p. 277; emphasis in the original). I do not consider that such revisionary metaphysics is untenable per se; but it does pose (at least) two problems. The first, most obvious challenge for the configuration space realist is that they owe us an account of the manifest three-dimensional character of our perception. Let me refer to this as the "problem of perception". A second, not completely unrelated difficulty is what I call the "problem of

[3] Supporters of the quantum potential approach are, for instance, Bohm (1952), Bohm & Hiley (1993) and Holland (1993).

[4] Supporters of the guidance approach are, for instance, Bell (1987), Valentini (1992, 1997) and Dürr, Goldstein, & Zanghì (1992, 1997).

[5] Many authors refer to what I call the quantum potential approach as the '*causal*' view of the theory; whereas the guidance approach is sometimes dubbed the '*minimalist*' view of the theory. Since both approaches are open to an interpretation of the movement of Bohmian particles in deterministic causal terms, I think that the use of the term 'causal' to refer to just one of them is misleading. I describe both approaches in some detail in Section 3 below, but the *locus classicus* for a characterization of both views is Baublitz & Shimony (1996). Belousek (2003) also offers a lengthy discussion of this interpretive divide.

[6] Monton (2002) assumes that a *wave function ontology* is an ontology of objects all of which are defined in configuration space. A *mixed ontology* is an ontology that takes both configuration space and the ordinary three-dimensional space to exist. Finally, we could have purely three-dimensionalist ontologies. Here, when talking of doing Bohmian mechanics without wave function ontology, I am merely referring to imposing the three-dimensionalist constraint, according to which the wave function cannot be taken to represent a physical object inhabiting configuration space. This does not mean that there cannot be elements in the ontology that are related to the wave function; which is allowed, as long as those elements do not require us to presuppose the existence of configuration space.