# The Bohmian interpretation of quantum mechanics : a pitfall for realism

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## Abstract

The de Broglie-Bohm interpretation of quantum mechanics (BM) has been favored as the preferred alternative to standard quantum mechanics on the ground that it allows a realist construal of the quantum world. We examine in the present work whether BM is consistent with scientific realism. Indeed, Bohmian mechanics makes strong ontological claims but accepts in principle the impossibility of generating epistemic warrants in support of its assumptions. We will argue that such a situation gives rise, at best, to an unsolvable underdetermination dilemma. This leads in turn to the following paradox: although Bohmian mechanics has frequently been invoked to reconcile quantum mechanics with realism, its status as a valid interpretation of quantum mechanics hinges nonetheless on nonevidential epistemological arguments traditionally associated with antirealism.

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## 1. Introduction

Undoubtedly, quantum mechanics has been the most successful scientific theory of all times. According to the celebrated slogan stating that scientific "realism is the only philosophy that doesn't make the success of science a *miracle*" (Putnam 1975, p. 73), quantum mechanics should have strengthened the ideas that (i) scientific theories speak in some form of a mind-independent reality, (ii) certain terms in scientific theories relate to features of real entities and (iii) science gives to some extent an accurate representation of reality (the three building blocks of scientific realism). Quite the converse, quantum mechanics has triggered attacks against scientific realism, and it is commonly recognized that there is a problem either with realism or with the present form of quantum mechanics.

The first option has most often been invoked: quantum mechanics would constitute an empirical rebuttal of realism, since there is no agreement as to what the main theoretical terms mean or could refer to, and also because most properties of the physical entities are contextual and nonlocal, and are undefined prior to measurements. Hence the verdict that: "realism is dead, (…) its death hastened by the debates over the interpretations of quantum mechanics" (Fine 1986, p. 112). Putnam has backed away from his previous commitment to scientific realism and now asserts that "quantum mechanics has no realist interpretation at all" (Putnam 1992, p. 86). He criticizes scientific realism for its inability "to do justice to the most fundamental physical theory we have (quantum mechanics)" (Putnam 1992, p. *x*).

The second option, viz. that there is a problem with the present form of quantum mechanics, involves a search for new theories dealing with quantum mechanical phenomena that would appear to be compatible with realism. In this case the possible choices are (i) to change the theory, (ii) to change the interpretation or (in most cases) (iii) a combination of (i) and (ii), with the obvious restriction that (i) cannot affect the huge corpus of predictions that follow from standard quantum mechanics (QM). This constraint explains why there is no

radical alternative to QM, so that the proposed changes affect marginally the formalism and concern mostly the interpretation. At any rate, if these alternative theories are to match and eventually supersede QM, theoretical developments are necessary. The *only* such theory that has been developed to a certain extent while recovering the predictions of QM is the de Broglie-Bohm causal theory of motion to be termed here Bohmian mechanics (BM). In his authoritative account of BM, Holland (1993, p. 17) indicates the aim is to develop a theory of individual material systems which describes "an objective process engaged in by a material system possessing its own properties through which the appearances (the results of successive measurements) are continuously and causally connected", something which is not addressed at by standard QM and is said to have no meaning within the Copenhagen interpretation. Bohm and Hiley (1985) sustained their interpretation "makes possible universal realism", and in the last decade, Bohmian mechanics has come to emerge in the eyes of many as *the* realist interpretation of QM: for Cushing (1994, p. 204), BM constitutes nothing less than "a powerful means of rebuttal of antirealism". Norris (2001) insists that QM is incomplete whereas Bohm's theory "provides a credible realist ontology that makes adequate sense of the observed phenomena". He goes further by contending that the controversy over realism in philosophy in general is largely dependent on the issue of realism in quantum mechanics (Norris 1999). Niiniluoto (1999) thinks that the assessment of antirealists conclusions *vis à vis* QM will depend on future work on the Bohmian interpretation. Concurrently, a certain number of physicists have started calculating properties of Bohmian trajectories for a host of different systems, rendering BM accounts of definite systems available.

Our concern in this paper is to examine whether Bohmian mechanics does provide a satisfactory realist solution to the interpretational problems of quantum mechanics[1]. To this end, we will first give a brief summary of Bohmian mechanics, insisting on the ontological

[1] Note that the *internal* consistency of the Bohmian theory is unrelated to the status of the interpretation with regard to realism, which is the proper subject of this work.

aspects of the interpretation (Sec. 2). We will then succinctly state the main commitments we take scientific realism to uphold, and expose the benefits put forward by the tenants of Bohmian Mechanics (Sec. 3). Since realism is the main motivation given in purport of the introduction of BM, most of these benefits aim at unifying realism in the quantum and classical domains. Still, we will see in Sec. 4 that when Bohmian mechanics is put to work in definite physical situations one is faced with paradoxical interpretative features, such as the need to account for empty waves, for highly nonclassical trajectories even in the classical limit, or for surreal trajectories when a particle is detected. Although these paradoxes undermine a straightforward unification of classical and quantum phenomena, they do not represent, as such, a problem for realism, since these features could be attributed to the peculiar nature of quantum reality. However, it is generally accepted that Bohmian mechanics does not open new windows on quantum reality, so that these features are in reality accounted for by retreating behind the shield of predictive conformity. Indeed, most of the supporters of the interpretation agree that BM will never be able to do better than recover the statistical predictions of QM, and this has consequences with regard to realism that we tackle in Sec. 5. We shall argue that as the structure of Bohmian mechanics bars in principle the possibility of accessing any observational warrant that could attribute referentiality to its propositions, we are thus lead to an underdetermination dilemma, which by assumption cannot be lifted by evidential criteria. The upshot is that de Broglie-Bohm interpretation does not contain sufficient epistemic constraints capable of telling us what we should be realist about. Moreover, we will make the case that were the underdetermination dilemma true, favoring BM or any other ontological interpretation over standard QM would become a matter of taste, a pragmatic choice, grounded on epistemological arguments which are generally associated with antirealist positions. We will thus be led to conclude (Sec. 6) that strengthening the status of BM as a valid theory can only be done at the expense of weakening scientific realism, and

that the de Broglie-Bohm interpretation of quantum mechanics is rather inconsistent with realism.

## 2. Bohmian mechanics: basic constituents

The de Broglie-Bohm formalism starts from the same theoretical terms that are encountered in standard QM[2]. New theoretical terms are added, and the meaning of the standard terms is altered, in general by making specific assumptions, but the technical machinery employed in making the predictions in QM is not significantly changed. Let us start from the state vector $|\Psi>$, solution of the Schrödinger equation, which is the main theoretical term in QM. Whatever its interpretation, it allows to make all the physical predictions on the system. BM imposes a privileged representation for $|\Psi>$, the configuration space representation. Let us assume a system composed of $N$ particles, and let $x = (x_1,..., x_N)$ represent the coordinates of the $N$ particles. $\Psi(x)$ is seen as a complex-valued field in a space of dimension $3N$. Each of the $N$ particles that comprise the system is postulated to have at every instant and every point of space a definite position and velocity that depend on $\Psi$ and on the initial position of all the other particles. To do so, the field is decomposed[3] as $\Psi(x)=R(x)\exp(iS(x)/h)$. $S(x)$ determines the velocity: for the $i$th particle (of mass $m_i$) it is given by the gradient $\nabla_i S(x)/m_i$. $R(x)$ determines the so-called 'quantum potential' $Q(x)$, given by $Q(x)=-\hbar^2\sum_{i=1}^{N}\nabla_i^2 R(x)/(2R(x)m_i)$. In addition to the classical potential, the quantum potential

[2] We take standard QM to be what one can find in present day textbooks, usually employing the Dirac notation and updating the traditional atomic physics corpus by some notions of path integration and environmental decoherence. However, the precise formulation of standard QM that can be picked is not central to our arguments to the extent that the formulation has no claims towards realism.

[3] Of course, $S$ and $R$ are not independent, since the reformulation of the Schrödinger equation leads to two coupled equations. The present decomposition stems from a particular way of looking at the Hamilton-Jacobi equation of classical mechanics. $S$ fulfills a Hamilton-Jacobi like equation, whereas $R^2$ is obtained from the conservation of the flow.

controls the acceleration of the particles. Contact with quantum mechanics is made by postulating, as QM requires, that $R^2(x_1,..., x_N)$ gives the probability density of finding the particles in infinitesimal volumes around the coordinates $x$. These postulates also allow to identify mean values of quantum mechanical observables with average values of a statistical ensemble of particles.

According to BM both the wave and the particles have an objective existence. The wave is assumed to be a real physical field, though it is not defined in our usual four dimensional space-time but in a multidimensional configuration space. The particles move under their own energy while being guided by the wave. The "pilot-wave" plays this role through the quantum potential: the law of motion for a particle has a form akin to Newton's second law of motion, but the total potential contains, in addition to the classical potential, the quantum potential $Q(x)$. Hence, because of the quantum potential, a particle can be accelerated though no classical force is present; conversely, the quantum potential may cancel the classical one, yielding no acceleration where acceleration of the particle would be expected on classical grounds. We put the emphasis on the fact that $Q(x)$ depends on the wave (that is, on the quantum mechanical state), which is determined by the entire system. Hence, the trajectory of a given particle depends (i) on the overall experimental setup (including parts that on classical grounds are sufficiently spatially separated from the particle so as to have no influence on its dynamics) and (ii) on the trajectories (hence, on the initial conditions) of all the other particles (whatever their separation is).

The wavefunction is therefore the "*senior partner*" (Holland 1993, p. 79) of the pair: the particles' motion depends on the state $\Psi(x)$ (and more precisely only on the shape of $\Psi(x)$, not on its intensity) but the particles have no effect on the wave; there are portions of waves

that carry no particle[4], though no particle can be conceived without a wave. Interference and superposition – which are the most prominent quantum phenomena – only depend on the wave. This does not preclude however the calculation of the particles' trajectories; but the direct determination of $R(x)$ and $S(x)$ (solutions of nonlinear equations) is mathematically intricate, so here again it is necessary in practice to solve the Schrödinger equation for $\Psi(x)$ first, and then use the above-mentioned decomposition to calculate the quantum potential and to plot trajectories. The particles' importance is manifest in the measurement process, because according to BM the particles are the entities recorded in the experiments, and as such appear as "the immediate sensed 'reality'" (Holland 1993, p. 21). However despite the postulated existence of the particles and their trajectories, the physical predictions do not go beyond those of standard QM, because properties of an individual particle cannot be probed and only statistical averages (which by construction are the quantum mechanical expectation values) can be predicted. This is why the vast majority of supporters of BM do not think it could be possible to set up an experiment that could discriminate BM from QM; let us cite again Holland (1993, p. 372) who cautiously asserts that "it is not, in fact, possible to invent experiments compatible with the current quantum formalism whose results would allow one to infer support for the causal assumptions [i.e., Bohmian mechanics]".

## 3. The virtues of the Bohmian interpretation

### *3.1 Realism and quantum mechanics*

The difficulties encountered by realism in dealing with quantum phenomena are well established: they have been ubiquitous since the inception of quantum mechanics, to the extent that the main founders of the theory overtly promoted an instrumentalist approach, the Copenhagen interpretation. It does not fall within our scope to discuss this issue in general,

[4] E.g. when a wave is spatially separated into two spatially nonoverlapping parts, a given particle is guided by one of the two separated waves.

nor to detail the various sorts of partial-, pseudo- or quasi-realisms that have been proposed to be compatible with quantum mechanics (and most often taken to be incompatible with genuine realism). Our sole concern here will be to state the basic commitments we take a scientific realist to have. We will consider an intermediate position by which a realist recognizes that scientific theories are more than useful predictive tools – they tell us something about the nature of the world, but avoids any commitment to a particular theory of truth. In short, we will take a realist to believe that scientific theories (i) describe a mind independent world, (ii) by means of theoretical terms some of which refer to aspects of the world, and (iii) that the ensuing description is approximately accurate. (i) deserves little comment, as it is common to most forms of realism and is taken for granted by the overwhelming majority of physicists. The present formulation of (iii) is meant to sidestep the debates on the conceptions of truth taken to be compatible with and beneficial for realism (Alston 1996, Niiniluoto 1999), and can be seen as a surrogate for 'partial theoretical truth'. (ii) implies that although many theoretical terms may have only epistemic significance, there are theoretical terms that refer to real entities or properties thereof. This raises two questions. First, theories change: even successful, mature theories eventually get superseded. Second, and most importantly, how can we secure reference and avoid empirical equivalence? The first point is solved within a realist perspective by accepting arguments based on the continuity of reference through theory change, grounded on a causal and naturalistic theory of reference (Psillos 1999). So that a new theory will replace effectively the old mature theory only in the domain in which the latter fails (it is the case for instance for newtonian mechanics, which is still routinely employed where relativistic effects are negligible). Regarding the second point, we will require reference to be secured through observational warrants. The credibility of the theory regarding the putative entities depends on the observational consequences (e.g. predictions, number of independent observational windows

that fall under the theory's range), whereas the explanatory power of the theory comes in second, once reference is secured. Still, some form of theory is always necessary to account for the observation (often implicitly in trivial cases of direct observation, whereas the observation of microscopic phenomena require much more elaborate theories), and auxiliary hypotheses can always be introduced, affecting the observational consequences. We will require that only auxiliary hypotheses enlarging the empirical content of the theory are to be accepted, taking the line that ad-hoc assumptions protecting the theory by blocking observational consequences result in a loss of credibility of the realist relevance of the theory. Observational evidence is needed to secure referentiality (Agazzi 2000), and avoid reaching the conclusion that competing theories are no more than mere non-referring representations. The underlying reason, as we will discuss below (Sec. 5.3) is that epistemic constraints are necessary in order to escape from the consequences of underdetermination dilemmas, which are generally taken to be fatal to scientific realism.

As known, there is no universal agreement regarding the interpretation of quantum mechanics. The main challenge to scientific realism comes from the impossibility of ascribing reference to the theoretical terms, so there is no sense in trying to make sense of the predictive theoretical tool in accessing the nature and properties of the putative entities. The fact that the explanatory resources conveyed by scientific realism are successful in most other parts of science does not help, since quantum mechanics is at the base of the scientific edifice. There is at present no explanation supporting how our classical world can be recovered from quantum mechanics. Hence the need of finding a realist alternative to standard quantum mechanics.

### *3.2 The advantages of the Bohmian interpretation*

The additional assumptions introduced by Bohmian mechanics aim essentially at extending realism to the domain dealing with quantum phenomena. According to Bohm and Hiley (1985), the main motivation in introducing their interpretation is precisely that "it avoids making the distinction between realism in the classical level and some kind of nonrealism in the quantum level". To examine the manner in which this is done, we list the main merits of Bohmian mechanics as seen by supporters of the interpretation:

1. BM gives a coherent and credible ontology dealing with "*the objective reality of individual micro-objects*" (Vigier et al., 1987, p.169).
2. This ontology is in continuity with the ontological assumptions of classical physics.
3. The concepts of causality, continuity and (up to a certain point) locality are still valid in the realm of quantum physics according to BM.
4. BM leaves us in a better position to understand and explain the physical phenomena, especially when compared to the 'orthodox' interpretation.
5. Following BM, there is nothing strange or paradoxical in the nature of quantum reality (unlike other interpretations, such as the many-worlds interpretation that takes the ontologic status of the theoretical terms at face value).
6. BM gives a more adequate explanation than standard QM of certain physical problems, such as the measurement problem or how our classical world emerges from QM.
7. BM allows one to maintain a firm distinction between ontology and epistemology.
8. BM allows ascribing reference to the theoretical terms and is compatible with a correspondence theory of truth.

We can find three type of advantages more or less interrelated in these arguments. The first type of advantage concerns the ontological level: BM tells us what the quantum world is putatively made of. The second type of arguments regards the epistemological benefits:

certain categories (such as causality and continuity) that are assumed to be necessary for any understanding to take place are allowed to operate. The ontological and epistemological benefits result in the third type of advantage which plays at the level of the physical phenomena. Not only does BM contain a genuine explanatory virtue, but it also "solves" the main inconsistencies of standard QM that encapsulate the problems faced by realism: the measurement problem and the quantum to classical transition.

Theses arguments have indeed the apparent benefit of importing the 'classical' realist viewpoint (i.e., as it appears in most other parts of science and in particular in classical physics) into the quantum domain. The benefits are thus in line with the motivational rôle played by realism, as stated by Bohm and Hiley (1985): their interpretation shows that "there is no need for a break or 'cut' in the way we regard reality between quantum and classical levels". The third type of argument goes further by suggesting BM to be a unified theory of classical and quantum phenomena. This does not entail however that BM is downright compatible with realism. We will argue in Sec. 5 below that problems arise because securing reference is deemed unattainable, and this will be seen to have consequences regarding realism. We will first examine, however, how these benefits apply when BM is put to work in definite physical situations.

## 4. Bohmian mechanics at work

### *4.1 A benign choice?*

From a realist perspective, Bohmian mechanics must be taken seriously: the theoretical terms are not expedients, and the theory tells us what the structure of the world is (to a certain degree of accuracy) like. By way of the third type of advantage given in Sec. 3.2, it would appear surprising that only a small number of physicists has been convinced of working

within the de Broglie-Bohm framework, the overwhelming majority keeping with the operational laboratory account of standard quantum mechanics. On the contrary, we make the case in this Section that adopting Bohmian mechanics creates new problems for the physicists. For example generic Bohmian trajectories are of different nature than classical trajectories, the particles share their properties (mass, charge…) with the wavefunctions, detectors can be fooled, the well-known correspondence between classical and quantum chaotic or regular systems becomes meaningless, the empty waves can become active… Those are but a few examples of the consequences stemming from adopting the Bohmian framework, that we develop below. When BM is put to work, the apparent explanatory benefits of the theory presented in Sec. 3.2 give way to many paradoxical interpretative features. This does not render BM contradictory or inconsistent, and the examples we review below are well-known to the physicists working in the BM framework. These examples are however seldom cited in more general works dealing with the de Broglie-Bohm interpretation, and we believe that at the very least, they support the idea that the worldview arising from BM applied in definite physical situations does not unify the classical and quantum domains as straightforwardly and as smoothly as the advantages cited in Sec. 3.2 seemed to suggest. We first discuss the difficulties appearing in the ontological definitions, then the nature of the Bohmian trajectories and their relation to classical mechanics and finally the behavior of Bohmian trajectories in the presence of measuring devices.

*4.2 Subtle ontologies*

First of all, it must be clear that despite giving identical predictions to standard quantum mechanics, the Bohmian interpretation is not strictly equivalent to standard QM for two reasons. The first one is that only a tiny part of the area covered by QM has been explored

with the tools of BM[5]; the second is that the ontology of BM does not conform to the formal unity of QM, so that different physical aspects that are handled by QM on the same footing require different treatments and interpretations within BM. The simplest example concerns the photon, the particle associated with electromagnetic waves, which does not exist according to BM, in contrast with a non-relativistic electron (that BM takes to be a particle guided by a wave). The photon is banned from the quantized field because following BM the ontological entities are the field values at coordinate points. The reason is that bosons (such as photons) and fermions (such as electrons), which are treated in QM on the same footing, have differing ontological interpretations in BM, and there has been ongoing disagreements as to which equation must be taken as the starting point to develop an ontological interpretation (Kaloyerou 1996). The main problem is that fermion fields are generally taken to have an ontological interpretation in terms of particles, whereas a consistent particle ontology of boson fields is deemed impossible (bosons are hence interpreted as ontological classical-like but nonlocal fields): but as is well-known from elementary QM, a composite particle constituted of a pair number of fermions is a boson.

Another difficulty concerns the interplay of the wavefunction with the associated particle, which lacks a physical explanation. As briefly reviewed in Sec. 2, the wavefunction is a real physical field, but unlike the corpuscle, it does not live in our usual space-time (from which it follows that part of reality is not given to us, since we have no access to configuration space). Moreover, it does not act as a field producing force or pressure: the particle moves under its own energy, and is guided by $\Psi$ as a ship guides radio-waves (this analogy is employed by Bohm and Hiley (1993)). The role of $\Psi$ is then that of a carrier of information; for example in many-body systems, Bohm and Hiley (1993, p.60) state that $\Psi$

[5] This is reasonable, given the limited number of researchers dedicated to working in this direction. We can take for granted the fact that as long as BM adheres to the standard formalism, more areas of physics can in principle be spanned. However, as more systems come to be investigated within BM, additional specific interpretative assumptions need to be made (some examples are given in this section). The danger is that BM might lose credence as a greater domain of physics comes under its scrutiny, rather than the converse.

represents a "common pool of information" for the particles, rather than suggesting a mechanism by which the wave guides the particles. The same authors are thus led to acknowledge that the reality of $\Psi$ is somewhat "subtle" (p. 37). Indeed, the wavefunction depends, at any point of space, on the invariant properties of the particles (mass, charge,...) which are supposed to be localized at some definite points of space. Its interaction with the particle is postulated to be causal, but there is no mechanism by which the wave, living in a multidimensional configuration space and conceived as a carrier of information affects the particle, existing in our usual space-time. We also know that this causal interaction can never be observed since the positions of the particle are unknowable in principle. The apparent bonus found in BM – the causal description of individual systems – actually ends up accounting for the indeterministic outcome of statistical results, as in standard QM. This is why Home (1997, p. 342) recognizes that "in Bohm's interpretation, the interplay between causality and determinism is thus a bit subtle". Causality, which is cited as an epistemological advantage of adopting BM (see Sec. 3) is rendered unoperative whereas determinism must be abandoned, not only for all practical purposes, but also in principle[6].

The status of the empty waves is also problematic. Maudlin (1995, p. 483) might well boldly assert that "Bohm's theory solves the measurement problem completely and without remainder", it is hard to see how this could be so if the wavefunction is a real field. For example, when the wavefunction separates into different parts, the particle is said to follow one of the branches, leaving the other bits of the wavefunction empty. The same process is at work during a measurement: the wavefunction does not collapse when a particle is detected, and the empty waves objectively exist though they are inactive. According to BM, the particle (in our physical four dimensional space-time) has followed one of the branches of the wave

[6] It is sometimes asserted (e.g. Cushing, 1994, Sec. 11.3) that BM can be said to be deterministic in principle, in the same sense that classical chaos is deterministic. The analogy is unwarranted, because an individual chaotic trajectory with well-defined initial conditions can be probed, whereas Bohmian mechanics allows only access to the statistical distribution of the initial conditions of Bohmian trajectories as it is given by the initial wavefunction.

through a causal but indeterministic process. The other branches are still absolutely real (but in configuration space) and we do not see them in physical space unless they are rendered active by overlapping with the branch of the wave which is guiding the particle. This raises again the problem of the significance of the wave: it depends on the particle's properties (mass, charge,...) even though it is empty, it is a carrier of information but still exists when no particles are guided, and it cannot be discarded since under certain conditions an empty wave can affect the particle (see Vaidman (2003)). In short the measurement problem seems to be solved for the particle, but not for the wave. As Zeh (1999) points out, BM is identical in this respect to the many-world interpretations of quantum mechanics (since the global wavefunction has a real existence which is independent and more important than the particle's), which is regarded by the followers of BM as the prototype of "extravagant conjectures" (Norris 2001) against which the Bohmian interpretation should act as an antidote.

Summarizing the main points, we see that the ontology of BM does not arise in a general and unified manner from the formalism of QM, as could be expected from the advantages cited in Sec. 3. Specific assumptions on different levels are needed to account for the nature of the ontology. Information related terms in physical theories, such as the entropy or the action in classical mechanics, are generally associated with epistemic, not ontologic, significance as in BM. Here the nature of the wavefunction as an objective physical field remains subtle, especially as the world is beset with empty wavefunctions. The validity of concepts such as causality or the explanatory power of BM have a more limited scope than could have been expected given the motivation in introducing the interpretation.

### *4.3 Trajectories and the classical limit*

As briefly mentioned in Sec. 2, the shape of a particle's trajectory depends on the quantum mechanical state $\Psi$ and on choosing the polar decomposition of $\Psi$, with the functions $R$ and $S$. This may look vaguely classical, but the presence of the quantum potential which appears in addition to the usual potential[7] in the dynamical equation affects the particle's motion in a peculiar and highly nonclassical manner. For example in the hydrogen atom, the electron in an energy eigenstate is either at rest (if the azimuthal quantum number is 0) or displays an asymmetric motion around the quantization axis. This contrasts with the classical trajectories, which respect the symmetry of the usual potential (just as the wavefunction does). Note also that a system may be in one of two different quantum states, each state having different wavefunctions and different physical properties (for instance the ground and excited states of an atom), though the Bohmian trajectories in the two cases can be identical. Another celebrated example is the particle in a one dimensional box: classically the particle has a constant velocity until it hits the walls of the box; at that point the velocity instantly changes sign and the particle leaves the other way and so on. However, BM asserts that the particle in such a system must be still, a behavior that following BM is conserved in the classical limit.

Quite generally, it is straightforward to show that Bohmian trajectories (positions and velocities) are generically nonclassical. The only way to make them look classical is to construct a suitable superposition of wavefunctions (a wave-packet). But this fares no better than in standard QM, and there is no reason to suppose that in the classical limit those particular wavepackets would be singled out. The way out for supporters of BM is (i) to assert that systems or states presenting those problems (such as stationary bound states) have in fact no classical limit (e.g. Holland 1993, Chap. 6) and (ii) to contend that by definition an isolated particle cannot be observed, so the fact that it displays nonclassical trajectories even in the

[7] We use the term 'usual' potential instead of 'classical' potential because the classical potential is generally the sole potential term in the Schrödinger equation of standard QM. This is why unlike Bohmian trajectories, the wavefunction may have the same symmetry properties as the classical trajectories of the equivalent classical system.

classical limit "has no bearing on their empirical acceptability" (Appleby 1999). The latter point is in agreement with an important property of BM, namely that measured values of dynamical properties are different from their ontological value, because the wavefunction of the measuring apparatus gets entangled with the wavefunction of the test particle; this has some paradoxical consequences known as the surreal trajectories problem, developed in Sec. 4.4.

As for the other point (the physics in the classical limit), it brings about another feature of the Bohmian interpretation, namely the conflicting relations it has with quantum mechanical theories that employ classical terms in their formulations, such as the Feynman path integral formalism or the theories of semiclassical physics and quantum chaos (Gutzwiller 1990). These theories incorporate in an albeit non-ontological manner theoretical terms from classical phase-space mechanics in the construction of quantum-mechanical propagators or wavefunctions, and are very useful to explain the correspondence between quantum-mechanical systems and their classical equivalent. For example it is known that quantum systems having a classically chaotic counterpart behave very differently from quantum systems for which the classical counterpart is regular: the statistics of the energy levels is different and the semiclassical quantization of these systems follows distinct paths. Of course chaos in QM cannot be defined, as in classical mechanics, by the exponential sensitivity to initial conditions, since in standard QM there is no concept of trajectory. However semiclassical theories explain to a large extent the above-mentioned correspondence by having recourse to arguments based on the properties of the periodic classical trajectories of the classical system. It was hoped that BM would clarify the issue of quantum chaos due to the existence of Bohmian trajectories (Holland 1993, Sec. 6.10, Cushing 2000). However, whether Bohmian trajectories are chaotic or regular depends on the choice of the wavefunction, and not on intrinsic properties of the system. For example Alcantara Bonfim et

al. (1998) investigated Bohmian trajectories for a quantum system whose classical counterpart is regular, and which displays the spectral statistics characteristic of regular systems; they found that generic Bohmian trajectories were chaotic, and concluded that "the chaotic nature of Bohmian trajectories is not dictated by whether or not the underlying classical Hamiltonian counterpart is chaotic". This is in stark contrast with the properties of classical trajectories that determine the behavior of the wavefunctions in the semiclassical limit.

To sum up, Bohmian trajectories are radically different from the trajectories of classical mechanics. This nonclassical behavior survives even in the classical limit, spoiling the correspondence between quantum Hamiltonians and their classical counterpart. Far from providing "an attractive understanding of the classical limit" (Callender and Weingard 1997, p. 20), BM on the contrary faces new problems in accounting for the existence of classical trajectories. Note that this does not entail problems for de Broglie-Bohm interpretation regarding empirical adequacy or theoretical consistency, but the benefits brought in by BM, in particular those regarding the emergence of the classical world and the continuity with classical physics, may be questioned. It is not evident that adopting Bohmian mechanics brings any advantage on these issues. As a matter of fact, BM claims that the classical limit is undefined or does not exist. Bohm and Hiley (1985) bring consistency to its paroxysm by claiming that if the trajectory of the particle in a box could be detected without disturbing the system, then the motion predicted by BM would be found, not the classical one.

*4.4 Surreal trajectories*

What came to be termed as surrealistic (or irony aside, surreal) trajectories are the behavior of calculated Bohmian trajectories in the presence of measuring devices. A simple example, studied by Aharonov et al (1999) involves a particle in a box, with a detector placed at the center. This detector is assumed to interact locally and adiabatically with the particle. When

the detector is turned on, the particle is eventually detected, although a typical BM trajectory never comes to the box center where the detector is placed.

A more complicated but striking case involves which-way detectors in an interferometer. In short (for a description see Scully 1998 and references therein), a wavefunction is split in two spatially separated branches; each branch is deflected so that both branches cross again in a region in which interference would be observed if a detector was placed there; here two detectors are placed behind that interference zone to determine which way the particle traveled. It turns out that a detector (say detector 1) can be triggered even though the Bohmian trajectory never came near it. Conversely, a detector can affect the particle's motion although the particle never approached it. Worse, detector 1 can be triggered although the Bohmian trajectory actually travelled through detector 2: the detectors have been fooled. The underlying reason for such a paradoxical behavior is to be found in the different symmetries obeyed by the Bohmian trajectories on the one hand, and by the classical trajectories as well as the quantum-mechanical wavefunction in the other, touched upon in Sec. 4.3. Supporters of BM tell us that we should not be surprised of finding paradoxes in quantum mechanics; more importantly, having fooled detectors does not make BM inconsistent since the statistical predictions of standard QM are recovered (Dürr et al. 1993). Dewdney et al. (1995) remark, quite consistently from the BM viewpoint, that this effect should be simply taken as an illustration of the non-locality of the quantum potential.

We must once more weigh in the advantages of adopting the de Broglie-Bohm interpretation, in particular regarding points 2 to 6 (Sec. 3.2), since these benefits do not operate in the same manner as in the classical domain. Here, BM tells us that quantum reality is such that the detectors can be fooled. In a more dramatic setup, millions of atoms can be fooled: if we put the interferometer in a bubble chamber (Vaidman 2003), the bubbles will be observed not along the Bohmian trajectory, but precisely along the opposite branches of the

interferometer. We therefore see that a BM account demands for a nonlocal influence where QM (and classical mechanics alike) require a simple local interaction, viz. the particle/wave-packet has hit the detector (or the atoms giving rise to the bubbles in the chamber). The upshot is that either the Bohmian trajectory is not related to the position of the detected particle, or that the particle's trajectory is unrelated to the position of the detector that has been triggered.

### *4.5 Conclusion*

We have described in this Section some features encountered by Bohmian mechanics when the theory is put to work in physics to solve definite problems. We mention again that these features do not render BM internally inconsistent nor do they lead to predictive inadequacies. Rather, these problems afflict the benefits that should emerge from adopting BM, at least in the motivational sense. To the extent that the virtues cited in Sec. 3 constitute the consequence of the main motivation behind the introduction of the de Broglie-Bohm interpretation – to fill the gap between nonrealism in the quantum domain and realism at the classical level, the fact that these benefits have a limited range might affect the credibility of the interpretational enterprise. Now, a realist supporter of the Bohmian interpretation would certainly claim that what appears as a retreat is actually forced upon us by the peculiar nature of quantum reality. This opens the problem of knowing what quantum reality is like, and in particular the question of assessing whether quantum reality is such as Bohmian mechanics tells us it is.

## 5. Arguments with realism

### *5.1 The strength of the unobservable*

The main problem, as we see it, of taking the de Broglie-Bohm interpretation as a realist construal of quantum mechanical phenomena is that BM does not open new observational windows on the nature of quantum reality. There seems to be a quasi general agreement on the unobservability of the specific propositions of Bohmian mechanics among the supporters of the interpretation (Holland 1993, Cushing 1994, 2000): at best, BM can reproduce the predictions of standard QM, but it cannot formulate any prediction that would go beyond the predictions of QM. Many supporters of BM also believe that this will also always be the case in the future, i.e. that in principle, BM will never be able to differentiate itself from QM as far as empirical adequacy is concerned. Indeed, the Bohmian trajectories are in principle unobservable and no novel empirical prediction has ever been made. In a sense, this has been a strength for the interpretation: it has allowed BM to cover many areas of quantum physics without risking refutation or internal contradiction. However, it is a long way from the expectations one can find in Bohm's original paper, published more than half a century ago: he argued there that the standard interpretation "presents us with a considerable danger of falling into a trap, consisting of a self-closing chain of circular hypotheses, which are in principle unverifiable if true" (Bohm 1952 p. 169), whereas his interpretation could give rise to new predictions based on the states of hidden variables.

With respect to realism, we argue below that this sets a stage in which the usual arguments of antirealism can be developed. As pointed out in Sec. 3.1, realism requires theories to be more than pragmatic constructs aimed at 'saving the phenomena'; within a realist perspective, theories tell us something about the nature of the world. To do so, realism demands more than empirical adequacy and internal consistency: it requires reference. And reference needs to be secured through observational warrants. If a determinate ontology is specified but no epistemic warrants are given, the relation between what the theory says is 'out there' and what reality is becomes a matter of arbitrary convention, leading to a well-known

inconsistency for realism. We will see that the de Broglie-Bohm interpretation leads to such a contradiction, by considering first the free choices that are made within the theory, then by putting forward the underdetermination dilemma that, even according to supporters of BM, is in principle unsolvable. The realists' standard move to overcome underdetermination dilemmas is to restrict the type of additional auxiliary assumptions employed by theories to those that create observational evidence. Since this is not within the scope of Bohmian mechanics, we will put forward the paradox by which despite its motivational realism, the status of the theory is made to rely on pragmatic or constructivist arguments traditionally associated with antirealism.

*5.2 The theory decides: arbitrary choices*

A first consequence of the unobservability of the specific propositions of BM resides in the extreme theory dependence of the postulated reality that takes place behind the observed phenomena. First, the theory decides how it will transform the basic equations of QM and which terms will be given an ontological dress. In part, this depends on the motivation, as discussed in Sec. 3; thus Home (1997, p. 165) asserts that postulating the existence of the particle as "an additional conceptual element is needed at a fundamental level in interpreting quantum theory, so that the classical ontology of the macroworld emerges smoothly without abrupt conceptual discontinuity". So the postulated ontology [point 1 of Sec. 3.2] is actually needed because Home sees the issue of how to recover classical mechanics [points 2 and 6 of Sec. 3.2] as the main advantage brought by BM. We have also mentioned above the problems faced by BM in choosing an ontology in relativistic physics, where there seems to be no general agreement within the supporters of the interpretation. But even the way in which trajectories are extracted from the non-relativistic Schrödinger equation is arbitrary for at least two reasons. First, the polar decomposition is not the only one available. For instance the

wavefunction may be decomposed as a sum of phase-amplitude functions from which 'trajectories' may be defined, their topology (which have nothing in common with Bohmian trajectories) depending on parameters which are freely specifiable (e.g. Matzkin 2001). Second, even within the BM framework, it is possible to add free additional terms, which have no consequence on the quantum mechanical wavefunction but which give rise to very different trajectories (Deotto and Ghirardi 1998). The very fact that the fundamental dynamical law of Bohmian mechanics can be freely modified without affecting the rest of the trajectory-based interpretation (and obviously the statistical predictions of QM) naturally follows from the unobservability of any phenomena that would, albeit indirectly, depend on the given shape of the trajectories. It constitutes a setback for a realist reading of the interpretation because the grounds on which the dynamical law can be chosen are to a large extent both arbitrary (regarding the theoretical aspects that are to be favored[8]) and unconsequential (as far as neither the coherence of the formalism nor the ensuing empirical consequences are modified).

The consequences of the arbitrary choices are not limited to the postulated unobservable reality, since the account of the observational process is also made to depend totally on these choices. We have mentioned above the surreal trajectory feature (Sec. 4.4). Barrett (2000) examined this feature as a striking example of the theory-ladenness of observation: what one detects depends on the theory that explains what is detected. Indeed, once it is recognized that the trajectories are in principle unobservable and that the theory reaches empirical agreement, there is no problem in having fooled detectors. The pertinent question is then shifted from knowing whether Bohmian trajectories are consistent with an accurate representation of reality to whether the properties of the Bohmian trajectories are

[8] Why should we favor a polar decomposition rather that an amplitude-phase one, since both formulations yield the same Hamilton-Jacobi like equation? Even then, there is no reason, for the sake of defining trajectories, to take the mathematical support given by a nonrelativistic classical equation instead of, say, the support furnished by the nonrelativistic limit of the Dirac equation.

consistent with what would be expected from BM, since the predictions made by BM are correct. The same reasoning was employed by Appleby (1999) when he explained that the fact that BM displays nonclassical trajectories even in the classical limit is not a problem for their "empirical acceptability", since the trajectories cannot be observed and that the statistical predictions of QM are recovered (see Sec. 4.3). The bottom line is that since BM does not open new windows on the nature of quantum reality, the only effective response in accounting for the paradoxical features consists in a retreat behind the shield of empirical adequacy. As Fine (1996) remarked, on points that matter to realists, the partisans of BM have replied by employing the same positivist lines of defense that are generally found in vindication of the Copenhagen interpretation, namely that what matters is the predictive agreement with experiments and that it is impossible in principle to observe isolated systems or trajectories. But departing from the standard interpretation, which tells us that describing an isolated system has no meaning, BM nevertheless claims to give a full description, in terms of waves and particles trajectories, of what an individual isolated system is really like. What a realist supporter of the Bohmian interpretation overlooks is that any realist construal (i) requires warrants to endorse reference if the theory is to be more than a consistent but non-referring representation and (ii) must put constraints on any introduction of auxiliary hypotheses so that the achieved empirical equivalence does not turn into an underdetermination dilemma.

### *5.3 Underdetermination and reference*

By and large, the Duhem-Quine thesis is typically employed in an instrumentalist perspective to assert that with sufficient imagination – that is with any auxiliary assumption, any theory can be made to corroborate any experimental result. Therefore rival theories are empirically equivalent, and the strong version of the Duhem-Quine thesis logically results in the strongly antirealist underdetermination dilemma, one of the most widely employed and most effective

arguments against scientific realism. As given by Devitt (2002, p. 42), this strong version reads (this is his 'EE3 thesis') that "any theory positing unobservables has genuine rivals which are such that when it and any rivals are conjoined with any possible acceptable auxiliaries they entail the same possible observational evidence". Were this thesis true, it would thus be impossible to distinguish between competing theories, which claim to have the same empirical content but which call for different or antagonistic ontologies -- hence theories could not be said to speak of reality. Therefore scientific realism would not hold, in the impossibility of knowing what to be realist about. Indeed, combining a determinate ontology with an indeterminate or conventional identity relation represents an internal inconsistency for realism (Blackburn 1994). In a realist perspective, we cannot freely associate the same theoretical constructs with different ontologies while at the same time claiming that the ontology does not depend on us. This is why the received view among realists is that the validity of the 'EE3' thesis recalled above is inconsistent with scientific realism, given that realists would only be able to appeal to nonempirical virtues, to a large extent arbitrary and a matter of convenience, to choose between theories, without the slightest prospect of observational confirmation (Devitt 2002).

For realists, the typical way out to overcome the danger stemming from underdetermination dilemmas is to assert that it is incorrect to state that any auxiliary hypothesis can be introduced (Laudan and Leplin 1991), and to put the stress on the relation between the observational consequences of the competing theories and the epistemic constraints that must be placed on the auxiliaries. The line of reasoning is that auxiliary assumptions can be freely and arbitrarily generated at will, so that if no constraints are placed on the auxiliary hypotheses, empirical equivalence becomes trivial, resulting in a "sweeping skepticism that it does not take realism to oppose" (Leplin 1997, p. 155). The constraints put on auxiliary hypotheses must be epistemic. Auxiliary hypotheses should enlarge the empirical

content of the theory and they may lead to a revision of the theory, which would gain greater explanatory content. But auxiliary hypotheses which in principle cannot create evidence have the flavor of ad-hoc assumptions, which are inadmissible: they are untestable and reduce the scientific status of the theory.

Thus, if BM refers to reality, then there must be observable consequences other than those made without the additional assumptions of the Bohmian interpretation. Since the specific additional assumptions of BM involve ontological commitments, we expect, on realist grounds, empirical evidence that would, however indirectly, attribute reference to these assumptions. But as stressed above, there is general agreement, among the proponents and supporters of BM, on the fact that the additional propositions lead *in principle* to unobservable consequences. Undeniably, none of the additional assumptions have led to a testable consequence from which reference could emerge. In terms of the growth of scientific knowledge, the auxiliary hypotheses employed by BM have been completely sterile. No new observation, no novel prediction has ever been made through work engaged in the BM framework. As such, this sole argument should be enough to rule out BM from having a realist reading: the prediction of novel phenomena is very generally taken as the landmark of realism. Indeed as Leplin (1997) has convincingly argued, only novel success requires that the theory gives an accurate (albeit partial) construal of reality. Here on the contrary, the de Broglie-Bohm interpretation combines strong ontological commitments with some form of epistemic retreat: we have encountered above several examples in which a conflict with the putative ontological continuity is avoided by having recourse to arguments based on the unobservability of a given physical process combined with arguments stressing *in fine* the empirical acceptability of the ensuing (statistical) physical predictions. Bitbol (1996, Ch. 4) remarked that in some extreme cases (such as the fooled detectors example discussed above), BM even demands a radical rupture in the epistemological continuity: we accept the reliability

of a measuring instrument in classical physics while accepting to be fooled by instruments detecting quantum phenomena.

*5.4 The status of realism vs. the status of Bohmian mechanics*

Quite obviously, Bohmian mechanics generates an underdetermination dilemma and this has not escaped to the proponents of the interpretation. The thesis of Cushing (1994) is precisely that the adoption of the Copenhagen interpretation instead of some programme resembling the one that would later be proposed by Bohm is a matter of historical contingency. Cushing recognizes that favoring the standard interpretation over Bohm's version of quantum mechanics cannot be based on evidential criteria; then sociological factors, philosophical preferences, or political contexts decide over the construction and the selection of competing theories. The crux of the argument is that standard QM and BM are strictly empirically equivalent, creating not a simple example of underdetermination that could be lifted by hypothetical future observations but rather an underdetermination dilemma which is to last in principle, since no "objective, evidentially probative criteria" can resolve this dilemma (Cushing 1997).

The consequence of Cushing's thesis is twofold: on the one hand, it strengthens the status of the de Broglie-Bohm interpretation relative to standard QM, because the fact that present-day textbooks on quantum phenomena are presented in the QM framework rather than in a BM dress would be the result of historical contingency. On the other hand, it undermines realism completely, because if as stressed by Cushing and accepted by most supporters of BM, we are in presence of a genuine underdetermination dilemma which in principle can never be lifted, then the strong version of the underdetermination dilemma holds. And we have just seen that the validity of the 'EE3' thesis recalled above is inconsistent with scientific realism. Moreover, it is clear that if such an underdetermination dilemma between the

Bohmian theory and standard QM really exists, as supporters of BM are inclined to believe, there is no reason to extend it to any other alternative interpretation of quantum mechanics, be it based or not on trajectories, provided it achieves empirical adequacy. For example analyzing a given experiment from the BM approach and from his own 'consistent histories' perspective, Griffiths (1999, p. 230) points out that "Bohmian mechanics and consistent histories, both of which claim to go beyond standard textbook quantum mechanics in providing a *realistic* description of what is happening to a quantum system as it develops in time, in the absence of measurements, yield completely opposite and contradictory results".

The upshot is that in the absence of evidential criteria, we are faced with underdetermination dilemmas and favoring one or the other interpretation becomes a matter of taste, based for instance on putting the stress on certain preferred pragmatic or aesthetic virtues. Thus, Cushing (1994, p. 18) insists that the main benefit of adopting BM is of epistemological nature; he argues there are contingently necessary conditions for understanding, such as causality and locality, and that the theory compatible with these conditions should be favored on these grounds. So that looking back at the benefits arising from embracing BM, cited in Sec. 3.2, we see that the ontology of Bohmian mechanics [point 1] is postulated not because of specific empirical consequences on the physical predictions, but instead because of its fitness with points 3 and 4 [concepts of classical physics such as causality that have a restricted significance in standard QM are allowed to operate in the Bohmian interpretation].

While it is true that the arguments developed here do not only apply to the de Broglie-Bohm interpretation but also to any other consistent and empirically adequate alternative to QM (that by construction recovers the statistical predictions of QM) we believe that no other interpretation has so much insisted on its advantages with regard to realism. We have indeed seen in Sec. 3 that the main motivation leading to BM was to reconcile realism with quantum

phenomena. The paradox is that the status of the interpretation as a valid theory rests on an unsolvable underdetermination dilemma (which we have argued to contradict realism) whereas justifying the status of BM among the interpretations, explaining its marginality, involves calling for the usual themes of antirealism such as social construction of theories or relativism, which are sharply criticized in more general contexts by other supporters of BM (such as Norris 1999). But Bohmian mechanics may not at the same time be taken as the antidote against antirealism in quantum mechanics while relying on antirealists arguments to justify its position as a valid interpretation of microphysical phenomena. This is a pitfall for realism.

Therefore, in our view, we find surprising that in his vibrant defense of the Bohmian interpretation, Norris (2001) grants BM for saving realism by keeping firmly in place the distinction between ontology and epistemology. He argues that the "chief virtue" of Bohmian mechanics is that it avoids conceiving quantum reality as "eluding our utmost powers of conceptual grasp" (p. 69), which would compel us to abandon realism – in physics, in science, and beyond. We are again in the situation in which instead of examining the observable consequences arising from the postulated ontology, the emphasis is laid on a freely chosen benefit that is assumed to follow from the adoption of BM. Here the points found to be of upmost significance are points 7 and 8 of Sec. 3.2 [a formulation of quantum mechanics compatible with a definite and intelligible ontology can be conceived independently of any kind of warrant we have for claiming knowledge of it], and BM is therefore to be favored irrespective of the precise physical content of the theory [points 1 and 2]. Quite the contrary, we have argued that establishing such a strict separation between the postulated ontology and the epistemic warrants evades referentiality and leads to a contradiction for realism; the ontological discourse of BM then becomes gratuitous, being arbitrarily determined by the theory. Unsurprisingly this separation entails, even within the community of researchers

working in the BM framework, strong disagreements over the ontological status of the theoretical terms, resulting in antagonistic ontological pictures. Indeed, in the nonrelativistic case (the difficulties of choosing ontological beings in the relativistic case were already mentioned above) some authors have argued the quantum potential approach is misleading and that the wavefunction has no material existence, only a "nomological" one (Dürr et al 1997), a situation that is difficult to apprehend in realist terms. From a more general perspective, Callender and Weingard (1997) have analyzed three different and incompatible metaphysical pictures available to supporters of BM, depending on the ontological status given to spacetime and to configuration space[9]: consequently, it seems Bohmian mechanics is unable to really tell us unambiguously what we can be realist about.

## 6. Conclusion

We have seen that extending realism to the quantum level is cited as the main motivation in introducing, adopting and supporting the Bohmian programme. Although from a motivational point of view BM appears to bring advantages for the realist, we have argued that in practice this is not the case for the following reasons: (i) no empirical prediction depends and will depend on the specific assumptions of BM, as there are no observational warrants to secure reference for the putative ontology, which therefore leaves too much place for arbitrary and unconsequential statements; (ii) the arbitrariness is such that even within BM there is no unique ontological picture (there are differing viewpoints on the relative ontological status and properties of the wavefunction), so we do not know what to be realist about; (iii) in certain physical situations, the BM account raises new problems which in principle cannot be accounted for realistically (since the nature of quantum reality remains hidden behind the

[9] This is why de Broglie's double solution, which asserts that $\Psi$ is a hybrid and unreal theoretical construct *proportional* to a real wave (de Broglie 1978), is incompatible with Bohm's monistic (and quasi-mystical) ideas of the unfoldment of an implicate order (Bohm 1987).

shield of predictive conformity – which does not need any of the specific assumptions of BM).

Fundamentally, we have argued that on the one hand, BM leads to an underdetermination dilemma which in principle can never be lifted, and whose existence represents a contradiction for realism. On the other hand the status of the interpretation as a valid theory relies on pragmatic or aesthetic or any other nonevidential criteria, traditionally associated with a nonrealist position regarding the status of scientific theories. This does not entail that BM *per se* is downright uninteresting: as stressed by Bohm (1952) in his original papers, the fact that consistent alternative interpretations can be set up challenge the view purported by standard QM asserting that the wavefunction gives the most complete description of a physical system. Nor does our conclusion render BM internally inconsistent, since in all cases investigated the statistical predictions of standard quantum mechanics can be recovered. But challenging the orthodox interpretation (which has no claims toward realism) by comparing antagonistic claims generated by different interpretations, each of which is endowed with an unconsequential and freely specifiable ontological package is inconsistent with realism. We thus conclude that, in our view, far from being *the* realist approach to quantum mechanics, the de Broglie-Bohm interpretation is inconsistent with realism and undermines it.

Of course, a supporter of Bohmian mechanics is always free to believe that the BM approach to reality does not differ from the ones conveyed by any previous or current scientific theory, but she then abandons scientific realism, at least in the form we have defined it, and at least in the quantum domain. Indeed, following Cushing's line of reasoning, favoring the Bohmian interpretation (or, say, the Consistent histories interpretation) on pragmatic grounds can be justified. The problem remains for scientific realists, since we do not see at present any options they could consider. Scientific realism demands a consistency

and a coherence between the different perspectives from which we look: in particular we must be able to explain classical physics from quantum mechanics, just as newtonian mechanics is recovered from special relativity in the limit $v/c \ll 1$. Although quantum mechanics has now been around for about 80 years, we believe the quantum/classical transition is still today an unsolved scientific problem We hope that a realist construal of quantum mechanical phenomena will come through a satisfactory physical solution to the measurement problem and the quantum/classical transition.

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