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Classical and Bohmian trajectories in semiclassical systems: Mismatch in dynamics, mismatch in reality?

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Abstract

The de Broglie–Bohm (BB) interpretation of quantum mechanics aims to give a realist description of quantum phenomena in terms of the motion of point-like particles following well-defined trajectories. This work is concerned with the BB account of the properties of semiclassical systems. Semiclassical systems are quantum systems that display classical trajectories: the wavefunction and the observable properties of such systems depend on the trajectories of the classical counterpart of the quantum system. For example the quantum properties have regular or disordered characteristics depending on whether the underlying classical system has regular or chaotic dynamics. In contrast, Bohmian trajectories in semiclassical systems have little in common with the trajectories of the classical counterpart, creating a dynamical mismatch relative to the quantum-classical correspondence visible in these systems. Our aim is to describe this mismatch (explicit illustrations are given), explain its origin, and examine some of the consequences for the status of Bohmian trajectories in semiclassical systems. We argue in particular that semiclassical systems put stronger constraints on the empirical acceptability and plausibility of Bohmian trajectories because the usual arguments given to dismiss the mismatch between the classical and the BB motions are weakened by the occurrence of classical trajectories in the quantum wavefunction of such systems.

Keywords: Quantum mechanics; Semiclassical systems; de Broglie–Bohm interpretation; Realism; Classical limit

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1. Introduction

Based on the seminal ideas put forward by de Broglie (1927) and Bohm (1952), the de Broglie–Bohm (BB) causal theory of motion is an alternative formulation of standard quantum mechanics (QM). It is probably the alternative interpretation that has been developed to the largest extent, allowing to recover many predictions of QM while delivering an interpretative framework in terms of point-like particles guided by objectively existing waves along deterministic individual trajectories. As put by Holland (1993, p. 17) 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’’. Bohm and Hiley (1985) state that their interpretation shows that ‘‘there is no need for a break or ‘cut’ in the way we regard reality between quantum and classical levels’’. Indeed one of the main advantages of adopting the BB interpretative framework concerns the ontological continuity between the quantum and the classical world: the trajectories followed by the particles are to be regarded as real, in the same sense that macroscopic objects move along classical trajectories: ‘‘there is no mismatch between Bohm’s ontology and the classical one regarding the existence of trajectories and the objective existence of actual particles’’ (Cushing, 1994, p. 52). From a philosophical stance this ontological continuity allows the BB interpretation to stand as a realist construal of quantum phenomena, whereas from a physical viewpoint the existence of trajectories leads to a possible unification of the classical and quantum worlds (allowing for example to define chaos in quantum mechanics). As is very well known, both points are deemed unattainable within standard quantum mechanics: QM stands as the authoritative paradigm put forward to promote anti-realism (not only in physics but also in science and beyond (Norris, 1999)), whereas the emergence of the classical world from quantum mechanics is still an unsolved intricate problem.

Concurrently, intensive investigations have been done in the last 20 years on quantum systems displaying the fingerprints of classical trajectories. Indeed in certain dynamical circumstances, known as the *semiclassical regime*, the properties of excited quantum systems are seen to depend on certain properties of the corresponding classical system. The recent surge of semiclassical physics (Brack & Bhaduri, 2003) has been aimed at studying models of nonseparable systems in solid-state, nuclear or atomic physics that are hard to solve or impossible to interpret within standard quantum mechanics based on the Schrödinger equation. One consequence of these investigations was that the content of the quantum-classical correspondence was enlarged by highlighting new links between a quantum system and its classical counterpart, such as the distribution of the energy levels, related to the global phase-space properties of the classical system. In particular classical chaos was seen to possess specific signatures in quantum systems (Haake, 2001). Moreover, due to their high degree of excitation, many semiclassical systems typically extend over spatial regions of almost macroscopic size.