Arxiv Review

Experimental Comparison of Bohm-like Theories with Different Primary Ontologies

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Abstract

The de Broglie-Bohm theory is a hidden-variable interpretation of quantum mechanics which involves particles moving through space along deterministic trajectories. This theory singles out the position as the primary ontological variable. Mathematically, it is possible to construct a similar theory where particles are moving through momentum-space, and momentum is singled out as the primary ontological variable. In this paper, we construct the putative particle trajectories for a two-slit experiment in both the position and momentum-space theories by simulating particle dynamics with coherent light. Using a method for constructing trajectories in the primary and non-primary spaces, we compare the phase-space dynamics offered by the two theories and show that they do not agree. This contradictory behaviour underscores the difficulty of selecting one picture of reality from the infinite number of possibilities offered by Bohm-like theories.

Outline

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Experimental Comparison of Bohm-like Theories with Different Primary Ontologies

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- Objective: To compare the dynamics of two *Bohmian theories* with *different ontologies*
- Method: Simulate the double slit experiment with coherent light and *weak measurements*.

Introduction

Introduction

- Breaking the symmetry between x and p:
  1. *Status* in MC: (x, p)
  2. *Status* in MB: (x, ψ)

- Primary ontologies:
  1. x-Bohm;
  2. p-Bohm;
  3. others

x-Bohm: Usual Description

Deterministic premise: There are particles with well-defined trajectories in *space*,

$$\dot{x} = v_x(x(t), t). \tag{1}$$

Pilot equation:

$$v_x(x,t) = \frac{1}{m}\frac{\partial S_x(x,t)}{\partial x}; \qquad \psi(x,t) = R_x(x,t)\exp\left[iS_x(x,t)/\hbar\right] \tag{2}$$

Alternatively:

$$v_x(x,t) = \frac{j_x(x,t)}{|\psi(x,t)|^2}; \qquad j_x(x,t) = \frac{\hbar}{2mi}\left(\psi^*(x,t)\frac{\partial\psi(x,t)}{\partial x} - \psi(x,t)\frac{\partial\psi^*(x,t)}{\partial x}\right) \tag{3}$$

Comments

- Trajectories of *position* do not intersect;
- $\dot{p} \neq 0$.

x-Bohm: Operational Description[1]

$$p_x(x,t) = \mathrm{Re}\left[\frac{\langle x|\hat{p}|\psi(t)\rangle}{\langle x \mid \psi(t)\rangle}\right] \tag{4}$$

The momentum of the particle at instant t is equivalent to:

1. measure the moment p weakly;
2. measure position x strongly;
3. compute the average only over the eigenstates associated with x. (post-selection in x).

Observation:

- Weak measurements satisfy PI

[1] Wiseman

Premise:

$$\dot{p} = v_p(p(t), t) \tag{5}$$

There is, in general, no pilot equation, but there is:

$$v_p(p,t) = \frac{j_p(p,t)}{|\tilde{\psi}(p,t)|^2}; \qquad j_p(p,t) = \frac{2}{\hbar}\int_{-\infty}^{p} \mathrm{Im}\left(\tilde{\psi}^*\left(p',t\right)\left(V\left(i\hbar\frac{\partial}{\partial p'}\right)\tilde{\psi}\left(p',t\right)\right)\right)dp' \tag{6}$$

Comments:

- Trajectories of the *moment* do not intersect;
- $\dot{p} = 0$.

Objective and procedure

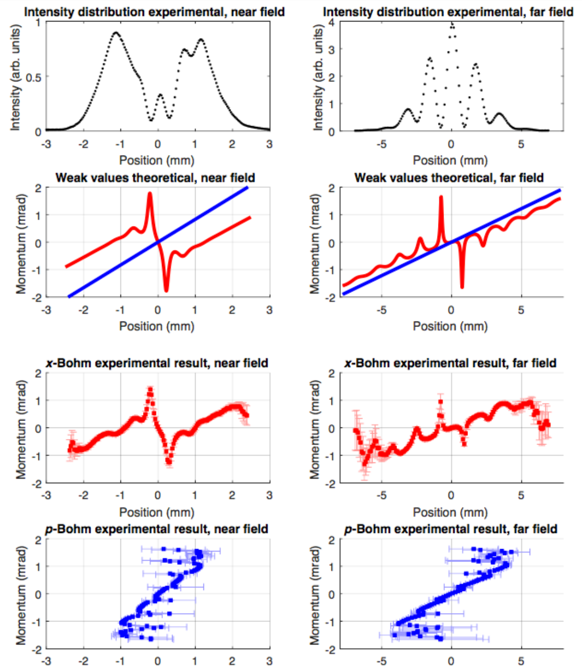
Compares the dynamics in phase space of each theory:

Theory	Primary variable	Non-primary variable (mean)
x-Bohm	x(t)	$\mathrm{p}_x(x(t),t) = \mathrm{Re}\left[\frac{\langle x\|\hat{p}\|\psi(t)\rangle}{\langle x\|\psi(t)\rangle}\right]$
p-Bohm	p(t)	$\mathrm{x}_p(p(t),t) = \mathrm{Re}\left[\frac{\langle p\|\hat{x}\|\psi(t)\rangle}{\langle p\|\psi(t)\rangle}\right]$

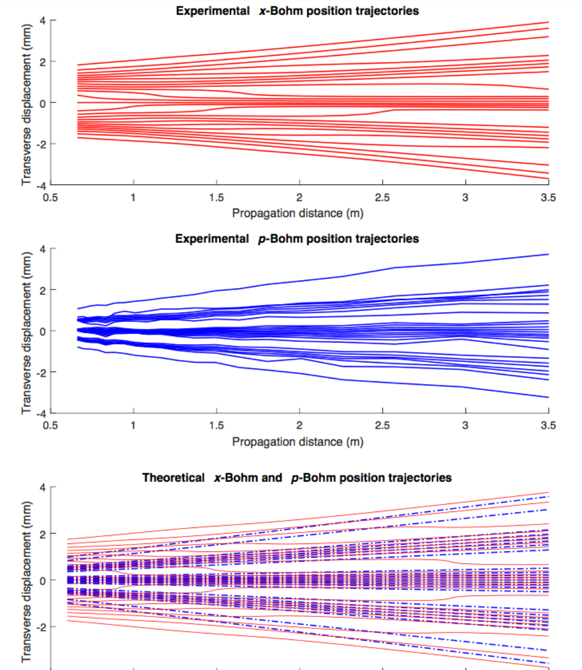
x_p is the trajectory in real space of the particle with momentum p.

Results

Near and Far Field Snapshots



Position paths based on x-Bohm (red) and p-Bohm (blue)



Moment trajectories based on x-Bohm (red) and p-Bohm (blue)