Scientific Research Publishing

Retraction Notice

Title of retracted article: **What is Wrong with Bohm's Mechanics? An Analysis of a Hong-Ou-Mandel Type Experiment**

Author(s): Sofia Wechsler
* Corresponding author. Email: sofia10@012.net.il

Journal: Journal of Modern Physics (JMP)
Year: 2016
Volume: 7
Number: 10
Pages (from - to): 1091 - 1097
DOI (to PDF): http://dx.doi.org/10.4236/jmp.2016.710097
Paper ID at SCIRP: 7502727
Article page: http://www.scirp.org/Journal/PaperInformation.aspx?PaperID=67482
Retraction date: 2017-02-14

Retraction initiative (multiple responses allowed; mark with **X**):

X All authors
☐ Some of the authors:
☐ Editor with hints from
- ○ Journal owner (publisher)
- ○ Institution:
- ○ Reader:
- ○ Other:

Retraction type (multiple responses allowed):

☐ Unreliable findings
- ○ Lab error ○ Inconsistent data **X** Analytical error ○ Biased interpretation
- ○ Other:

☐ Irreproducible results
☐ Failure to disclose a major competing interest likely to influence interpretations or recommendations
☐ Unethical research

☐ Fraud
- ○ Data fabrication ○ Fake publication ○ Other:

☐ Plagiarism ☐ Self plagiarism ☐ Overlap ☐ Redundant publication *
☐ Copyright infringement ☐ Other legal concern:

☐ Editorial reasons
- ○ Handling error ○ Unreliable review(s) ○ Decision error ○ Other:

☐ Other:

Results of publication (only one response allowed):

X are still valid.
☐ were found to be overall invalid.

Author's conduct (only one response allowed):

X honest error
☐ academic misconduct
☐ none (not applicable in this case – e.g. in case of editorial reasons)

* Also called duplicate or repetitive publication. Definition: "Publishing or attempting to publish substantially the same work more than once."

History
Expression of Concern:
Date(YYYY-MM-DD):none Link:

Correction:
Date(YYYY-MM-DD):none Link:

Comment:

The paper does not meet the standards of "Journal of Modern Physics".

This article has been retracted to straighten the academic record. In making this decision the Editorial Board follows COPE's Retraction Guidelines. Aim is to promote the circulation of scientific research by offering an ideal research publication platform with due consideration of internationally accepted standards on publication ethics. The Editorial Board would like to extend its sincere apologies for any inconvenience this retraction may have caused.

Editor guiding this retraction: Prof. Yang-Hui He (EIC of JMP).

Journal of Modern Physics, 2016, 7, 1091-1097
Published Online June 2016 in SciRes. http://www.scirp.org/journal/jmp
http://dx.doi.org/10.4236/jmp.2016.710097

What Is Wrong with Bohm's Mechanics? An Analysis of a Hong-Ou-Mandel Type Experiment

Sofia Wechsler

Kyriat Motzkin, Israel
Email: sofia10@012.net.il

Received 19 April 2016; accepted 15 June 2016; accepted 20 June 2016

RETRACTED

Abstract

The predictions of the Bohmian mechanics are compared with the predictions of the standard quantum mechanics. The analysis is done on a recently performed experiment of Hong-Ou-Mandel type. To the difference from the experiment of Hong, Ou, and Mandel with photons, the new one used bosons possessing rest-mass, ^{4}He atoms. Another novelty is that vis-à-vis the old experiment with identical photons, the recent one proves that distinguishable states of identical bosons can be used on condition that those states can transform into one another. The analysis here is done separately in the standard quantum formalism, and on base of the Bohmian velocities. Calculating the Bohmian trajectories, a contradiction arises. A major advantage of the present work over previous works that found the Bohmian mechanics problematic—typically based on counterfactual reasoning—is that the analysis here uses no counterfactual reasoning. Also, there is an advantage vis-à-vis the Brida experiment based on a thought-experiment of P. Ghose that also showed a contradiction between the quantum and Bohm's mechanics. Brida's experiment is done with photons, for which Bohm's mechanics is not valid, while the experiment analyzed here is carried with particles possessing rest-mass.

Keywords

Gratings of Light, Bragg Scattering, Bohmian Velocity, Bohmian Trajectory

1. Introduction

The Standard Quantum Mechanics (SQM) is plagued by the collapse postulate which besides being alien to the SQM formalism, leads to various contradictions. A famous example is offered by the so-called Hardy's paradox

How to cite this paper: Wechsler, S. (2016) What Is Wrong with Bohm's Mechanics? An Analysis of a Hong-Ou-Mandel Type Experiment. *Journal of Modern Physics*, **7**, 1091-1097. http://dx.doi.org/10.4236/jmp.2016.710097

with a two-particle entanglement [1], in which the collapse postulate in conjunction with the special relativity produces a contradiction [2] [3].[1]

Vis-à-vis these problems, different "interpretations" of the quantum mechanics were proposed, suggesting different solutions. It is beyond the scope of this work to examine all these interpretations and their weak points. A review of the interpretations most often discussed in the literature can be found in [5]. We focus here on D. Bohm's interpretation [6] [7] in the spirit of the guide-wave idea of L. de Broglie [8], since it is the most thoroughly elaborated and investigated.

Bohm's Mechanics (BM) eliminates the collapse postulate by assuming the existence of a quasi-classical particle—called in the literature *Bohmian particle*—that has at once a well-defined position and velocity, and therefore follows a well-defined *trajectory*. Thus, BM depicts a clear picture on how the measurements' outcomes are produced: the detector through which passes the Bohmian particle, makes a recording, while the other detectors remain silent although different parts of the wave-function impinge on them too. Thus, the collapse postulate becomes futile.

Unfortunately, the BM encounters hard problems.

One problem is that the BM is unfit for photons, as the formula of the Bohmian velocity involves the mass of the particle. Trials to take, for instance, the quantity $\hbar\omega/c^2$ as mass of a photon, encounter difficulties [9].

Another problem is that reasoning from the point of view of observers in relative movement, as in Hardy's analysis [1]-[3], the Bohmian trajectories predicted by the different observers are different. The contradiction would be avoided only if the wave-function would be valid in one single frame—a *preferred frame*—and invalid in all the other frames [10]. But the theory of relativity doesn't allow preferred frames.

Though, searches for frames in which the wave-function was violated were done in different ways, with moving detectors [11] or beam-splitters [12], or supposing some ether moving together with the Earth [13]. The experimental results didn't reveal any such invalidating frames.

P. Ghose pointed to one more problem, appearing in two-particle interferometry [14]-[16], and *working with one single frame*, the lab frame. In experiments with more than one particle, the Bohmian trajectories make predictions compatible with SQM if the particles are *distinguishable*. However, if the particles are *indistinguishable* and their wave-functions overlap, one cannot follow the evolution of each particle individually simply because one cannot distinguish between them. P. Ghose proposed an experiment with indistinguishable bosons, each boson passing through a different slit, and showed that the BM predictions differ clearly from those of the SQM.

A simulation of this proposal was realized with down-conversion photons by G. Brida and his co-workers [17] [18]. It confirms the SQM predictions, but it is questionable if that can be taken as disproving the BM because *the BM is not applicable to photons*.

For this reason, another experiment is analyzed here, recently performed at the Charles Fabry labs [19]. The experiment is a realization of the Hong-Ou-Mandel (HOM) experiment, with bosons possessing rest-mass, ^{4}He atoms, instead of photons. This analysis shows a contradiction which appears between BM and SQM when the wave-function is a superposition of different states of two identical particles. This analysis is also done *only in the lab frame*, and the proof is much simpler than that of P. Ghose.

The next sections are organized as follows: Section 2 describes the experiment main line. Section 3 presents the QM analysis of the experiment. Section 4 calculates the Bohmian trajectories of the two involved particles. Section 5 comprises discussion.

2. A Hong-Ou-Mandel Type Experiment with Bosons

The first step in the HOM-type experiment is the generation of pairs of atoms, **Figure 1**. On a trapped Bose-Einstein condensate (BEC) is superimposed a moving optical lattice created by two counter-propagating laser beams between which there is a small difference in frequency, $\delta\nu$. Thus, the atoms in the BEC appear as having a relative movement with respect to the lattice, with a mean *z*-component of the linear momentum, p_0, dependent on $\delta\nu$.

Under such conditions, if a collision of two atoms occurred, and was also accompanied by interaction with the lattice, the *z*-linear momenta of the atoms is changed to new values, P and p, $P > p$, see figure 1, **a** in [20] or

[1]Hardy's analysis was focused on ruling out local hidden variables, but it was immediately realized that it implies that the collapse clashes with the relativity, even without involving hidden variables. Berndl and Goldstein suggested that the clash is due to drawing conclusions on non-performed measurements [4]. Their suggestion is in line with the claim that the wave-function has an epistemological character, but it brings no contribution to the effort of understanding the measurement process.

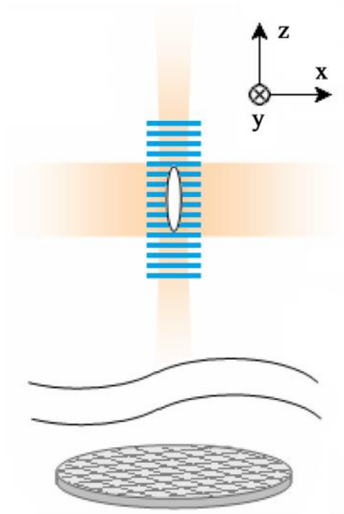

Figure 1. Generation and detection of the atom pairs. (not to scale) This figure is similar with the figure 1, **a** in [19] and represents schematically the elements used in producing and detecting atom pairs. On a BEC (white vertical oval) located in an optical trap (pink shaded) is superimposed a moving optical lattice (blue). When the lattice and the trap are switched off, the atoms fall toward a micro-channel plate detector located below the BEC.

[21] (these articles contain a detailed explanation of the pair generation process). The values *P* and *p* are quite well-defined due to the restrictions imposed by the conservation laws of linear momentum and energy, and by the lattice constant, see figure 1, **b** in [20]. Thus, a pair of atoms is created, one atom labeled below as **a**, with *z*-linear momentum *P*, the other, labeled **b**, with *z*-linear momentum *p*.

At a time t_1 the optical lattice is switched off, and 200 μs later the optical trap is switched off too. Since this moment on, the atoms fall freely under the action of the gravity and of their initial linear momenta. Due to the difference in linear momentum along the axis *z*, they separate spatially, see **Figure 2**.

At a time $t_2 = t_1 + 500\ \mu\text{s}$ the atoms meet a second optical lattice, non-running, with the fringes in the plane *x-y*. The lattice is sufficiently thick in the *z*-direction for being felt by both atoms although there is a distance between them. The lattice is kept active for 100 μs, and the effect is that the *z*-linear momenta of the atoms are swapped.

From now on, the distance along the axis *z* between the two atoms decreases steadily and they meet again at a time t_3 that satisfies $t_3 - t_2 = t_2 - t_1$, see **Figure 2**. At t_3 the second optical lattice is switched on again, but only for an interval of 50 μs. This shorter interval of atom-lattice interaction has the effect that the lattice acts similarly with a beam-splitter that transmits and reflects in equal proportion. In consequence, both atoms leave the lattice with the same *z*-linear momentum, either both with *P* (the output **c**), or both with *p* (the output **d**).[2]

3. Analysis of the Experiment According to the Quantum Mechanics

In this analysis only the evolution along the *z*-axis is relevant, because the velocity of the atoms in the plane *x-y* had quite a narrow peak around zero, as shows the figure 2(c) in [19]. The fringes of all the optical lattices were perpendicular to the *z*-axis and so the detector plate. Therefore, the calculi below are done in one dimension, on the axis *z*.

Between the times t_1 and t_2 the atoms are distinguishable by their linear momentum s.t. the wave-function of the boson pair is

$$\left|\mathbf{a},\mathbf{b}\right\rangle_1 = \hat{\mathbf{a}}_P^\dagger\, \hat{\mathbf{b}}_p^\dagger \left|0\right\rangle = \left|1_{\mathbf{a},P}\right\rangle \left|1_{\mathbf{b},p}\right\rangle, \tag{1}$$

As said in Section 2, at t_2 the second optical lattice is switched on.

[2]Since the time the trap is switched off, on the atoms acts the gravitational acceleration which alters the linear momenta *P* and *p*. However, inside the interferometer the alteration is small, moreover, inside the optical lattices activated at t_2 and t_3 compensation is done for this acceleration.

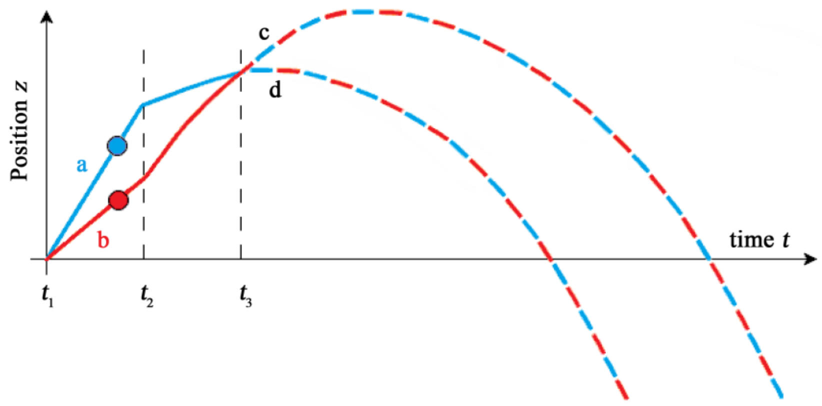

Figure 2. The time-evolution of the atom pairs. (Not to scale). This picture is similar with the figure 1, **b** in [19]. The origin of the vertical axis is at the point where the pair is supposed to have been generated. The horizontal axis represents time of flight. Each one of the curves after t_3 symbolize that both atoms got the same linear momentum.

According to [19] the behavior of the wave-packets in this lattice is well described by the Rabi formalism of a two-state system driven by an oscillatory field. The two states allowed by the interaction with the lattice under the energy and momentum conservation constraints, correspond to the linear momenta P and p. Thus, the evolution of an atom **q** in the field is described by a linear superposition

$$\hat{\mathbf{q}}_P^\dagger \to A(\tau)\hat{\mathbf{q}}_P^\dagger + B(\tau)\hat{\mathbf{q}}_p^\dagger,\quad \hat{\mathbf{q}}_p^\dagger \to C(\tau)\hat{\mathbf{q}}_P^\dagger + D(\tau)\hat{\mathbf{q}}_p^\dagger, \tag{2}$$

where the symbol $\to$ means "transforms into", τ is the interval of exposure to the field, and

$$|A(\tau)|^2 + |B(\tau)|^2 = |C(\tau)|^2 + |D(\tau)|^2 = 1. \tag{3}$$

As reported in [19], after an interval of 100 μs the coefficients $A(\tau)$ and $D(\tau)$ became zero, therefore the linear momenta of the two atoms were swapped,

$$\hat{\mathbf{a}}_P^\dagger \to \iota e^{-\iota\varphi_2}\hat{\mathbf{a}}_p^\dagger, \quad \text{and} \quad \hat{\mathbf{b}}_p^\dagger \to \iota e^{\iota\varphi_2}\hat{\mathbf{b}}_P^\dagger,$$

s.t. the following transformation occurred (leaving aside constant phase-factors)

$$|\mathbf{a},\mathbf{b}\rangle_2 = \hat{\mathbf{a}}_p^\dagger \hat{\mathbf{b}}_P^\dagger \hat{\mathbf{a}}_P \hat{\mathbf{b}}_p |1_{\mathbf{a},P}\rangle|1_{\mathbf{b},p}\rangle = |1_{\mathbf{a},p}\rangle|1_{\mathbf{b},P}\rangle, \tag{4}$$

At the time $t_3 = t_2 + 500\ \mu\text{s}$ the second optical lattice is switched on again. Since t_3 obeys $t_3 - t_2 = t_2 - t_1$ the wave-packets of **a** and **b** *overlap*, rendering the two atoms indistinguishable. With the lattice active for only 50 μs, it was found that the Equations (2) and (3) yielded,

$$\hat{\mathbf{a}}_p^\dagger \to \frac{1}{\sqrt{2}}\left(\hat{\mathbf{d}}_p^\dagger + \iota e^{\iota\varphi_3}\hat{\mathbf{c}}_P^\dagger\right), \qquad \hat{\mathbf{b}}_P^\dagger \to \frac{1}{\sqrt{2}}\left(\hat{\mathbf{c}}_P^\dagger + \iota e^{-\iota\varphi_3}\hat{\mathbf{d}}_p^\dagger\right). \tag{5}$$

Thus, the lattice acted similarly to a beam-splitter equally transmitting and reflecting (see section "The HOM effect" in [19]).

In the rest of the text the subscripts p and P will be omitted for the outputs **c** and **d**, because the beam **c** is produced only with linear momentum P, and **d** only with the linear momentum p.

Therefore, after $t_3 + 50\ \mu\text{s}$ the pair passes into the state

$$|\mathbf{c},\mathbf{d}\rangle = \frac{1}{2}\left\{\iota\left(e^{\iota\varphi_3}\hat{\mathbf{c}}^{\dagger 2} + e^{-\iota\varphi_3}\hat{\mathbf{d}}^{\dagger 2}\right) + \left(-\hat{\mathbf{c}}^\dagger\hat{\mathbf{d}}^\dagger + \hat{\mathbf{d}}^\dagger\hat{\mathbf{c}}^\dagger\right)\right\}\hat{\mathbf{a}}_p \hat{\mathbf{b}}_P |1_{\mathbf{a},p}\rangle|1_{\mathbf{b},P}\rangle. \tag{6}$$

The content of the second pair of round parentheses on the RHS vanishes because of the indistinguishability of the particles. The resulting wave-function is,

$$|\mathbf{c},\mathbf{d}\rangle = \frac{\iota}{\sqrt{2}}\left(e^{\iota\varphi_3}|2_{\mathbf{c},P}\rangle + e^{-\iota\varphi_3}|2_{\mathbf{d},p}\rangle\right), \tag{7}$$

which means that both atoms exit the lattice with the same linear momentum.

For the benefit of the next section it is useful to write the wave-functions (4) and (7) in coordinate representation

$$\psi_2(z_{\mathbf{a}}, z_{\mathbf{b}}) = \langle z_{\mathbf{a}} | 1_{\mathbf{a},p} \rangle \langle z_{\mathbf{b}} | 1_{\mathbf{b},P} \rangle = \frac{1}{2\pi} \mathrm{e}^{\iota(pz_{\mathbf{a}} + Pz_{\mathbf{b}})}, \tag{8}$$

$$\begin{aligned} \psi(z_{\mathbf{c}}, z_{\mathbf{d}}) &= \frac{\iota}{2\sqrt{2\pi}} \left\{ \mathrm{e}^{\iota(\varphi + 2Pz_{\mathbf{c}})/\hbar} + \mathrm{e}^{\iota(-\varphi + 2pz_{\mathbf{d}})/\hbar} \right\} \\ &= \frac{1}{\sqrt{2\pi}} \mathrm{e}^{\iota(Pz_{\mathbf{c}} + pz_{\mathbf{d}})/\hbar} \cos\left(\frac{Pz_{\mathbf{c}} - pz_{\mathbf{d}}}{\hbar} + \varphi \right). \end{aligned} \tag{9}$$

In these wave-functions were omitted leading constant phase-factors.

4. Analysis of the Experiment According to the Bohmian Mechanics

Bohm's interpretation of the QM is based on the concept of particles that move along well-defined trajectories. The BM predicts that an atom should have at each time t a well-defined coordinate $\mathbf{r}$ and a well-defined velocity $\dot{\mathbf{r}}$. Given a system of two quantum objects, **a** and **b**, of space-coordinate u and v respectively, if the joint wave-function is expressed as

$$\Psi(u,v,t) = R(u,w,t)\exp\left[\iota S(u,v,t)/\hbar\right], \tag{10}$$

BM predicts for each object the velocity

$$\dot{u}_{\mathbf{a}}^{\mathrm{BM}}(u,v,t) = \frac{1}{\mu_{\mathbf{a}}} \frac{\partial}{\partial u} S(u,v,t), \qquad \dot{v}_{\mathbf{b}}^{\mathrm{BM}}(u,v,t) = \frac{1}{\mu_{\mathbf{b}}} \frac{\partial}{\partial v} S(u,v,t), \tag{11}$$

where $\mu_{\mathbf{a}}$ and $\mu_{\mathbf{b}}$ are the masses of the particles, in our case, both equal to the mass μ of ^{4}He.

For the present analysis we are interested in the velocities before t_3, and those after the transformation (5) takes place.

The wave-function (8) gives according to the formulas (10) and (11) that between $t_2 + 100\ \mu\mathrm{s}$ and t_3,

$$\dot{z}_{\mathbf{a}} = \frac{1}{\mu} \frac{\partial S(z_{\mathbf{a}}, z_{\mathbf{b}})}{\partial z_{\mathbf{a}}} = \frac{p}{\mu}, \qquad \dot{z}_{\mathbf{b}} = \frac{1}{\mu} \frac{\partial S(z_{\mathbf{a}}, z_{\mathbf{b}})}{\partial z_{\mathbf{b}}} = \frac{P}{\mu}. \tag{12}$$

The wave-function (9) gives according to (10) and (11) that after the transformations (5),

$$\frac{\partial S(z_{\mathbf{c}}, z_{\mathbf{d}})}{\partial z_{\mathbf{c}}} = P, \qquad \frac{\partial S(z_{\mathbf{c}}, z_{\mathbf{d}})}{\partial z_{\mathbf{d}}} = p, \tag{13}$$

$$\dot{z}_{\mathbf{c}} = \frac{1}{\mu} \frac{\partial S(z_{\mathbf{c}}, z_{\mathbf{d}})}{\partial z_{\mathbf{c}}} = \frac{P}{\mu}, \qquad \dot{z}_{\mathbf{d}} = \frac{1}{\mu} \frac{\partial S(z_{\mathbf{c}}, z_{\mathbf{d}})}{\partial z_{\mathbf{d}}} = \frac{p}{\mu}. \tag{14}$$

Comparing the velocities (14) with (12) one may assume that in each trial of the experiment a fast particle—**c**, and a slow particle—**d**, leave the beam-splitter. However, that is disconfirmed by the experiment.

In [19] it is reported that precise measurements of the atoms' velocities were done. It was found that what emerged in the single trials of the experiment were two atoms of the same speed, either both fast, or both slow, as predicts the wave-function (7) and its subsequent forms, and not one fast atom and one slow, see the dip in figure 3 in [19].

Therefore in the formulas (14) the velocity of one particle should be calculated by dividing by 2μ not by μ, since there are two atoms in the beam **c**, not one. Similarly for the beam **d**. By doing so one would obtain

$$\dot{z}_{\mathbf{c}} = \frac{P}{2\mu}, \qquad \dot{z}_{\mathbf{d}} = \frac{p}{2\mu}. \tag{15}$$

Let's now remind that the meaning of the action function S is the Lagrangian of the *total* system integrated over time. In an experiment in which two identical particles, each one traveling with linear momentum P, and moving together, *i.e*. having the same space-coordinate $z_\mathbf{c}$, the classical Hamilton-Jacobi formalism predicts $\partial S(z_\mathbf{c}, z_\mathbf{d})/\partial z_\mathbf{c} = 2P$, not only P as in (13). Similarly, for two identical particles, each one of linear momentum p, and moving together with the same space-coordinate $z_\mathbf{d}$, $\partial S(z_\mathbf{c}, z_\mathbf{d})/\partial z_\mathbf{d} = 2p$, to the difference from (13).

In continuation, the velocity of one single particle should be obtained by division to 2μ, $\dot{z}_\mathbf{c} = P/\mu$ and $\dot{z}_\mathbf{d} = p/\mu$ to the difference from (15).

Thus, an incompatibility resulted between the experiment and the BM definitions.

5. Discussion

The Bohmian mechanics is a hidden-variable, non-local theory, in which the hidden variables are the initial position of the Bohmian particles, at some time t_0. For $t > t_0$, the definitions (11) together with the form (10) of the wave-function allow obtaining the position of each particle step by step,

$$z_\mathbf{x}(t+\Delta t) = z_\mathbf{x}(t) + \dot{z}_\mathbf{x}(z_\mathbf{a}(t), z_\mathbf{b}(t), t)\Delta t \text{, where } \mathbf{x} = \mathbf{a}, \mathbf{b}. \tag{16}$$

In this way one can obtain a unique trajectory for each particle.

However, as the Equation (16) shows, the Bohmian velocity of each particle at a given time t may depend on the position of both particles at t. In this case the BM becomes problematic vis-à-vis the theory of relativity. In the lab frame the two particles have at a given time t certain positions, e.g. $z_\mathbf{a}$ and $z_\mathbf{b}$. Though, according to the time-axis of another frame, in movement with respect to the lab, by the time the particle **a** has the position $z_\mathbf{a}$, the particle **b** has the position $z'_\mathbf{b}$. The Bohmian trajectories of such a system of particles are therefore frame-dependent.

For avoiding this ambiguity the BM has to postulate the existence of a preferred frame. The question whether the wave-function evolves according to a preferred frame is an issue of debate.

Here is the advantage of the present analysis, which, as Ghose's analysis, is done in the lab frame only. However, the present analysis is much simpler than that of P. Ghose, and is based on an experiment with particles possessing rest-mass, to which the BM can be applied.

Acknowledgements

This work was inspired by the thought-experiment proposed by Ghose in 2000, by the experiment performed by Brida in 2002, and by the HOM-type experiments recently performed at the Laboratoire Charles Fabry. It is a deep pleasure for me to thank to Prof. Christoph Westbrook for the detailed explanations about the HOM-type experiment reported in [19].

References

[1] Hardy, L. (1992) *Physical Review Letters*, **68**, 2981-2984. http://dx.doi.org/10.1103/PhysRevLett.68.2981

[2] Wechsler, S. (2003) Where Was the Particle? https://arxiv.org/ftp/quant-ph/papers/0301/0301098.pdf

[3] Wechsler, S. (2016) Contextual Experiments, Influence from Future, and the Wave-Function "Collapse". https://www.researchgate.net/publication/281210065_Contextual_Experiments_Influence_from_Future_and_the_Wave-Function_Collapse

[4] Berndl, K. and Goldstein, S. (1994) *Physical Review Letters*, **72**, 780. http://dx.doi.org/10.1103/PhysRevLett.72.780

[5] Bassi, A. and Ghirardi, G.-C. (2003) *Physics Reports*, **379**, 257-426. http://arxiv.org/abs/quant-ph/0302164

[6] Bohm, D. (1952) *Physical Review*, **85**, 166-179.

[7] Bohm, D. (1952) *Physical Review*, **85**, 180-193. http://dx.doi.org/10.1103/PhysRev.85.180

[8] de Broglie, L. (1926) Ondes et mouvements. Gauthier-Villars, Paris.

[9] Tumulka, R. (2012) Private Communications.

[10] Berndl, K., Dürr, D., Goldstein, S. and Zanghì, N. (1995) EPR-Bell Nonlocality, Lorentz Invariance, and Bohmian Quantum Theory. http://arxiv.org/abs/quant-ph/9510027

[11] Zbinden, H., Brendel, J., Tittel, W. and Gisin, N. (2001) *Journal of Physics A*: *Mathematical and General*, **34**, 7103-7110. http://dx.doi.org/10.1088/0305-4470/34/35/334

[12] Stefanov, A., Zbinden, H., Gisin, N. and Suarez, A. (2003) *Physical Review A*, **67**, 042115. http://dx.doi.org/10.1103/PhysRevA.67.042115

[13] Salart, D., Baas, A., Branciard, C., Gisin, N. and Zbinden, H. (2008) *Nature*, **454**, 861-864. http://dx.doi.org/10.1038/nature07121

[14] Ghose, P. (2003) Incompatibility of the de Broglie-Bohm Theory with Quantum Mechanics. https://arxiv.org/abs/quant-ph/0001024

[15] Ghose, P. (2003) An Experiment to Distinguish between de Broglie-Bohm and Standard Quantum Mechanics. http://arxiv.org/abs/quant-ph/0003037

[16] Ghose, P. (2003) On the Incompatibility of Standard Quantum Mechanics and the de Broglie-Bohm Theory. http://arxiv.org/abs/quant-ph/0103126v8

[17] Brida, G., Cagliero, E., Falzetta, G., Genovese, M., Gramegna, M. and Novero, C. (2002) *Journal of Physics B*: *Atomic, Molecular and Optical Physics*, **35**, 4751. http://dx.doi.org/10.1088/0953-4075/35/22/316

[18] Brida, G., Cagliero, E., Falzetta, G., Genovese, M., Gramegna, M. and Predazzi, E. (2002) *Physical Review A*, **68**, 033803. http://dx.doi.org/10.1103/PhysRevA.68.033803

[19] Lopes, R., Imanaliev, A., Aspect, A., Cheneau, M., Boiron, D. and Westbrook., C.I. (2015) An Atomic Hong-Ou-Mandel Experiment. https://arxiv.org/abs/1501.03065 http://dx.doi.org/10.1038/nature14331

[20] Bonneau, M., Ruaudel, J., Lopes, R., Jaskula, J.-C., Aspect, A., Boiron, D. and Westbrook, C.I. (2013) *Physical Review A*, **87**, 061603(*R*).

[21] Campbell, G.K., Mun, J., Boyd, M., Streed, E.W., Ketterle, W. and Pritchard, D.E. (2006) *Physical Review Letters*, **96**, 020406. http://dx.doi.org/10.1103/PhysRevLett.96.020406