Wave Mechanics vs Quantum Mechanics

Adriano Orefice*, Raffaele Giovanelli, Domenico Ditto

Università degli Studi di Milano - DISAA - Via Celoria, 2 - 20133 - Milano (Italy)

1 - **Introduction**

As is told in excellent books such as Refs.[**1-3**], the emerging *Wave Mechanics*, which was developing, between 1923 and 1927, under the impulse of its founding fathers L. de Broglie and E. Schrödinger [**4-7**], was overwhelmed by a group of influential physicist such as N. Bohr, W. Heisenberg, W. Pauli, M. Born and P. A. M. Dirac, who passed it off as a synonym, or even as a minor particular case, of their pre-existent *Quantum Mechanics*.

This *coup d'état* - whose main result was the (nowadays persistent) hegemony of the probabilistic Copenhagen interpretation (overthrowing de Broglie's and Schrödinger's realistic point of view), took basically place at the 5th Solvay International Conference, in 1927. The most distinguished victim of this hegemony was de Broglie himself, who felt forced to withdraw his own realistic point of view for over two decades.

A small breach was open in 1952 by Bohm [**8-9**], who re-discovered an approach similar to the one of de Broglie, and by de Broglie himself, who took the opportunity to go back [**10-13]** to his own ancient realistic ideas, but wasn't able to make himself heard beyond a small circle of followers. Bohm's work, in its turn, was carried on and kept alive in Refs.[**14-17**], but remained almost ignored for many years, and began to bear fruit in chemical physics and nanoscale systems just before the beginning of the present century, raising a widening trend [**18-23**].

Both Bohm and de Broglie, however, had been affected, more or less consciously, by the Copenhagen hegemony - and it's on this point that we began, a few years ago, to express our humble opinion, proposing an interpretation of Wave Mechanics based on a novel mathematical property we had found for any kind of wave-like features described by Helmholtz-like equation. The most direct and important consequence of de Broglie's relation $\vec{p} = \hbar \vec{k}$ turned out to be the *time-independent* Schrödinger equation, allowing an *exact, non-probabilistic description* in terms of point-like particle trajectories and proving therefore that the Copenhagen generality claim is false. The *time-dependent* Schrödinger equation, which is a *consequence* of the time-independent one, lends itself, on the other hand, to a *statistical description*, visually described by Bohm's probability flux lines.

We published on this topic - together with a series of papers placed on arXiv, the e-print archive of the Cornell University - three articles [**24-26**], the last of which appeared in 2013 on *Les Annales de la Fondation Louis de Broglie,* an open-minded Research Institute connected with the *Académie des Sciences de Paris*. In the meantime we had submitted another paper (whose most recently revised form may be found at the arXiv link [**27**]) to *Foundations of Physics*, whence it was *rejected* - although it was the continuation of a work previously published by the same journal - by a Bohmian Referee, strongly affected by the Copenhagen tradition.

Because of the exemplary character of this episode, closely reminding a famous Galilean dialogue [**28**], the present short communication contains both the Referee's report and our reply, hoping to raise and extend a long-due discussion on the role of Wave Mechanics.

* Corresponding author: adriano.orefice@unimi.it

2 - **FoP Referee's Report**

*The authors present in their paper a **fundamental misunderstanding** of Bohm's theory, of which they assume that that theory is fundamentally stochastic. The mistake was once understandable and was also made by Pauli shortly after Bohm's papers appeared, but nowadays, with all the excellent literature on Bohmian Mechanics, one can and must expect from researchers in the field a correct understanding of the facts. In Bohm's theory the wave guides the particles and the dynamics is clearly deterministic. The misunderstanding appears because in some interpretations the wave function is an epistemic quantity, merely a probability expressing ignorance. That is however not so in Bohmian mechanics. The wave functions does also determine a statistical ensemble in the very same way as the Hamiltonian in classical mechanics determines the statistical ensembles of statistical mechanics. Surprisingly the authors motivate their work with a quote which says exactly that, namely, that Bohmian mechanics is not fundamentally random, but seem to misunderstand completely what they quote. In any case the approach of the authors using Helmholtz wave equation must at some point also invoke some statistical argument since they must reproduce eventually Born's statistical law. I do not see in the paper any argument connecting their approach to random outcomes typical for quantum mechanics. **The paper cannot be published**.*

3 - **Authors' Reply**

Let us remind, to begin with, that, in Bohm's words [**8**], *"**the use of statistical ensembles**, although not a reflection of an inherent limitation on the precision with which it is correct for us to conceive of the variables defining the state of the system, **is a practical necessity**, as in the case of classical statistical mechanics".*
Bohm's particles are therefore represented, *by practical necessity*, by means of *statistical wave-packets*, travelling according to a *time-dependent* Schrödinger equation **-** just like in the standard Copenhagen interpretation.
Bohm's basic contribution was the re-discovery (independently from de Broglie) that these wave-packets may be viewed as moving under the action of a statistical term (the so-called Quantum Potential) provided by the time-dependent Schrödinger equation itself, and allowing a visual representation of the standard solutions in terms of fluid-like probability flow-lines.
It goes without saying that the *time-dependent* Schrödinger equation, just like any other differential equation, provides (for any set of initial and boundary conditions) the *deterministic* evolution of its solutions: i.e. (according both to Copenhagen and Bohm) the deterministic evolution of *probability* distributions.
But does this fact *determine a statistical ensemble in the very same way as the Hamiltonian in classical mechanics determines the statistical ensembles of statistical mechanics?*
According to Bohm's *faith* (in timid contradiction with the Copenhagen dogma) there does exist in principle, below the level of human knowledge, i.e. below the statistical distributions deterministically provided by the *time-dependent* Schrödinger equation, a physical reality which doesn't concern statistical wave packets but classical-looking point-like particles and trajectories. He declares however, in spite of this *faith*, that *one must resort, by necessity, to the use of statistical ensembles*. Is this sufficient to justify the Referee's pun that *Bohmian Mechanics is not fundamentally random*? Bohm's *faith* in a non-random reality remains confined to the sterile Empyreum of platonic ideas, and

doesn't modify the unavoidably statistical character of his approach. His *faith*, indeed, is the only, evanescent difference with respect to the Copenhagen paradigm.
In our line of work [**23-26**], on the other hand, we *demonstrate* the existence of realistic, non-statistical point-like particle trajectories by directly pulling their (easily computable) dynamics out of Plato's Empyreum. Contrary to what the Referee claims, no particular argument must be *invoked in order to reproduce the random outcomes typical for quantum mechanics*: Wave Mechanics, in fact, *is not* intrinsically based on random outcomes. Statistical averages are possible, but not essential, and may be performed, just like in good old classical physics, over quantities whose existence is well-established, and not simply assumed by faith. *Independently* from Bohm's theory we present a self-consistent, non-probabilistic interpretation stemming from de Broglie's seminal relation $\vec{p} = \hbar \vec{k}$ and from its most direct consequence, the *time-independent* Schrödinger equation. Isn't it high time for de Broglie's and Schrödinger's revenge?

REFERENCES

[**1**] L. de Broglie/G. Lochak, *Un itinéraire scientifique* (Ed. La Découverte, Paris, 1987)
[**2**] J. T. Cushing, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony* (The University of Chicago Press, 1994)
[**3**] G. Bacciagaluppi and A.Valentini, *Quantum Theory at the Crossroad. Reconsidering the 1927 Solvay Conference* (Cambridge University Press, 2009)
[**4**] L. de Broglie, *Compt. Rend. Acad. Sci.* **177**, pg. 517, 548 and 630 (1923)
[**5**] L. de Broglie, *Annales de Physique* **3**, 22 (1925) (Doctoral Thesis of 1924)
[**6**] E. Schrödinger, *Annalen der Physik* **79**, pg. 361 and 489 (1926)
[**7**] E. Schrödinger, *Annalen der Physik* **81**, 109 (1926)
[**8**] D. J. Bohm, *Phys. Rev.* **85**, 166 (1952)
[**9**] D. J. Bohm, *Phys. Rev.* **85**, 180 (1952)
[**10**] L. de Broglie, *La Physique Quantique restera-t-elle indéterministe?* (Gauthier-Villars, 1953)
[**11**] L. de Broglie, *Une tentative d'interprétation causale et non-linéaire de la Mécanique Ondulatoire* (Gauthier-Villars, 1956)
[**12**] L. de Broglie, *la Théorie de la Mesure en Mécanique Ondulatoire* (Gauthier-Villars, 1957)
[**13**] L. de Broglie, *L'interprétation de la Mécanique Ondulatoire par la Théorie de la Double Solution* (Proc. Intern. School of Physics "E. Fermi", Course XLIX ,Varenna, 1970)
[**14**] D. J. Bohm and B. J. Hiley, *Found. Phys.* **5**, 93 (1975)
[**15**] D. J. Bohm and B. J. Hiley, *Found. Phys.* **12**, 1001 (1982)
[**16**] D. J. Bohm and B. J. Hiley, *Found. Phys.* **14**, 255 (1984)
[**17**] P. E. Holland, *The Quantum Theory of Motion* (Cambridge University Press, 1993)
[**18**] A. S. Sanz, F. Borondo, S. Miret-Artès, Phys. Rev. B, **61**, 7743 (2000)
[**19**] R. E. Wyatt, *Quantum Dynamics with Trajectories: Introduction to Quantum Hydrodynamics* (Springer, 2005)
[**20**] D. Dürr and S. Teufel, *Bohmian Mechanics* (Springer -Verlag, 2009)
[**21**] A.A.V.V., *Quantum Trajectories* (ed. by Pratim Kuman Chattaraj, CRC Press, 2011)
[**22**] A.A.V.V., *Quantum Trajectories* (ed. by K. H. Hughes and G. Parlant, CCP6, Daresbury, 2011)
[**23**] A.A.V.V., *Applied Bohmian Mechanics: from Nanoscale Systems to Cosmology* (ed. by X. Oriols and J. Mompart, Pan Stanford Publishing, 2012)
[**24**] A. Orefice, R. Giovanelli and D. Ditto, *Found. Phys.* **39**, 256 (2009)
[**25**] A. Orefice, R. Giovanelli and D. Ditto, Ref.[**22**], Chapter 7, pg.425-453 (2012)
[**26**] A. Orefice, R. Giovanelli and D. Ditto, *Annales de la Fondation Louis de Broglie*, **38**, 7 (2013)
[**27**] A. Orefice, R. Giovanelli and D. Ditto, http://arxiv.org/abs/1310.8077
[**28**] G. Galilei, *Dialogo sopra i due massimi sistemi del mondo* (G. B. Landini, Florence, 1632)