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Quantum Potential: Physics, Geometry and Algebra

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Foreword

It is extremely satisfying to see how the original work of de Broglie and Bohm is now being explored more fully from a number of different perspectives, leading to fresh insights into quantum phenomena and showing that the conventional interpretation is limited.

First came the claim that it was "impossible" to explain quantum phenomena in terms of individual particle movements. Then, when this was shown to be incorrect, the criticism changed to "this teaches us nothing new. Why add the metaphysical baggage of actual particles when the Bohm momentum $pB = \nabla S$ and the kinetic energy cannot be measured." But even this criticism has now been shown to be wrong with the appearance of weak measurements.

Rick Leavens and others have shown that the weak value of the momentum operator at a post-selected position *is* the Bohm momentum and that the weak value of the operator $\widehat{P}^2(x,t)/2m$ *is* the Bohm kinetic energy. The quantum potential is now open to experimental investigation. Numbers can be attached to these quantities which can then be compared with experiment. Recently, experiments of this kind have been carried out on photons by Aephraim Steinberg and his group in Toronto. More experiments are in progress, this time to make weak measurements on atoms, bringing the experiments even closer to verifying the predictions of the extra phenomena revealed through the de Broglie–Bohm approach.

Now we appear to have a more believable explanation of quantum phenomena, but it still leaves us with one feature that many find objectionable, namely, quantum nonlocality. This opposition is maintained in spite of all the theoretical and experimental support for some form of nonlocality. It leaves us with the question of how we are to understand the resulting tension that exists between local relativity and quantum nonlocality.

Experiments show that the nonlocal correlations turn out to be correct even when detection events are space-like separated. Of course we should not be surprised at these results because Bohr had already argued that there was a novel kind of wholeness involved in all quantum phenomenon. He talks of the "impossibility of making any sharp separation between the behaviour of atomic objects and the interaction with measuring instruments which serve to define the conditions under which the phenomena appear." When replying to EPR, he talks about "an influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system." An *influence* acting over space-like separations? What *influence*? Could it be the quantum potential?

Although the de Broglie–Bohm approach allows a separation between particles, it is the quantum potential that "locks" them together. Furthermore, this coupling does not appear to be propagated as in a classical interaction. Rather it appears as a global constraint on the whole process that begins to make Bohr's claims of "wholeness" clearer. Could these global constraints, which are reflected in the covering groups of the symmetries involved, be the real explanation of these apparently nonlocal effects? More investigations are needed and this is where this book can play a valuable role. Ignazio Licata and Davide Fiscaletti have collected together a number of substantial explorations of the de Broglie–Bohm model, particularly those that explore possible meanings of the quantum potential. This gives us a valuable source of relevant material which can play an important role in taking these investigations further into new areas.

17 October 2013 B. J. Hiley

Preface

Who Needs Quantum Mechanics Interpretations?

The activity on Quantum Mechanics "interpretations" is still a flourishing industry cranking out new products every change of season. Like any production activity, it shows many self-referential aspects tending to wear out criticality the logistic curve of economists. Most of such research is justified by the longstanding—and unsolvable—problems of Copenhagen interpretation, such as the physical nature of the wave function, the collapse problem, and the observer role.

And yet, if we look outside of what H. Pagels called "the bazaar of reality," that is the actual use of Quantum Physics in real physics problems, we will see that something significant has happened for "foundations" in these years.

For example, the 2012 Nobel prize has been awarded to David Wineland and Serge Haroche, whose by far classical experiments in quantum optics has showed the full citizenship of those "strange"—and so embarrassing for the Standard Interpretation—negative probabilities of Wigner–Feynman distribution. It is just of negative probabilities that Feynman, with his usual intellectual audacity, has talked about in his contribution in honor of David Bohm [1].

The development of quantum cosmology has incisively proposed again the Robert Serber statement: "Quantum Mechanics laws are applied to Big-Bang now, but there were no observers then!" [2], so driving the metaphysics of the observer more and more toward Alice's wonderland. After all, restarting from Pascual Jordan and Werner Heisenberg, Marcello Cini, one of the masters of Italian theoretical physics, wrote: "I know very well we can't come back and physicists will keep on looking at Schrödinger equation as a fundamental pillar of their subject, as for me, after having teach it for 50 years, I'm happy I realized that wave functions can go and take their place next ether at the junk store" [3]. He completely developed such magnificent program in a 2003 paper; here we quote a key statement from the abstract: "In this formulation the wave/particle duality is no longer a puzzling phenomenon. The wave/particle duality is instead, in this new perspective, only the manifestation of two complementary aspects (continuity versus discontinuity) of an intrinsically nonlocal physical entity (the field) which objectively exists in ordinary three-dimensional space" [4].

On an opposite and a complementary front, G. Preparata stated: "The unacceptable subjectivism permeating the generally accepted Quantum Mechanics (QM) interpretation based on Niels Bohr ideas and Copenhagen school makes sense only in understanding it is not a complete theory of reality (…) To complete it we have to put it aside and admit Quantum Field Theory (QFT) as the only description of reality. Quantum Mechanics is so just an approximation of QFT and it is limited to the analysis of quantum processes in space-time regions where, in all probability, we can find a single quantum with its respective wave field" [5, 6]. The recent Afshar experiment [7] seems to confirm what Cini and Preparata said; it does not "demolishes" nor does it "elude" Heisenberg Uncertainty Principle, but places it within its natural version in QFT, which links the number of quanta to phase. In short, as J. Cramer says, a real "farewell to Copenhagen" [8], which gave birth to strong processes of critical revision starting just from that 1927 Solvay Conference where it become the standard interpretation [9, 10]. Obviously, an amazing series of experiments has been crucial in showing that nonlocality is neither something mysterious buried under the statistical machinery of probabilistic interpretation nor the Einstein spooky action at a distance, but a central element of the physical world' logics.

Such processes should not be possible without an increasing acceptance of the David Bohm Quantum Physics vision. Today, it can be considered, at least For All Practical Purpose! (FAPP) as the dominant reading of Quantum Physics, able to reopen many questions which were considered closed or forever "paradoxical". For the most of physicists, thinking in Bohmian terms is simpler than thinking within the restricted vetoes of the Copenhagen vulgate. We recall that it was just D. Bohm who changed the "ideal" EPR experiment in an operative procedure which experimental physicists uses largely still today and that John Bell, by starting from Bohm work, developed his famous inequality, so becoming one of the most brilliant supporter of Bohmian "speakability" of QM [11]. The constant and distinctive element of Bohm's work has been the crucial role of nonlocality to be introduced ab initio in the structural corpus of the physical theory, and quantum potential, even in the plurality of the mathematical treatments, is in the center of such structure, the nonlocal trait d'union between the post-classical features of Quantum Physics and the most advanced perspectives of Field Theory [12, 13].

For a long time, Bohm's one has been "just" another interpretation, and almost till the day before yesterday it was tout court identified with the de Broglie-Bohm Pilot Wave Theory. Actually, the idea of a particle surfing a wave is typical of de Broglie who felt the need to recover somewhat the classical concept of trajectory, still today a sort of dogma motion central in the work of exceptional and very active Bohmians [14, 15]. The fact that Bohm's ideas were considerably different from classical and post-classical ones is witnessed by this excerpt from the "duel" with M. Pryce, a defender of the orthodox vision, broadcasted by BBC in 1962:

"We wondered what actually an electron does. What should it do while it passes from the source to the slit? That's the point. Well, I could propose, for example, that the electron is not a particle in the sense it is currently meant, but an event. I assume such event happens in a generic medium—a "field"—we can suppose in this field there's an impulse. A wave moves forward and converges in a point so producing a very strong impulse and then diverges and scatters away. Let's imagine these impulses in a series all reaching a line there producing a series of intense pulses. The impulses will be very close one to the other, and so they will look like a particle. In most cases, all that will behave just like a particle and will behave differently when goes through the two slits, because each impulse will come out according to the way the incident wave passes the slits. The result is that we are looking at something it's neither a wave nor a particle. If you wonder how the electron has actually passed the slit and if it has really passed one slit or the other, I would reply that probably is not that kind of thing which can pass a slit or the other one. Actually, it is something which forms and dissolves continuously and that can be the way it really acts" [16].

His collaboration with J. P. Vigier, the most famous and brilliant among de Broglie disciples, will last for a long time (very strong between 1954 and 1958, it become progressively less intense after 1963); the French scientist will pursue his idea of a quantum stochastic geometrodynamics where particles are like solitons in nonlinear fields and nonlocality is a form of superluminality [17]. Bohm, convinced that this approach is not sufficiently radical, will instead follow the algebraic-topological line which characterizes his intense last years work with Basil Hiley. The revolutionary idea is that nonlocality does not look like a field at all, but it is "written" in the informational structure of a pre-space that Bohm-Hiley called "Implicate Order". This one is revealed only partially, depending on the information the observer chooses to extract from the system, and gives to QM its characteristic "contextuality" [18]. It is the recovery of the old Bohr complementarity, now based not on something "elusive" and the "uncertain" role of the observer, but on the deep logic of the physical world and the noncommutative relation between system and environment. It is not only a matter of re-reading the wave function as a statistical covering of a great number of transitions between the field modes. The theory of Implicate/Explicate order is the first real attempt to realize the J. A. Wheeler program of It from Bit (or QBit), the possibility to describe the emergent features of space-time-matter as expressions, constrained and conveyed, of an informational matrix "at the bottom of the world" [19].

Beyond any more or less ephemeral trends, this is the research of the great climbers of theoretical physics, such as Basil Hiley and David Finkelstein.

Anyway, the most prevailing reading of the Bohm work is still that known as the de Broglie-Bohm Wave Pilot Theory, surely for its intuitive advantages and the relatively simple formalism. We could say that Hiley and his collaborators are Bohmist rather that Bohmian, in the same sense as the word Marxian is opposed to Marxist. Everybody agree on the fact that beyond Copenhagen Quantum Theory can produce good Physics without (bad) Philosophy. Even the longstanding question of the "realism" of trajectories seems to have found its turning point in the connections with the Feynman Paths and the pregeometries [for a review, see: 20–22]. Thus, the quantum potential showed to be the most powerful, inclusive, and flexible tool "to tell" the nonlocal quantum processes, so opening new perspectives in Field Theory, Particle Physics, Gravitation Theory, Cosmology, Quantum Information and Chaos, and laying the foundations for a grounded bridge able to unify QM and QFT. Obviously, there are many ways "to read" the quantum potential, and it is worthy to be underlined that the differences more that interpretative are linked to the problem under consideration. There are semiclassical approaches, stochastic ones, geometrodynamic ones up to the purely algebraic and topological ones. The subtitle of this short book (Physics, Geometry, and Algebra) suggests we tried to provide the reader with complete review of the different positions into play: from the wave pilot, into subquantum thermodynamics and stochastics up to the noncommutative geometries and Clifford Algebras. The heedful reader will maybe able to reveal some little, subtle dissonances here and there, due to the fecund and sometimes fierce debating between the authors.

The prefacer (IL) is definitely a Bohmist, whereas my co-author is more at ease with quantum geometrodynamics. What come out in the end is not what Piotr Garbaczewski defines as quantum political/quasi-religious parties but—at least we hope so—a careful and punctual survey of the main results of a growing bibliography, updated till the very moment I write such lines.

We have neither authorial aspirations nor the pretense to replace the D. Bohm, B. Hiley great classical books, or the P. Holland and D. Dürr, S. Goldstein, e N. Zanghì treatises. As for the applications we address the reader to the monumental Applied Bohmian Mechanics [23].

We hope to give a light introductive guide to what can be actually done by the Bohmian and Bohmist tools and to contribute to the awakening from that "dogmatic sleep" about the mysteries of the wave function, a direction that seems to be followed also by the recent operational trend of quantum Bayesism [24].

The quantum potential not only explains the probabilistic nature of the wave function, but is an open door into the deep informational structure of the Universe.

Ignazio Licata

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