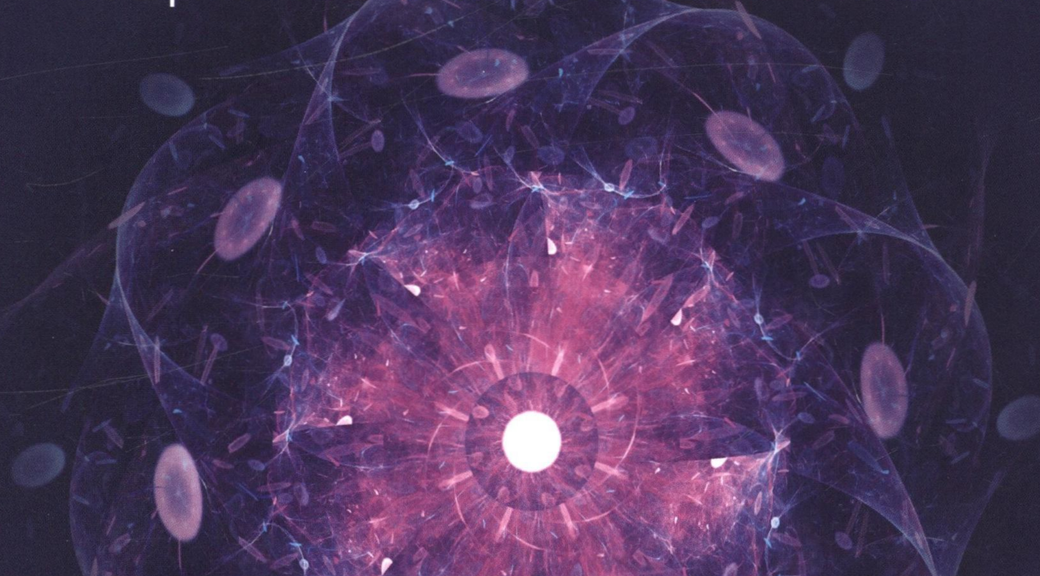
THE GEOMETRY OF QUANTUM POTENTIAL

Entropic Information of the Vacuum



Davide Fiscaletti

World Scientific

THE GEOMETRY OF QUANTUM POTENTIAL

Entropic Information of the Vacuum

In virtue of its features, Bohm's quantum potential introduces interesting and relevant perspectives towards a satisfactory geometrodynamic description of quantum processes. This book makes a comprehensive state-of-the-art review of some of the most significant elements and results about the geometrodynamic picture determined by the quantum potential in various contexts. Above all, the book explores the perspectives about the fundamental arena subtended by the quantum potential, the link between the geometry associated to the quantum potential and a fundamental quantum vacuum.

After an analysis of the geometry subtended by the quantum potential in the different fields of quantum physics (the non-relativistic domain, the relativistic domain, the relativistic quantum field theory, the quantum gravity domain and the canonical quantum cosmology), in the second part of the book, a recent interpretation of Bohm's quantum potential in terms of a more fundamental entity called quantum entropy, the approach of the symmetryzed quantum potential and the link between quantum potential and quantum vacuum are analysed, also in the light of the results obtained by the author.

World Scientific
www.worldscientific.com
10653 hc

ISBN 978-981-3227-97-2
9 789813 227972

THE GEOMETRY OF QUANTUM POTENTIAL

Entropic Information of the Vacuum

Fiscaletti

THE GEOMETRY OF QUANTUM POTENTIAL

Entropic Information of the Vacuum

Davide Fiscaletti
SpaceLife Institute, Italy

World Scientific

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI • TOKYO

Published by

World Scientific Publishing Co. Pte. Ltd.
5 Toh Tuck Link, Singapore 596224
USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601
UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

THE GEOMETRY OF QUANTUM POTENTIAL
Entropic Information of the Vacuum

ISBN 978-981-3227-97-2

For any available supplementary material, please visit
http://www.worldscientific.com/worldscibooks/10.1142/10653#t=suppl

Desk Editor: Christopher Teo

Typeset by Stallion Press
Email: enquiries@stallionpress.com

Printed in Singapore

THE GEOMETRY OF QUANTUM POTENTIAL

Entropic Information of the Vacuum

Introduction

Phenomena studied by quantum physics are far outside the range of parameters of our daily experience. The behaviour and the evolution of quantum systems do not seem to be compatible with a description in visualizable terms. Quantum physics turns out to appear extremely exotic, unnatural and mysterious to us because of our incapability to visualize a subatomic particle (such as an electron) and its motion or the uncertainty principle or the processes of creation and annihilation of quanta in the quantum vacuum.

If in classical physics systems can be analysed in terms of elements of information represented by a certain number of well-defined states, which are determined by the values of a certain number of physical quantities (such as position and speed) and our ignorance about the knowledge of the state of the system is owed to the loss of the ability to follow information, in quantum mechanics the physical variables of a system do not seem to have a well defined value at each instant and thus the ignorance seems to be intrinsic to the nature of objects. In the study of the microscopic world it seems that there is no way to avoid the introduction of the probability and that, when a property of an object is measured, its state turns out to be modified dramatically by virtue of the irreversible interaction with the measurement apparatus. Quantum mechanics leads to develop an entirely new kind of programme in order to study physical processes — with respect to classical physics — which takes account of the fact that each system can be found in a state belonging to its Hilbert space with a certain probability distribution. For example, if we prepare an electron with the spin oriented along a vertical direction by creating a large external magnetic field oriented along this direction, it turns out that the electron spin has only two possible configurations, parallel or antiparallel, to the external magnetic field. By repeating the same experiment many times in an identical way, in each experiment we discover the same result regarding the spin of the electron, namely: sometimes the spin is "up" and sometimes the spin is "down". In the light of all experimental results, we can conclude that the states "spin up" and "spin down" are the two possible states of the spin and that the real, actual state of the spin of the electron may be known only after a measurement is performed, in other words probability seems to play an important role as regards the behaviour and the evolution of the spin of the electron.

Quantum mechanics is perhaps the fundamental theory of 20^{th} century which has determined the most profound changes in the understanding of the physical world. Despite its extraordinary successes from the predictive point of view (as regards, in particular, the study of the microscopic world, from atomic physics to nuclear physics and subnuclear physics and so on), it is plagued by several problems of interpretation as regards what it says about the world. After 80 years since its birth, the meaning of quantum theory remains as controversial as ever. Nevertheless, quantum theory has introduced much more spread perspectives and scenarios inside theoretical physics than those offered by every previous theory.

The debate about the meaning of quantum mechanics can be traced back to 1927 when the participants at the fifth Solvay conference in Brussels distinctly failed to arrive at a consensus (this emerges in a clear way from the actual proceedings of the conference) [1]. In order to put in evidence the relevant disagreement existing among the participants at this congress, Paul Ehrenfest made an emblematic gesture, during one of the discussions, by writing the following quotation from the book of Genesis on the blackboard: "And they said one to another: 'Go to, let us build us a tower, whose top may reach unto heaven; and let us make us a name'.

And the Lord said: 'Go to, let us go down, and there confound their language, that they may not understand one another's speech"'.

If the builders of the Tower of Babel could not realize one another's speech, in analogous way in the fifth Solvay Conference in Brussels it seemed as if the eminent physicists gathered in it could no longer understand one another's speech. In particular, at the crucial 1927 Solvay conference, three quite distinct theories of quantum physics were presented and discussed on an equal footing: de Broglie's pilot-wave theory, Schrödinger's wave mechanics, and Bohr's and Heisenberg's quantum mechanics. According to de Broglie's theory, subatomic particles (such as electrons) can be seen as point-like objects moving with continuous trajectories 'guided' or choreographed by the wavefunction. In Schrödinger's wave mechanics, particles can be seen as localized wave packets moving in space, that emerge out of the wavefunction, intended as the fundamental reality. Instead, according to Born's and Heisenberg's view, in the study of microscopic processes the interference between measured system and observer has to be taken into consideration: the idea of definite states of reality at the quantum level cannot be maintained in a way that is independent of human observation.

In order to describe the atomic and subatomic world, quantum theory, as presented in classical textbooks, implies to consider a human observer performing experiments with microscopic quantum systems by making use of a macroscopic classical apparatus. As physicists know from the reading of classical textbooks on these topics, in quantum mechanics the state of a physical system is described by introducing the concept of wavefunction, a mathematical object that is used to calculate probabilities but which provides no clear description of the state of reality of a single system. Instead, the observer and the apparatus are described classically and are assumed to have definite states of reality. For example, a pointer on a measuring apparatus always indicates a particular reading, corresponding to the measured value of the quantity in consideration. Quantum systems seem to inhabit a fuzzy, indefinite realm, while our everyday macroscopic world — although is ultimately built from the quantum laws — does not.

Quantum theory is formulated in such a way that causes a sharply defined boundary between the quantum and classical domains. Even today Newton's laws of classical mechanics are seen as an approximation of the more general quantum mechanics and it is implicitly assumed that they must be considered valid as long as the dimensions of the system under study are big. However, the correspondence principle, which expresses this peculiar characteristic of Newton's laws to appear only at macroscopic level, indeed does not turn out to be demonstrable, and thus one can say that, strictly speaking, the classical domain practically does not exist. The following questions become thus natural. How does everyday reality emerge from the fuzzy and exotic quantum domain? What does it happen to real macroscopic states as we move to smaller scales? In particular, when and in which situations does physical reality generate microscopic fuzziness? What are really the phenomena occurring inside an atom? Despite the astonishing progress made in high-energy physics and in cosmology since the Second World War, today there is no precise and satisfactory answer to these simple questions.

The Founding Fathers of quantum theory, namely the exponents of Copenhagen and Gottinga schools (Bohr, Heisenberg, Born, etc...) handed to us a view known as standard (or Copenhagen) interpretation of quantum mechanics. According to the Copenhagen interpretation, a causal description of atomic subatomic processes in agreement with the motion dogma cannot be provided: the wavefunction carries only the information about possible outcomes of a measurement process [2]. In the original formulation of the theory, a measurement derives from the interaction of a quantum microsystem S with a classical macrosystem O [3, 4]. After the microsystem S under consideration interacts with its surroundings, the microsystem and its surroundings then become entangled and they are in a quantum mechanical superposition. If the macrosystem O interacts with the variable q of the microsystem S, and S is in a superposition of states of different values of q, then the macrosystem O measures only one of the values of q, and the interaction modifies the state of S by projecting it into a state with that value: in every measurement the wavefunction of a microsystem collapses into the state specified by the outcome of the measurement. Until a measurement is not performed, a microscopic system may be in an undefined state, which describes only a "potentiality" of the physical system into consideration, namely contains the information on a set of possible values, each with a corresponding probability to become real and objective when the measurement takes place. This means that, according to the standard interpretation of quantum mechanics, the evolution of a given physical microscopic system materializes only after a measurement is performed and an interaction between the microscopic system and a macroscopic apparatus occurs. Therefore, whenever a measurement is performed the wavefunction of the physical system ceases to evolve according to the Schrödinger equation (the evolution law of every isolated microscopic system) and collapses into one of its eigenstates. The final state is not predictable with certainty but only probabilistically and, according to the standard version, the reduction of the wavefunction is provoked by the observer, in other words happens at the moment in which the information about the interaction between the microsystem and the macrosystem arrives in the observer's brain: it is the observer who forces nature to reveal itself in one of its possible states [5]. The absolute square of the scalar product of the wavefunction with its eigenfunctions are the probabilities (or probability densities) of the occurrence of these particular eigenvalues in the measurement process [3, 6]. Inside the Copenhagen interpretation, the postulate of the reduction of the wavefunction can be also considered as a sort of device, of a way out which is introduced in order to reproduce the non-linear complex nature of the quantum phenomena associated with the problem of the wave-particle duality.

There was a general movement in theoretical physics in the 1920s against the idea that individual atomic events could be visualized as parts of causally connected sequences of spacetime processes. In the paper where he developed the probability interpretation of the wavefunction, Born wrote: "I myself am inclined to give up determinism in the world of atoms. But that is a philosophical question for which physical arguments alone are not decisive" [7]. The standard interpretation of quantum mechanics seemed to consider as almost axiomatic that the trajectory concept of classical mechanics is incompatible with atomic and subatomic processes. As regards the philosophy of standard quantum mechanics, the following Bohr's sentences are significant too: "A phenomenon is not a phenomenon until it is observed" and "It is a mistake to think that physics' aim is to find how nature is. Physics concerns what we can say about nature" [8]. Bohr thought that in quantum mechanics the observer does not reveal the phenomenon but somehow fixes and defines it. According to Bohr's view, the observer plays an active role in the study of the behaviour of elementary particles, in other words the observer influences in a decisive way the experimental results regarding atomic and subatomic processes: the real and objective features of a physical system are ultimately created by the interaction of the observer and its macroscopic measuring apparatus with the measured system.

The central claim made by standard quantum mechanics is that the wavefunction provides a complete description of a quantum system: all we can know about a physical system is contained in its wavefunction. This would seem to imply that quantum mechanics is, fundamentally, a theory about wavefunctions. However, if one accepts such a proposition an inescapable problem is derived, which was eloquently formulated by Schrödinger within the context of his famous cat paradox: namely, the question of what it actually means for an object to literally exist in a superposition of eigenstates of a measurement operator [9]. In the light of its formal structure and its conceptual foundations as regards the study of the measurement processes, the standard interpretation of quantum mechanics can be also considered as the "minimal" interpretation of quantum theory: it provides us only the mathematical structure and the minimum interpretative propositions needed to define the relation between the mathematical structure itself and the experience.

On the other hand, it must be emphasized that several authors introduced the possibility to understand quantum processes on the basis of a geometric interpretation. According to these proposals, quantum mechanics might not be a fundamental theory but rather emerge from an underlying geometry. In particular, in 1984–1885

Santamato first found a similarity between Weyl geometry and the structure of quantum mechanical equations [10, 11]. In 1990 J.T. Wheeler suggested a geometric picture of quantum theory in which the quantum measurement and the related uncertainty emerge directly from Weyl geometry [12]. In 1995 Wood and Papini developed a modified Weyl–Dirac theory which unifies the particle aspects of matter and Weyl symmetry breaking [13]. More recently, studies in this direction focused on the non-commutative non-integrable geometry [14] or on the Ricci flow [15–20] or on a geometric reduction of the dimensionality of space-time [21, 22].

According to the results of other authors, the formalism of quantum mechanics may be derived from the covering space of the symplectic group (see, for example, the works of Guillemin and Sternberg and of De Gosson [23–25]). These research imply that it is possible to derive the Schrödinger equation rigorously from classical symplectomorphisms by lifting the classical phase space behaviour onto a covering space, if one assumes that the Hamiltonian is up to quadratic in position and momentum. In this picture, the wave and particle aspects of the quantum entities may be described inside a unifying formalism: the particle properties are described on the underlying phase space while the wave properties appear at the level of the covering space. Moreover, as shown by de Gosson in the recent paper *The symplectic camel and quantum universal invariants: the angel of geometry versus the demon of algebra*, the orthogonal projection operator of the phase space R^{2n} of a continuous variable system with n degrees of freedom onto an arbitrary symplectic subspace F_{2k} is an ellipse of area not inferior to $\frac{1}{2}h$ (h being Planck's constant), which is a geometric version of Heisenberg's uncertainty principle [26].

On the other hand, although the standard interpretation of quantum mechanics functions perfectly from the predictive point of view, it is nevertheless characterized by inner contradictions and paradoxes. Besides the impossibility to describe quantum processes as events happening in a space-time picture, other crucial problems which plague the Copenhagen interpretation regard the treatment of measurement processes and, in particular, the definition of the boundary between the microscopic world, governed by the superposition principle, and the macroscopic world, in which one has well-defined perceptions as regards the properties of physical systems. The failure of the standard quantum theory to offer any sort of coherent resolution to these problems is largely the reason for which it has continually remained so ambiguous and obscure. As a consequence, the ontology which derives from the standard quantum mechanics cannot be considered a completely satisfactory starting-point in order to develop a coherent geometrodynamic picture of the quantum world.

Since the birth of quantum mechanics in the second half of the 20s of last century, Einstein claimed that the description of quantum phenomena proposed by Copenhagen and Gottinga schools, despite functioned well in the prediction of experimental results, was not complete, did not constitute a perfect theory and that it could be made causal by introducing some additional parameters. Einstein's point of view was thus that the behaviour of subatomic particles is independent from the observer, that it depends on some "hidden variables" besides their wavefunctions. In this way a strong well-known debate between Einstein and Bohr as regards the meaning of quantum theory occurred. Despite the majority of physicists think that the debate on the foundations of quantum mechanics between Einstein and Bohr, lasted many years, was won by Bohr and that the Copenhagen interpretation should simply be accepted, over the last 30 years the consensus about the interpretation of quantum processes has evaporated and physicists find themselves faced with a set of different alternative interpretations of quantum mechanics. In particular, today we can affirm with certainty that what Einstein wished and Bohr thought impossible exists. A quantum mechanics without the observer exists, in which the measurement processes can be analysed in terms of more fundamental concepts.

Today we have got some significant versions of quantum mechanics which do not ascribe a special role to the observer: they demonstrate that Bohr's interpretation of quantum processes cannot be considered convincing and satisfactory, both from the physical and from the philosophical point of view. In this regard, as we have said before, one of the theories presented at the 1927 Solvay Conference was Louis de Broglie's pilot-wave dynamics according to which subatomic particles are point-like objects with continuous trajectories "guided" or choreographed by the wavefunction [27–29]. De Broglie's pilot wave theory can be considered as the first significant geometrodynamic non-linear way of thinking for solving the enigma posed by the wave-corpuscle duality. Moreover, de Broglie provided another development of this line of research, regarding how the pilot wave would actually guide the particle, known as "double solution theory": in this picture, for each quantum particle the fundamental non-linear nature of the interaction determines a singular solution, representing the particle, which fits smoothly onto a weak background field, obeying Schrödinger's equation as a linear approximation.

The concepts of pilot wave and double solution theory introduced by de Broglie lead to important developments towards the construction of a clear ontology and geometrodynamics of quantum processes (which allows us to avoid the spectrum of the observer). On one hand, de Broglie's pilot-wave theory was resurrected in 1952 when Bohm used it to describe a general quantum measurement (for example of the energy of an atom). Bohm showed that the statistical results obtained would be the same as in conventional quantum theory — if one assumes that the initial positions of all the particles involved (making up both "system" and "apparatus") have a Born-rule distribution, that is, a distribution proportional to the squared-amplitude of the wavefunction (as appears in conventional quantum theory). In his classic works of 1952 Bohm developed a mathematical treatment of de Broglie's pilot-wave concept, realizing that this theory provided a foundation for a clear causal ontology of non-relativistic quantum mechanics. Bohm's approach reproduces all the empirical results of quantum theory and at the same time has the merit to explain the quantum behaviour of matter remaining faithful to the principle of causality and the motion dogma, thus avoiding to ascribe a special role to the observer and recovering some causality also in the microscopic world [2, 30–34]. On the other hand, also de Broglie's double solution theory has resurrected today as one of the basic starting-point of the non-linear quantum physics which emerges, for examples, in some works of Croca [35–38]. Croca's non-linear approach suggests that a quantum particle is composed of an extended region, the theta wave, and inside it there is a kind of a very small localized structure, the acron, which satisfies a fundamental principle, the principle of eurhythmy, which states that the acron moves in a stochastic way preferentially to the regions where the intensity of the theta wave field is greater. In the picture of Croca's non-linear quantum physics the classical domain can be obtained directly when there is a complete independence between corpuscles and waves, in other words quantum physics can be seen as a real generalization of classical physics inside an unifying formalism. As a consequence, Croca's non-linear approach can be considered another interesting starting-point in order to build a fundamental clear ontology and geometrodynamics which is at the basis of quantum phenomena. In particular, it allows us to derive a new set of more general uncertainty relations which may be tested by the current super-resolution optical microscopes.

As regards the perspective of a geometric description of quantum processes, according to the author of this book, above all it is important to emphasize that in recent years it is possible to remark a growing interest in De Broglie-Bohm realist interpretation of quantum mechanics. Among the merits of de Broglie-Bohm approach, one of the most significant regards indeed the doors that it opens towards the construction of a purely geometrodynamic picture of the quantum world. De Broglie-Bohm interpretation of quantum mechanics, thanks to its most important element, namely the quantum potential, introduces interesting and relevant perspectives towards the interpretation of quantum phenomena as a modification of the geometrical properties of the physical space, in other words towards the interpretation of quantum mechanics as a corresponding "deformation" of the space-time background. In Bohm's approach, the quantum potential emerges indeed as the crucial physical entity which allows us to construct a satisfactory geometrodynamic picture of the quantum world, as a fundamental reality which underlines the geometry of the quantum processes. The aim of this book is to make a